AUSTRALIAN RESEARCH COUNCIL
Discovery Projects
Proposal for Funding Commencing in 2018

DP

PROJECT ID: DP180101103

First Investigator: Prof Maurice Pagnucco

Admin Org: The University of New South Wales

Total number of sheets contained in this Proposal: 112

Certification

Certification by the Deputy/Pro Vice-Chancellor (Research) or their delegate or equivalent in the Administering Organisation

I certify that—

- I have read, understood and complied with the ARC *Funding Rules for schemes under the Discovery Programme (2016 edition)* (the Funding Rules) and to the best of my knowledge all details provided in this Proposal form and in any supporting documentation are true and complete in accordance with these Funding Rules.
- Proper enquiries have been made and I am satisfied that the Participants and the organisations listed in this Proposal meet the requirements specified in the Funding Rules. I will notify the ARC if there are changes to any named Participant or organisation after the submission of this Proposal.
- To the best of my knowledge, all Conflicts of Interest relating to parties involved in or associated with this Proposal have been disclosed to this Administering Organisation, and, if the Proposal is successful, I agree to manage all Conflicts of Interest relating to this Proposal in accordance with the *Australian Code for the Responsible Conduct of Research* (2007).
- The listed Participants are responsible for the authorship and intellectual content of this Proposal, and have appropriately cited sources and acknowledged significant contributions to this Proposal.
- I have obtained the agreement, attested to by written evidence, of all the relevant Participants and organisations necessary to allow the Project to proceed. This written evidence has been retained and will be provided to the ARC if requested.
- This Proposal complies with the eligible research requirements set out in the *ARC Medical Research Policy* located on the ARC website.
- This Proposal does not duplicate Commonwealth-funded research including that undertaken in a Commonwealth-funded Research Centre.
- If this Proposal is successful, I am prepared to have the Project carried out as set out in this Proposal and agree to abide by the terms and conditions of the Funding Rules and the ARC *Funding Agreement regarding funding for schemes under the Discovery Programme (2016 edition).*
- The Project can be accommodated within the general facilities in this organisation and, if applicable, within the facilities of other relevant organisations specified in this Proposal, and sufficient working and office space is available for any proposed additional staff.
- All funds for this Project will only be spent for the purpose for which they are provided.
- The Project will not be permitted to commence until appropriate ethical clearance(s) has/have been obtained and all statutory requirements have been met.
- I consent, on behalf of all the parties, to this Proposal being referred to third parties, who will remain anonymous, for assessment purposes.
- I consent, on behalf of all the parties, to the ARC copying, modifying and otherwise dealing with information contained in this Proposal.
- To the best of my knowledge, the Privacy Notice appearing at the top of this form has been drawn to the attention of all the Participants whose personal details have been provided at the Personnel section.

Part A - Administrative Summary (DP180101103)

A1. Proposal Working Title

(Provide a short working title of no more than 75 characters (approximately ten words). Avoid the use of acronyms, quotation marks and upper case characters.)

Learning Ethical Behaviours by Demonstration in Social Robots

A2. Person Participant Summary

(Add all people participating in this Proposal as a Chief Investigator or Partner Investigator. Note that a person's RMS email address must be used to invite them to participate in this Proposal. Click on the information icon or refer to the Instructions to Applicants for further information.)

Number	Name	Participant Type	Current Organisation(s)	Relevant Organisation
1	Prof Maurice Pagnucco	Chief Investigator	The University of New South Wales, The University of New South Wales, The University of New South Wales, The University of New South Wales	The University of New South Wales
2	A/Prof Mari Velonaki	Chief Investigator	Waseda University, Japan, The University of Sydney, The University of New South Wales, The University of New South Wales	The University of New South Wales
3	Prof Claude Sammut	Chief Investigator	The University of New South Wales	The University of New South Wales
4	Prof Katsumi Watanabe	Partner Investigator	Waseda University, Japan, University of Tokyo	Waseda University, Japan
5	Prof Dr Gerhard Lakemeyer	Partner Investigator	RWTH Aachen University of Technology, Germany	RWTH Aachen University of Technology, Germany

A3. Organisation Participant Summary

(Add all organisations participating in this Proposal. Click on the information icon or refer to the Instructions to Applicants for further information.)

Number	Name	Participant Type
1	The University of New South Wales	Administering Organisation
2	Waseda University, Japan	Other Organisation
3	RWTH Aachen University of Technology, Germany	Other Organisation

A4. Proposal Summary

(Provide a written Proposal summary of no more than 750 characters (approximately 100 words) focusing on the aims, significance, expected outcomes, benefits and impacts of this Project. Avoid the use of acronyms, quotation marks and upper case characters. Please click on the information icon or refer to the Instructions to Applicants for further information.)

Advances in robotic hardware and software have us on the cusp of robots inhabiting complex social settings; working in close cooperation with humans in homes and work places. However, there remain two significant obstacles to realising this goal. The first is the ability to efficiently develop robot programs in social settings. The second is to ensure that these programs result in social robot behaviours that cooperate safely with human collaborators and the environment. This project will develop techniques for learning robot programs by demonstration and subsequently ensuring that the resulting robot behaviours collaborate safely with humans in complex social environments by following stipulated ethical principles.

A5. Impact Statement

(In no more than 500 characters (approximately 75 words), outline the intended impact of the Project. Click on the information icon or refer to the Instructions to Applicants for further information.)

This project builds on advances in learning by demonstration in artificial intelligence to synthesise social robot programs that provide for safe interaction with human co-workers. Developing robot programs is a challenging task that we address by utilising humans working alongside robots, teaching them appropriate behaviours. The outcomes will have a direct impact on society through development of robots that can work cooperatively with humans in social environments such as the home or office.

Part B - Classifications and Other Statistical Information (DP180101103)

B1. Does this Proposal fall within one of the Science and Research Priorities?

No

Science and Research Priority	Practical Research Challenge

B2. Field of Research (FoR)

(Select up to three classification codes that relate to your Proposal. Note that the percentages must total 100%. Click on the information icon for further information.)

Code	Percentage
080101 - Adaptive Agents and Intelligent Robotics	100

B3. Socio-Economic Objective (SEO-08)

(Select up to three classification codes that relate to your proposal. Note that the percentages must total 100%. Click on the information icon for further information.)

Code	Percentage
890201 - Application Software Packages (excl. Computer Games)	70
890202 - Application Tools and System Utilities	30

B4. Interdisciplinary Research

(This is a 'Yes' or 'No' question. If you select 'Yes' two additional questions will be enabled:
1. Specify the ways in which the research is interdisciplinary by selecting one or more of the options below.
2. In no more than 375 characters (approximately 50 words), indicate the nature of the interdisciplinary research involved.)

Does this Proposal involve interdisciplinary research?

Yes

Please specify the ways in which the research is interdisciplinary by selecting one or more of the options below.

Investigatory Team
Methodology

In no more than 375 characters (approximately 50 words), please indicate the nature of the interdisciplinary research involved.

This project involves interdisciplinary researchers from engineering and art & design. These researchers have a demonstrated track record of research collaboration.

B5. Does the proposed research involve international collaboration?

(This is a 'Yes' or 'No' question. If you select 'Yes' two additional questions will be enabled:
1. Specify the nature of the proposed international collaboration by selecting one or more of the options below.
2. Specify the countries which are involved in the international collaboration.)

Yes

B6. What is the nature of the proposed international collaboration activities?

(Select all options from the drop down list which apply to this proposal by clicking on the 'Add' button each time you select an option.)

Correspondence: eg email; telephone; or video-conference
Face to face meetings
Attendance at and/or hosting of workshop or conference
Collaborative fieldwork
Hosting international collaborator: short-term (less than 4 weeks)

B7. If the proposed research involves international collaboration, specify the country/ies involved

(Commence typing in the search box and select from the drop-down list the name of the country/ies of collaborators who will be involved in the proposed Project. Note that Australia is not to be listed and is not available to be selected from the drop-down list.)

Japan
Germany

B8. How many PhD, Masters and Honours places will be filled as a result of this project?

(The ARC is interested in reporting the number of Research Students that would be involved in this Proposal if it is funded. Enter the number of student places (full-time equivalent) that will be filled as a result of this project:)
Number of Research Student Places (FTE) - PhD

4

Number of Research Student Places (FTE) - Masters

0

Number of Research Student Places (FTE) - Honours

4

Part C - Project Description (DP180101103)

C1. Project Description

(Please upload a Project Description as detailed in the Instructions to Applicants in no more than eight A4 pages and in the required format.)

Uploaded PDF file follows on next page.

PART C1 PROJECT TITLE: Learning ethical behaviours by demonstration in social robots

Robotic technologies are developing at such a rapid pace that it is quite feasible to predict that sophisticated robotic assistants will be commonplace in home and office environments within the next 5-10 years. Simple robotic assistants are already appearing but have limited capabilities (e.g., the Aldebaran Pepper[1]). These robotic assistants will need to work closely with their human owners, collaborators and co-workers. Setting aside the cost of these technologies, that are nevertheless likely to reduce over time, there are two major obstacles that remain to be addressed:

- the rapid and efficient development of robot programs; and,
- guarantees that these robot programs exhibit the desired behaviours and, in particular, are able to interact with their human collaborators without placing them at significant risk.

This project builds on previous research by the CIs and PIs: CI Pagnucco's DP150103034 project on "Representation and Reasoning for Cognitive Personal Robots" is currently investigating some of the basic science issues on this topic building on the work of Braun [2010] co-supervised by CI Pagnucco and PI Lakemeyer and their work [CI Pagnucco F13 No. 3, 5, 8, 9, 19, 32] [PI Lakemeyer F13 No. 10, 14, 18, 21]; CI Sammut's DP130102351 "Learning and Planning with Qualitative Models". CI's Velonaki and Pagnucco LIEF grant LE150100090 "Facility for Experimental Human-Robot Interaction Research" provides a physical environment in which to test the outcomes of this project (Task 5). Furthermore, the CI's have recently been selected, on a competitive basis, to participate in the annual RoboCup@Home Standard Platform League using the Human Service Robot (HSR) platform provided by Toyota. This serves as a further evaluation opportunity (Task 5) in a real-world setting.

More precisely, this project builds on advances in the robot programming paradigm: cognitive robot programs. Although there are several paradigms commonly used to facilitate the programming of high-level controllers for mobile robots, little is known about how well they scale. That is, can large sophisticated robot programs in these programming languages be easily written, debugged and maintained? Obviously, they can be written with a great amount of manual effort on behalf of a programmer. However, this is not a satisfactory nor feasible solution. Even if such programs could be easily written, it is difficult to determine whether they would carry out the intended behaviours; or, conversely and perhaps more importantly, not carry out un-intended behaviours. This project builds on these advances and the work of the CIs and PIs to develop techniques for learning ethical robot programs by demonstration; that is, robot programs that adhere to certain ethical principles. It then sets out a framework for determining whether the learned behaviours exhibit the desired actions and satisfy these ethical principles. Finally it thoroughly tests and analyses the results of these techniques on a robot in a real, social setting.

The significance of robotics to our economy cannot be underestimated. In 2016, the International Federation of Robotics (IFR)[2] reported that "In 2015, robot sales increased by 15% to 253,748 units, again by far the highest level ever recorded for one year". The importance to Australia is also clear from this report: "Asia (Australia and New Zealand included in the category) is still the world's strongest growth market. This region saw a total of 160,600 units sold in 2015 – a rise of 19%. This was the highest sales level ever recorded for the fourth year in a row". While these are industry robots, the IFR also reports significant growth for service robots: "The total number of professional service robots sold in 2015 rose considerably by 25% to 41,060 units up from 32,939 in 2014. The sales value increased by 14% to US$ 4.6 billion".[3] Companies like Google are investing significantly in robotics [Adam, 2014]. Recently prominent scientists and entrepreneurs like Stephen Hawking and Elon Musk have warned against the dangers of unfettered Artificial Intelligence (AI) and, by implication, intelligent robots. Nevertheless, the increasing use of AI and robots is inevitable as countries and companies strive for economic advantage. It is therefore essential that we begin to consider how to develop sophisticated robot programs that adhere to ethical principles.

AIMS AND BACKGROUND

Aims

The aim of this project is to develop techniques for learning robot programs that result in behaviours that have the desired ethical effects. It develops techniques for: learning ethical robot programs; determining whether these programs adhere to ethical restrictions required of their behaviour; otherwise modifying the programs to adjust these behaviours; and testing these robot programs in a realistic office setting.

Background

Consider the following task:

> A personal robot is placed in a typical open-plan office environment. It is required to interact with its environment and, in particular, people inhabiting that environment. It can carry out tasks like delivering objects from one person to another, retrieving (electronic) documents for human co-workers, alerting

[1] http://www.nestle.com/media/news/nestle-humanoid-robot-nescafe-japan
[2] http://www.ifr.org/industrial-robots/statistics/
[3] http://www.ifr.org/service-robots/statistics/

people when they should take a break, fetching people when they have a visitor at reception and assisting them to evacuate the building when the fire alarm sounds.

In this project, we will focus on learning programs to complete tasks like the one in this example while adhering to strict ethical principles (e.g., do not cause harm to human collaborators). Robot programming can be distinguished by two broad approaches: *deliberative* and *behaviour-based*. Deliberative programs usually implement a "sense–plan–act" cycle in which sensing of the environment is performed, a plan is formulated to respond to the current state of the world, as reported by the sensors, and then the plan is enacted, with the cycle repeating. Some deliberative paradigms like the Golog-based [Lesperance *et al.* 1997] framework that we adopt here only provides for active sensing, i.e., the program needs to explicitly sense its environment by performing so-called *sensing actions*. Behaviour-based programs are "event driven". That is, there is a more immediate connection between the sensors and actuators. Rather than carrying out any complex planning, a behaviour-based system will have preconfigured responses to sensory inputs. Behaviour-based systems are usually much faster than deliberative systems, however, deliberative systems are more flexible. *Cognitive Robot Programs* combine aspects of both paradigms to try to gain the advantages of each, while avoiding their disadvantages.

Robot programs. One of the key outcomes of this project is to assess the effectiveness of learning sophisticated cognitive robot programs that adhere to ethical principles. CI Pagnucco's DP150103034 project on "Representation and Reasoning for Cognitive Personal Robots" is currently investigating some of the basic science issues on this topic building on the work [Braun, 2010] co-supervised by CI Pagnucco and PI Lakemeyer and their work [CI Pagnucco F13 No. 3, 5, 8, 9, 19, 32] [PI Lakemeyer F13 No. 10, 14, 18, 21]. This work focusses on what we will term *deliberative cognitive robot programs* (or, simply, cognitive robot programs). We extend this work by learning ethical principles that the cognitive robot programs must follow. In the latter stages of this project, these principles will be learned by demonstration and incorporated into robot programs.

Cognitive Robot Programs are procedural programs where the basic statements are actions that can be performed directly by a robot using one of its behaviours. In this project we will be using the Golog [Lesperance *et al.* 1997] cognitive robot programming language and its variants. Along with the usual procedural constructs, Golog adds constructs for non-deterministic choice of objects and actions. It should be noted that non-deterministic choice in Golog is a *reasoned* choice. Golog will determine an appropriate choice of object or action that guarantees complete execution of the program to termination, e.g., the following Golog program might be used to complete the tasks given in the example above by (non-deterministically) selecting a task to be completed and determining the appropriate sequence of actions required to complete that task (here π represents non-deterministic choice of objects, in this case a task that needs to be completed):

while ($\exists$ x).taskToDo(task) **do**
  (π task). taskToDo(task)?
  if delivery(task)
  then *goto*(origin(task)); *pickup*(item(task)); *goto*(destination(task))
  else if visitor(task)
  then *goto*(reception); *collect*(person(task)); *goto*(destination(task))
  else if alert(task)
  then *goto*(destination(task)); *alertToBreak*(person(task))
  else if alert(task)
  then *goto*(destination(task)); *alertToBreak*(person(task))
end while;

It should be noted that the basic statements of this program are actions (highlighted in italic text, like *goto*) and properties of the robot's environment (or state; in non-italic text like taskToDo). Actions have specified *preconditions,* stating when it is possible for the robot to perform the action, and *effects,* that state how performing the action changes the state of the robot's environment. Preconditions and effects for actions constitute what is referred to as an *action theory* for the cognitive robot program. In this project we begin by assuming that the action theory is correct and therefore does not need to be modified. However, as we progress through the project tasks, we consider whether the action theory should be modified in order to incorporate learned ethical courses of action.

Other Robot Program Paradigms. While this project focusses on cognitive robot programs, it is important to understand that there are alternative approaches to programming high-level controllers for robots. We briefly mention some here to provide some context around the work to be completed in this project and the implications that this work will have for developing sophisticated robot programs. In the example above, the flow of control is determined by the program. In contrast to cognitive robot programs that are based on reasoning, control flow in behaviour-based programs is determined by the current state of the robot's model of the world. Behaviour-based robotics [Arkin,

1998] originated with Brooks' subsumption architecture [Brooks, 1986]. Other examples include Reactive Action Packages [Firby 1987], SOAR's production rules [Laird *et al,* 1987] and Nilsson's teleo-reactive programs [Nilsson, 1994]. We use a TR program to illustrate the properties of a behaviour-based system.

Teleo-reactive (TR) programs are composed of procedures whose bodies are made up of a list of condition action rules:

$$C_1 \rightarrow A_1; C_2 \rightarrow A_2; \ldots ; C_n \rightarrow A_n$$

The conditions (C_i) in each rule are continuously evaluated, determining the first condition in the list that is true in the current robot state and then performing the corresponding action (A_i). The condition-action rules can be viewed as listed in priority order. TR programs can also call other TR programs as the action A_i in a rule.

One other paradigm we will mention is that of Belief-Desire-Intention (BDI) programs [Bordini *et al.,* 2005, Rao & Georgeff, 1995] since there is preliminary work by Dennis *et al.* [2016] in providing ethical principles that such programs should satisfy (see below). The BDI paradigm sits between cognitive robot programs and behaviour-based programs in that they may require some level of deliberation; more than behaviour-based programs but less than (deliberative) cognitive robot programs. The basic idea is that desires represent things an agent (e.g., a robot) would like to do and, as events occur, they form intentions (or plans) to carry out those desires. These intentions are conditioned by the agent's beliefs about the current state of its environment.

Programming by demonstration. The predominant approaches to programming by demonstration in robotics usually address the problem of learning motor skills [Schaal & Atkeson, 2000; Sammut *et al*., 1992; Sheh et al., 2011]. In contrast, the problems addressed in this proposal are high-level behaviours that may involve human interaction. As such, they require different representations and decision-making mechanisms than are used for low-level motor skills. Fritz and Gil (2010, 2011) refine a given Golog program with positive and consistent demonstrations. The problem with programming by demonstration is, usually, that it is difficult to generalise from naturally linear examples when the target-program has complex structure. Therefore, instead of using programming by demonstration to generalise the program, here it is used to make the program more specific, i.e., instantiate the program in the parts where it was nondeterministic before, based on the provided examples. In the example Golog program above, this would, for instance, lead to more specific behaviours that refine the way existing tasks are dealt with.

Ethical/Moral Behaviours. Another major outcome of this project will be to ensure that learned robot programs do not exhibit unintended behaviours. Dennis *et al.* [2016] define ethical principles as "rules of conduct that should guide the behaviour of moral agents when making decisions".

Ethical Behaviours in Cognitive Robot Programs: In this project, we assume that the ethics of the robot are encoded as constraints on its behaviour. That is, any plan that is executed by the robot must not violate any of the ethical constraints. Obvious ethical considerations would be concerns for the safety of nearby humans (i.e., so-called *no-harm* principles). In a social context, other (ethical) constraints may encode the conventions of the society within which the robot operates, e.g., a robot should obey conventions about what is considered a comfortable distance from any humans with which the robot is interacting, what behaviours may be misinterpreted as threatening, etc. Dennis *et al.* [2016] encode ethical principles as modal formulas E.φ. Here φ is a formula representing a property of the world that needs to be guaranteed, e.g., the statement human(person) $\rightarrow$E.distance(robot, person) > 1*m* specifies that a robot should maintain a distance of at least 1 metre from a human collaborator. We will utilise a similar representation of ethical principles in Task 1 of this project.

Of course, ethical principles can be in conflict with one another and it may not be possible to guarantee satisfaction of all ethical principles. Following Dennis *et al.* [2016] we suppose that there will be an ordering over ethical principles (a ranking or *total pre-order* will suffice for our purposes here). One of the most interesting classes of conflicting ethical principles is that of *ethical dilemmas*. For example, suppose there is a fire in the building and the robot can only assist one person to safety. Who should the robot choose to save? Even if the robot is able to help multiple people, how should it prioritise its choices? While this is indeed an interesting issue it will not be at the forefront of considerations in this project.

One way of addressing this problem is to use a formal methods approach that is common in software engineering. However, this would require significant manual effort to formally represent ethical principles, programs and action theory. Furthermore, it requires the identification of properties to verify. This task is fraught with difficulty and does not scale easily. Therefore, we propose a different approach in this project.

Robot Middle-ware. The purpose of robot middle-ware is to provide an abstraction of robot platforms so that common algorithms for abilities such as locomotion, localisation, mapping, path planning, vision, object detection, etc., can be made available to a variety of diverse robot platforms provided they possess the required devices (motors, sonars, laser range finders, cameras, etc.). Additionally, most robot middle-ware provides for robot simulators so that many algorithms can be tested in simulation before trying them out on physical robots. In this project, we will be

using robot simulators to test robot behaviours and ensure that they adhere to stated and learned ethical principles. ROS (Robot Operating System; www.ros.org) is arguably the most actively used robotic middle-ware by the major robotic research groups. Its modular approach lends itself to an extensible robotic platform. We will implement this project by making use of and building upon the ROS robotic middle-ware. The outcomes of this project will be open sourced and available publicly for download.

These developments lead naturally to the following research questions that this project will answer:

- How can ethical principles be represented?
- How can ethical principles be learned by having human collaborators demonstrate them?
- How are these learned ethical principles best incorporated into a cognitive robot program?
- How can we learn sophisticated ethical robot programs?
- How can these ethical cognitive robot programs be tested, analysed and verified?

INVESTIGATORS

Prof Pagnucco (20%) will be responsible for the overall management of the project and will also be the primary investigator for the representation and reasoning methods for the ethical behaviours. He will assume the main responsibility for Task 1 (together with PI Lakemeyer and with the senior research associate) and Task 4.

A/Prof Velonaki (20%) will be responsible for designing experimental robot behaviours in relation to situational context and, together with PI Watanabe, the design and conduct of the experiments and resulting analysis. She will assume the main responsibility for Task 5.

Prof Sammut (20%) will be responsible for developing and implementing the machine learning algorithms, with the assistance of the senior research associate. He will assume the main responsibility for Tasks 2 and 3.

Prof Dr Lakemeyer (20%) PI Lakemeyer brings expertise in knowledge representation and reasoning that will be important for Task1 and has extensive expertise in applications of cognitive robot programs, particularly in the RoboCup@Home competition, that will be essential for completion of Task 5.

Prof Watanabe (20%) PI Watanabe brings expertise in cognitive science and neuroscience, particularly in the areas of social cognition, motivation and reward. He has extensive experience in experimental design, human behavioral testing and analysis of experimental data, all of which are essential to the project. He will collaborate with CI Velonaki on the development of experimental scenarios, selection and adaptation of standard methods and tools, such as questionnaires, together with statistical analyses of experimental data (Task 5).

Research Associate (Software Engineer) This person will be involved during Years 1-3 (full-time). They will be responsible for robot software development and will assist the CIs and PIs in all aspects of the project.

PhD Student 1 (100%) will participate in Tasks 1, 2 and 5. They will focus on representing ethical principles and learning these principles separate to the Golog program.

PhD Student 2 (100%) will participate in Tasks 1, 3 and 5. They will focus on representing ethical principles and incorporating these principles into the Golog program and/or the underlying action theory.

It is expected that an additional two PhD students will be involved in the project and funded by APA or IPRS scholarships and that a further four Honours/thesis students will work on this project. These students will work on a research project aligned with one of Tasks 1-4 and contribute to Task 5, experimental evaluation, through the RoboCup@Home competition each year.

PROJECT QUALITY AND INNOVATION

Significance

The importance of this work is highlighted by the International Federation of Robotics statistics noted above and the extensive interest shown by the press, such as the interview with CI Pagnucco, The Mind in The Machine, ABC Radio National on 30 November 2013 and the interview World of Robots, appearing on Channel 9's A Current Affair on 8 January 2010.[4] More generally, an increased focus on the area of intelligent complex systems of research will contribute to maintaining Australia's high quality research and development in this area. As social robots gradually move into the workplace, we will need to develop complex programs to control them in an efficient way. Furthermore, we will require guarantees that these programs exhibit intended behaviours and do not exhibit un-intended behaviours.

Innovation

This project innovates in the following main areas:

1. it will develop methods for representing ethical principles;
2. it will develop techniques for learning these ethical principles;
3. it will create novel methods for ensuring that unintended behaviours are avoided; and,
4. it develops a methodology by which to test and analyse ethical robot behaviours in a social setting.

Approach

TASK 1: Development of Representation and Programming Ethical Behaviours

Before undertaking learning of ethical behaviours, the first stage of the project is to develop the language that will be used to express ethical constraints. A set of constraints will be provided along with a cognitive robot program written in Golog or one of its variants.[4] Following Dennis *et al.* [2016] we will start by representing ethical principles as modal formulas E.φ or simply logical constraints $\forall s.\text{context}(s) \rightarrow \varphi(s)$. That is, for any situation s (i.e., state of the environment), if the situation s satisfies some context (context(s)), then it should satisfy the ethical principle φ (i.e., φ(s)). This captures the notion that some ethical principles only apply under a given context and provides a more flexible representation. Ethical principles will also be ranked using a total pre-order so as to deal with any conflicts among ethical principles.

The experimental setup for the project will be tested by executing the Golog cognitive robot programs to achieve a given task. Golog programs output a sequence of actions that need to be performed by the robot. Before each action in the sequence is performed, the predicted resulting state is checked against the ethical constraints. If an ethical constraint is violated, the action is blocked. In this stage of the project, we will also create a simulation, using ROS/Gazebo, so that behaviours can be safely tested prior to execution by the real robot. The hand-coded system will act as a baseline for subsequent machine learning trials.

In this way, ethical principles act as a further constraining mechanism on the execution of actions that are provided by the Golog program. The reason for adopting this approach is to allow for efficient execution of Golog programs. However, there is one important drawback. Further constraining the execution of actions output by a Golog program may result in the program failing. This is therefore a crude mechanism for enforcing ethical principles and we will seek to refine this process in later tasks.

TASK 2: Learning Ethical Behaviours

Using the framework established by Task 1, we replace the hand-crafted ethical constraints by ones created by an incremental learning system. Initially, the constraints are null, that is, all behaviours generated by the Golog program are allowed. A human trainer acts as an oracle for the learning system, giving the robot a metaphorical slap on the wrist if it misbehaves. Alternatively, the human trainer may provide *positive examples*—sequences of actions that the ethical Golog program should allow, and *negative examples*—sequences of actions that violate ethical principles and should not be carried out. If the robot performs an action that is in violation of an ethical principle, this indicates that the constraints must be specialised to exclude a similar behaviour in the future. However, it is possible that this may result in constraints that are too tight, preventing behaviours that the oracle finds acceptable. In this case the constraints must be generalised.

The constraint language will be a subset of predicate logic, therefore we will adopt an Inductive Logic Programming framework and extend Inverse Entailment [Muggleton & de Raedt, 1994, Muggleton, 1995] to perform the generalisations and specialisation. It is important to note that, at this stage in the project, we are not so concerned about dealing with preferences over ethical principles. We will come back to this issue in Task 4 so as to keep things as simple as possible in the early stages of this project.

TASK 3: Learning to Behave Ethically

Having learned, or given ethical constraints, the next stage is to refine the behaviours coded in the Golog program so that they do not violate the constraints. The constraints may be thought of as the conscious decision not to misbehave (i.e., encoding the *no-harm* principle). Not attempting an acceptable action is equivalent to making ethical behaviour subconscious. Like the learning framework above, when negative feedback is received, the Golog program must be refined, or specialised. If it is over specialised, generalisation is required. The learning mechanism differs from Task 2, extending the approaches of Fritz and Gil (2010, 2011) and Pagnucco [DP150103034; F13 Items 3, 5, 8, 9, 19, 32]. In Tasks 1 and 2 we have represented ethical principles separately (either as modal "ethical" formulas or as logical constraints as noted in Task 1) and prioritised them using a ranking (i.e., total pre-order). However, one obvious question that has a good chance of having a positive answer is whether these principles could be directly incorporated into the Golog program itself. This would simplify the need to have a separate set of (ordered) ethical principles. As noted in the Background section above, Golog programs have two essential elements: the underlying action theory specifying preconditions and effects for each action; and, the Golog program itself. In the following subtasks we consider how to modify each of these two elements in turn.

SUBTASK 3.1: Learning to Behave Ethically by Modifying Golog Programs

In this subtask we assume that the underlying action theory is correct (as we have done thus far). We therefore investigate methods for incorporating the ethical principles directly into the Golog program. That is, we dispense with

[4] CI Pagnucco is currently developing an efficient implementation of a Golog variant known as Ergo with Emeritus Professor Hector Levesque from the University of Toronto. It is intended to use Ergo for this project.

the separate representation of ethical principles and, by considering each in turn, we determine how they can be captured by modifying the Golog program itself.

SUBTASK 3.2: Learning to Behave Ethically by Modifying Action Theories

In this subtask we turn our attention to the underlying action theory and keep the Golog program fixed. We develop methods for encoding and capturing the ethical principles by modifying (i.e., learning) the preconditions of actions in the action theory. As part of this sub-task we will assess to what extent ethical principles can be accommodated by changes to the action theory. In the following task, we investigate whether it is better to change both the action theory and the Golog program in order to best encapsulate the ethical principles that are demonstrated by a human trainer.

TASK 4: Co-evolution of Constraints and Behaviours

With both learning mechanisms in place (through Sub-tasks 3.1 and 3.2), both constraints and behaviours can be allowed to learn and evolve over time. As feedback is received from the oracle (or via positive and negative examples), constraints are updated. These, in turn, send feedback to the behaviours. It is not necessary for an update to a constraint to immediately trigger an update to a behaviour. There may be rare conditions that do not warrant changes throughout. Therefore, the system must be able to weigh the cost of an update versus living with an occasional blocking of a behaviour. This task will also investigate the important issue of how ethical principles are prioritised. In order to do so, more information will be required on the part of a human trainer in order to determine the ranking over ethical principles.

TASK 5: Experimental Evaluation

Tasks 1 to 4 can be completed largely within a computer or simulation environment. Although adequate to develop the proposed techniques, their evaluation requires implementation on a physical platform that is able to interact in some way with people. A Toyota HSR will be used in experiments to evaluate the effectiveness of the robot behaviours. This hardware is readily accessible to the CIs at UNSW in the School of Computer Science and Engineering and in the Creative Robotics Laboratory in the Faculty of Art and Deisgn. Experimental evaluation will be conducted in the National Facility for Human-Robot Interaction Research [LE150100090], directed by CI Velonaki. To further demonstrate the viability of the approach and its portability to other systems, PI Lakemeyer will perform experiments on the RWTH Aachen service robot in a home environment.

During experiments, all of the data that capture the 'internal states' of the robot, and that describe how participants move and interact with the robot will be collected automatically. These data will be recorded using the participant's location from the video cameras mounted in the experimental space and the robot's on-board sensing capabilities. These data will be analysed off-line using machine-learning techniques, to identify conformance or divergence of the robot from the underlying rules of contact. Patterns within the data, including participant proximity to the robot will be correlated with the actions of the robot to discern the underlying patterns of behaviour. Structural models of postulated behavior patterns can be written using dynamic Bayesian networks [Wood & Scheding, 2007] and numerical values of the parameters that define the models can then be identified directly from the data. The software for on-line data collection and off-line analysis previously developed and tested in the Diamandini project (DP0988336) by CI Velonaki will be used as a basis for developing the more advanced system required for the proposed research. After each experimental trial the Godspeed questionnaire [Bartneck *et al.,* 2009] will be used to evaluate the participants' perception of the robot's capabilities.

Training

This project will be highly attractive to research students and will contribute both to research training and to the development of cross-disciplinary research skills in the rapidly emerging area of social robotics. Funding is requested for two PhD students to undertake research linked to this project but it is anticipated that at least 2 further PhD and 4 undergraduate Honours/Thesis students will participate in this project.

FEASIBILITY

Sufficiency of Design, Expertise and Budget for Successful Completion within Budget and Timeframe

The CIs and PIs have a history of individual research excellence and a track record of collaboration. Each is internationally recognised in their field of expertise and has a reputation for delivering large research projects on budget and on time. This collective expertise and commitment ensures the success of this project.

Support and High Quality Project Environment

The University of New South Wales (UNSW) is one of Australia's leading research intensive universities, with a strategic focus on developing interdisciplinary, cross-faculty and cross-institutional research partnerships. This project will be located at the School of Computer Science and Engineering (CSE) and the Creative Robotics Lab (CRL) at UNSW Art & Design. It will also take advantage of the National Facility for Human-Robot Interaction Research [LE150100090, official opening June 2016]. The project clearly aligns with UNSW's defined research strength in 'ICT, Robotics and Devices'. Evidence of the University's standing in this area is demonstrated by UNSW's top rating of 5 "Well Above World Class" overall for the ICT Field of Research as well as in the areas of Computer Software (FoR 0803) and Information Systems (FoR 0806) and 4 "Above World Class" in Artificial

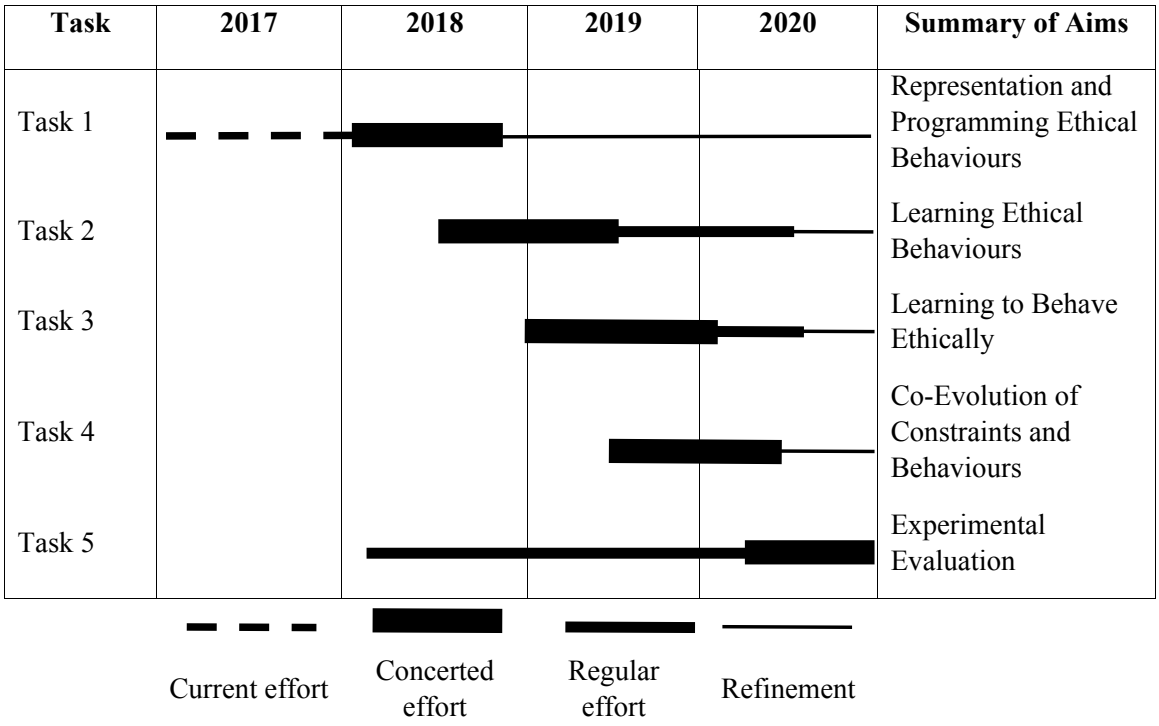
Intelligence and Image Processing (FoR 0801), the area of research relevant to this proposal, in the 2015 ERA Report.

Project Facilities

UNSW has several robot platforms including a Toyota HSR, a Rethink Robotics Baxter, 5 Turtlebots, 15 Aldebaran Nao humanoid robots, 3 urban search and rescue robots and 1 purpose built human-robot interaction robot based on the Segway RMP. In addition to these resources, the UNSW Faculty of Engineering has recently invested $500K on a 2,944 core computing cluster that is available for large scale simulation and compute-intensive tasks that will be useful for this project. The PIs have similar facilities.

Proposed timing.

The following schedule will guide the research on this project. Tasks tend to follow each other in sequence but significant effort on some tasks can be undertaken concurrently.



BENEFIT

Economic, Social and Cultural Benefits for Australia

This project has unquestionable economic benefits as noted by the IFR report noted above; service robots are becoming increasingly common, will become more sophisticated and cost effective as technology advances; and, be required in several application areas, e.g., assisted care as the population ages and driving efficiencies in offices.

The project also has important social and cultural benefits as robots are becoming commonplace and more accepted in society, yet there is a scepticism as to the reliability and trustworthiness of this new technology

Cost Effectiveness and Value for Money

The investment in this project is relatively modest given the potential returns once the technological problems outlined in this project are resolved during its development. The return on investment is likely to be significant. The CIs and PIs have an established record of turning research outcomes into practical results.

COMMUNICATION OF RESULTS

The CIs and PIs have demonstrated a consistent ability to have their research accepted at the top-rated conferences and journals. We will disseminate the results of our research in a number of ways:

- ERA A*/A Artificial Intelligence Journal (AIJ), and the Journal of Artificial Intelligence research (JAIR), and International Journal of Social Robotics.
- top-rated conferences in Artificial Intelligence, such as IJCAI (International Joint Conference on Artificial Intelligence), AAAI (Association for Advancement of AI Conference) and KR (Knowledge Representation and Reasoning), ICM/IEEE International Conference in Human Robot Interaction, IEEE RO-MAN and ICSR International Conference on Social Robotics.
- A project web page with information and outcomes that will be maintained for the project.

MANAGEMENT OF DATA

This project will involve experimentation with people. All experimental procedures will be developed in accord with the principles outlined in the National Statement on Ethical Conduct in Human Research, as implemented in UNSW policy and the procedures of the UNSW Human Research Ethics Committee.

Project data will be stored and managed in accordance with the Australian Code for the Responsible Conduct of Research, as implemented in the UNSW Procedure for Handling Research Material & Data. All data on paper will be converted to electronic form as soon as practical and the originals securely destroyed. In the interim, data on paper will be stored in a locked filing cabinet at the Creative Robotics Lab. All electronic data in active use will be stored on a secure server that is backed up daily. All information that could be used to identify participants will remain confidential and will be disclosed only with a participant's written consent, except as required by law. Data will be de-identified as early in the data cycle as practical.

De-identified data sets will be transferred intermittently to the UNSW Research Long Term Data Store, a large data store for archiving of electronic research data for UNSW researchers that ensures that data captured in the course of research is managed, backed-up and stored according to UNSW legislative obligations. These data will be made discoverable through publication by Research Data Australia in order to facilitate reuse.

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C2. Medical Research

(Does this Project contain content which requires a statement to demonstrate that it conforms with the eligible research requirements set out in the ARC Medical Research Policy located on the ARC website?)

No

C3. Medical Research Statement

(If applicable, in no more than 750 characters (approx.100 words), justify why this Project complies with the eligible research requirements set out in the ARC Medical Research Policy located on the ARC website.)

C4. Please list the objectives of your proposed Project.

(Please list each objective separately by clicking 'add answer' to add the next objective. You may enter 500 characters (approximately 70 words) per objective.

This information will be used for future reporting purposes if this Proposal is funded.

(This question must be answered))

Objective

Develop techniques for robot software that follows specified ethical principles

Objective

Develop methods for representing and specifying ethical principles for social robot programs

Objective

Develop techniques for learning ethical principles

Objective

Develop techniques to ensure that unintended robot behaviours violating ethical principles are avoided

Objective

Develop methodologies for testing and analysing ethical robot behaviours in social settings

Part D - Project Cost (DP180101103)

D1. What is the proposed budget for your Project?

(Please refer to the Instructions to Applicants for detailed instructions.)

Total requested budget: $652,458

Year 1

Description	ARC	Admin Org		Other Org	
	Cash	Cash	In-kind	Cash	In-kind
Total	209,979	22,105	142,347		99,584
Personnel	196,137	4,000	142,347		99,584
CI Pagnucco Level E Step 1, 0.2FTE + 29.42% on-costs			49,792		
CI Velonaki Level D Step 4, 0.2FTE + 29.42% on-costs			42,763		
Ci Sammut Level E Step 1, 0.2FTE + 29.42% on-costs			49,792		
PI Watanabe @ 0.2FTE					49,792
PI Lakemeyer @ 0.2FTE					49,792
Senior Research Associate (SRA) Level B, Step 3-5 @ 1.0FTE + 30% on-costs	143,537				
HDR (Higher Degree by Research stipend)	26,300	2,000			
HDR (Higher Degree by Research stipend)	26,300	2,000			
Travel	13,842	18,105			
Airfares - Sydney/Europe or US - SRA - IJCAI/AAAI/KR Conference	2,000				
Accommodation - Sydney/Europe or USA - SRA - 5 days @ $252 per day - IJCAI/AAAI/KR Conference	1,260				
Per diems - Europe or USA - SRA - 5 days @ $290 per day - IJCAI/AAAI/KR Conference	1,450				
Registration - Europe or USA - SRA - IJCAI/AAAI/KR Conference	1,000				
Airfares - Sydney/Europe or USA - CI Pagnucco - IJCAI/AAAI/KR Conference		2,000			
Aocommodation - Europe/USA - CI Pagnucco - 5 days @ $252 per day - IJCAI/AAAI/KR Conference		1,260			
Per diems - Europe or USA - CI Pagnucco - 5 days @ $355 per day - IJCAI/AAAI/KR Conference		1,775			
Registration - Europe or USA - CI Pagnucco - IJCAI/AAAI/KR Conference		1,000			
Airfares - Sydney/Europe or USA - CI Velonaki - IJCAI/AAAI/KR Conference		2,000			
Accommodation - Europe/USA - CI Velonaki - 5 days @ $252 per day - IJCAI/AAAI/KR Conference		1,260			
Per diems - Europe or USA - CI Velonaki - 5 days @ $355 per day - IJCAI/AAAI/KR Conference		1,775			
Registration - Europe or USA - CI Velonaki - IJCAI/AAAI/KR Conference		1,000			

Airfares - Sydney/Europe or USA - CI Sammut - IJCAI/AAAI/KR Conference		2,000			
Accommodation - Europe/USA - CI Sammut - 5 days @ $252 per day - IJCAI/AAAI/KR Conference		1,260			
Per diems - Europe or USA - CI Sammut - 5 days @ $355 per day - IJCAI/AAAI/KR Conference		1,775			
Registration - Europe or USA - CI Sammut - IJCAI/AAAI/KR Conference		1,000			
Airfares - Frankfurt/Sydney - PI Lakemeyer - Research Collaboration	2,000				
Accommodation - Sydney - PI Lakemeyer - 14 days @ $265 per day - Research Collaboration	3,710				
Per diems - Sydney - PI Lakemeyer - 14 days @ $173 per day - Research Collaboration	2,422				

Year 2

Description	ARC	Admin Org		Other Org	
	Cash	Cash	In-kind	Cash	In-kind
Total	214,779	22,105	142,347		99,584
Personnel	200,937	4,000	142,347		99,584
CI Pagnucco Level E Step 1, 0.2FTE + 29.42% on-costs			49,792		
CI Velonaki Level D Step 4, 0.2FTE + 29.42% on-costs			42,763		
Ci Sammut Level E Step 1, 0.2FTE + 29.42% on-costs			49,792		
PI Watanabe @ 0.2FTE					49,792
PI Lakemeyer @ 0.2FTE					49,792
Senior Research Associate (SRA) Level B, Step 3-5 @ 1.0FTE + 30% on-costs	148,337				
HDR (Higher Degree by Research stipend)	26,300	2,000			
HDR (Higher Degree by Research stipend)	26,300	2,000			
Travel	13,842	18,105			
Airfares - Sydney/Europe or US - SRA - IJCAI/AAAI/KR Conference	2,000				
Accommodation - Sydney/Europe or USA - SRA - 5 days @ $252 per day - IJCAI/AAAI/KR Conference	1,260				
Per diems - Europe or USA - SRA - 5 days @ $290 per day - IJCAI/AAAI/KR Conference	1,450				
Registration - Europe or USA - SRA - IJCAI/AAAI/KR Conference	1,000				
Airfares - Sydney/Europe or USA - CI Pagnucco - IJCAI/AAAI/KR Conference		2,000			
Aocommodation - Europe/USA - CI Pagnucco - 5 days @ $252 per day - IJCAI/AAAI/KR Conference		1,260			
Per diems - Europe or USA - CI Pagnucco - 5 days @ $355 per day - IJCAI/AAAI/KR Conference		1,775			
Registration - Europe or USA - CI Pagnucco - IJCAI/AAAI/KR Conference		1,000			

Airfares - Sydney/Europe or USA - CI Velonaki - IJCAI/AAAI/KR Conference		2,000			
Accommodation - Europe/USA - CI Velonaki - 5 days @ $252 per day - IJCAI/AAAI/KR Conference		1,260			
Per diems - Europe or USA - CI Velonaki - 5 days @ $355 per day - IJCAI/AAAI/KR Conference		1,775			
Registration - Europe or USA - CI Velonaki - IJCAI/AAAI/KR Conference		1,000			
Airfares - Sydney/Europe or USA - CI Sammut - IJCAI/AAAI/KR Conference		2,000			
Accommodation - Europe/USA - CI Sammut - 5 days @ $252 per day - IJCAI/AAAI/KR Conference		1,260			
Per diems - Europe or USA - CI Sammut - 5 days @ $355 per day - IJCAI/AAAI/KR Conference		1,775			
Registration - Europe or USA - CI Sammut - IJCAI/AAAI/KR Conference		1,000			
Airfares - Tokyo/Sydney - PI Watanabe - Research Collaboration	2,000				
Accommodation - Sydney - PI Watanabe - 14 days @ $265 per day - Research Collaboration	3,710				
Per diems - Sydney - PI Watanabe - 14 days @ $173 per day - Research Collaboration	2,422				

Year 3

Description	ARC	Admin Org		Other Org	
	Cash	Cash	In-kind	Cash	In-kind
Total	227,700	22,105	142,347		99,584
Personnel	205,726	4,000	142,347		99,584
CI Pagnucco Level E Step 1, 0.2FTE + 29.42% on-costs			49,792		
CI Velonaki Level D Step 4, 0.2FTE + 29.42% on-costs			42,763		
Ci Sammut Level E Step 1, 0.2FTE + 29.42% on-costs			49,792		
PI Watanabe @ 0.2FTE					49,792
PI Lakemeyer @ 0.2FTE					49,792
Senior Research Associate (SRA) Level B, Step 3-5 @ 1.0FTE + 30% on-costs	153,126				
HDR (Higher Degree by Research stipend)	26,300	2,000			
HDR (Higher Degree by Research stipend)	26,300	2,000			
Travel	21,974	18,105			
Airfares - Sydney/Europe or US - SRA - IJCAI/AAAI/KR Conference	2,000				
Accommodation - Sydney/Europe or USA - SRA - 5 days @ $252 per day - IJCAI/AAAI/KR Conference	1,260				
Per diems - Europe or USA - SRA - 5 days @ $290 per day - IJCAI/AAAI/KR Conference	1,450				
Registration - Europe or USA - SRA - IJCAI/AAAI/KR Conference	1,000				

Airfares - Sydney/Europe or USA - CI Pagnucco - IJCAI/AAAI/KR Conference		2,000			
Aocommodation - Europe/USA - CI Pagnucco - 5 days @ $252 per day - IJCAI/AAAI/KR Conference		1,260			
Per diems - Europe or USA - CI Pagnucco - 5 days @ $355 per day - IJCAI/AAAI/KR Conference		1,775			
Registration - Europe or USA - CI Pagnucco - IJCAI/AAAI/KR Conference		1,000			
Airfares - Sydney/Europe or USA - CI Velonaki - IJCAI/AAAI/KR Conference		2,000			
Accommodation - Europe/USA - CI Velonaki - 5 days @ $252 per day - IJCAI/AAAI/KR Conference		1,260			
Per diems - Europe or USA - CI Velonaki - 5 days @ $355 per day - IJCAI/AAAI/KR Conference		1,775			
Registration - Europe or USA - CI Velonaki - IJCAI/AAAI/KR Conference		1,000			
Airfares - Sydney/Europe or USA - CI Sammut - IJCAI/AAAI/KR Conference		2,000			
Accommodation - Europe/USA - CI Sammut - 5 days @ $252 per day - IJCAI/AAAI/KR Conference		1,260			
Per diems - Europe or USA - CI Sammut - 5 days @ $355 per day - IJCAI/AAAI/KR Conference		1,775			
Registration - Europe or USA - CI Sammut - IJCAI/AAAI/KR Conference		1,000			
Airfares - Tokyo/Sydney - PI Watanabe - Research Collaboration	2,000				
Accommodation - Sydney - PI Watanabe - 14 days @ $265 per day - Research Collaboration	3,710				
Per diems - Sydney - PI Watanabe - 14 days @ $173 per day - Research Collaboration	2,422				
Airfares - Frankfurt/Sydney - PI Lakemeyer - Research Collaboration	2,000				
Accommodation - Sydney - PI Lakemeyer - 14 days @ $265 per day - Research Collaboration	3,710				
Per diems - Sydney - PI Lakemeyer - 14 days @ $173 per day - Research Collaboration	2,422				

Other Organisation

Organisation	Year 1		Year 2		Year 3	
	Cash	In-kind	Cash	In-kind	Cash	In-kind
Waseda University, Japan		49,792		49,792		49,792
RWTH Aachen University of Technology, Germany		49,792		49,792		49,792
Total		99,584		99,584		99,584

Committed Total		99,584		99,584		99,584

Part E - Budget Justification (DP180101103)

E1. Justification of funding requested from the ARC

(In no more than five A4 pages and within the required format fully justify, in terms of need and cost, each budget item requested from the ARC. Use the same headings as in the Description column in the budget at Part D of this Proposal.)

Uploaded PDF file follows on next page.

E1: Justification of funding requested from the ARC for the duration of the Project

Total requested from ARC for the duration of the Project: $652 458

This project brings together a team of internationally renowned researchers and research centres from Australia, Germany and Japan. The ARC requested funding is mainly to support personnel: 1 senior research associate and 2 PhD stipends. The other major item is travel support for the senior research associate to attend one conference per year over 3 years and for the PIs to visit Sydney over 3 years: 1 visit in each of the first two years and 2 visits in the final year.

Personnel: Total $602 800 (93.4% of overall request to ARC)

Senior Research Associate: $143 537 (Year 1); $148 337 (Year 2); $153 126 (Year 3); Total $445 000 (68.2% of overall request to ARC)

To successfully carry out the proposed research it is necessary to have a Postdoctoral Research Associate working full-time as a large amount of detailed technical work is involved requiring strong research skills. This represents the majority of the funding sought. Although the Chief Investigators will be involved substantially, they will each devote one day a week each to the project, so the Research Associate's role is of vital importance to this project.

The Research Associate will carry out the detailed work associated with the project working closely with the CI's and PI's and also working closely with at least two PhD students working on the project. This person needs to have an extensive breadth of skills and knowledge in Artificial Intelligence. In particular, the project requires a researcher with a solid background in formal knowledge representation and reasoning as well as in automated planning. Preferably they will be familiar with the situation calculus and its use in providing a formal semantics for Golog along with an understanding of how to implement solutions on a robot. It will be necessary to employ someone who has a good grasp of both theoretical issues and practical concerns. They will also need to have a strong background in software development in order to program the systems required to complete Tasks 1-5. A PhD qualification in a related field is mandatory, so in order to attract the best researchers we request funding for a Level B Step 3 from Year 1 (progressing to Steps 4 and 5 in years 2 and 3 respectively).

PhD Stipend: 2× $26 300 per annum; Total $157 800 (24.2% of overall request to ARC)

We have applied for two PhD stipends since the project will benefit enormously from the participation of post-graduate students. This project has strong theoretical and strong practical components; it has potential benefits to industry in the longer term. As such, this project provides an excellent research training opportunity for PhD students. The students stand to gain a wide variety of technical skills which will place them in a strong position for future employment. The PhD students will work closely with the Research Associate in developing the algorithms and corresponding implementations, as well as performing the empirical analysis required for the project. Ideally, computer science students with excellent algorithmic and software engineering skills and some basic understanding of theoretical computer science would be required. However, the academic potential of the students is more important than their specific skills. One of the PhD students will focus on the learning of ethical behaviours by demonstration (Task 2). The other PhD student will work on learning of ethical cognitive robot programs by demonstration (Tasks 3). Both PhD students will work on the representation and programming of ethical behaviours (Task 1) and the experimental analysis in a domestic/office robot setting (Task 5) through an entry in the international RoboCup@Home competition (UNSW has been selected to participate, through a competitive process, in the newly created Standard Platform League of RoboCup@Home using the Toyota Human Servbices Robot (HSR) in 2017).

Travel: Total $49 658 (7.6% of overall request to ARC)

There are two components to the request for travel funding:

- international conference travel for the Research Associate ($5 710 per annum; Total: $17 130; 2.6% of overall request to ARC); and,
- travel to Australia for PI Watanabe and PI Lakemeyer ($8 132 per visit x 4 visits; Total: $32 528; 5.0% of overall request from ARC).

As is well-known, in Computer Science, premier conference publications are generally preferred to journal publications. Top conference publications in Computer Science are considered archival publications and they often have equal or even higher impact then journal publications. Furthermore, these conference publications undergo a rigorous peer review process to an extent that exceeds that of many journals. Thus, it is essential that the outcomes of the project be communicated in a timely manner to other researchers by attending and presenting papers at appropriate international conferences, such as the International Joint Conference on Artificial Intelligence (IJCAI), the IEEE International Conference on Robotics and Automation (ICRA), the International Conference on Agent and Multi-Agent Systems (AAMAS), the International Conference on Knowledge Representation and Reasoning (KR), the European Conference on Artificial Intelligence (ECAI) and the AAAI Conference on Artificial Intelligence (AAAI). All of these conferences have the highest ERA Conference Ranking of A and the highest CORE Conference Ranking of A*.

We have budgeted for one conference in each year for the Research Associate funded by the ARC at a cost of $5 710 each. This will cover airfares, accommodation, conference registration and daily travel allowance. We justify this estimate as follows based on our previous experience of attending such conferences: return economy airfare (North America or Europe) $2 000; conference registration $1 000; accommodation for 5 days @ $252 per day = $1 260; and, daily travel allowance for 5 days @ $290 per day = $1 450 (accommodation and per diems are quoted from the Australian Taxation Office allowances). We assume a location in Europe or the Americas as this is usual for the major conferences in our area. For example, IJCAI in 2016 was held in New York, KR in 2016 was held in South Africa, ICRA in 2015 was held in Seattle, ECAI in 2016 was held in The Hague, The Netherlands.

We also apply for travel funding for the PI to visit UNSW in each year of the project. This will allow the PI to spend 2 weeks at the start of each year of the project in Australia to work intensively with the CIs, Research Associate and PhD students on this project. During each visit, we will organise a workshop around the PI's visit so that the local research community can benefit from their expertise and to disseminate information regarding the project. The PI's has already visited Australia for significant periods of time each year. While the CIs, PI, Research Associate and PhD students will have regular conference calls by Skype or tele-conference, the PI's presence is vital for this project. There are complex technical details that need to be worked out during this project and it is difficult to have these completely resolved by working remotely. Furthermore, the PI's presence is required to ensure that the empirical studies carried out in Australia and in Japan are done so on an equal footing. The PI's visit will also be important to the local research community who will benefit from their knowledge and expertise. The PI has an outstanding reputation in the international research community and their presence in Australia will have an advantageous influence on local researchers in this field.

The PI's will visit UNSW in each year of the project. ARC funding is requested to cover PI Watanabe's visit at the start of Year 2 to work on scoping the experimental setting (Task 5) and at the start of Year 3 in order to work on the experimentation, assess progress and set the agenda for the remainder of the project and to guarantee its successful completion. ARC funding is also requested to cover PI Lakemeyer's visit at the start of Year 1 to work on representing and programming of ethical behaviours (Task 1), and at the start of Year 3 in order to work on experimentation, assess progress and set the agenda for the remainder of the project and to guarantee its successful completion. This will cover airfares, accommodation, and daily travel allowance. We justify this estimate as follows based on our previous experience of such visits: return economy airfare from Japan/Europe $2 000; accommodation for 14 days @ $265 per day = $3 710; and, daily allowance for 14 days @ $173 per day = $2 422 (accommodation is quoted from the UNSW allowance for international visitors while the per diem allowance is based on our past experience and is lower than the UNSW allowance for international visitors).

E2. Details of non-ARC contributions

(In no more than two A4 pages and within the required format, provide an explanation of how non-ARC contributions will support the proposed Project. Use the same headings as in the Description column in the budget at Part D of this Proposal.)

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E2. Details of non-ARC contributions

Total non-ARC contributions: $791 398

Personnel: Total $725 793 (91.6% of non-ARC contribution)

The primary non-ARC contribution to this project is in terms of personnel. UNSW will be contributing 20% time for CI Pagnucco, CI Velonaki and CI Sammut. The Waseda University will be contributing 20% time for PI Watanabe and RWTH Aachen will be contributing 20% time for PI Lakemeyer. Each CI and PI is a leader in their field of expertise. Furthermore, they have a high level of complementary expertise and skills, combined with their successful experience working together which is very important and valuable for the project. They have demonstrated a capacity to have their research work accepted at the most prestigious forums in artificial intelligence. Maurice Pagnucco has demonstrated expertise in knowledge representation and reasoning particularly, belief change, reasoning about action and change and cognitive robotics. Mari Velonaki has demonstrated expertise in social robotics. Claude Sammut has demonstrated expertise in machine learning and learning by demonstration. Katsumi Watanabe has demonstrated expertise in social robotics. He will prove invaluable in the development of a functioning robot prototype in a home/office setting. Gerhard Lakemeyer has demonstrated expertise in knowledge representation and reasoning and cognitive robotics. He has extensive experience in applying research to practical applications in robotics that will assist in the success of this project.
The CI's and PI's, are well acquainted with one another as evidenced by joint grants and joint publications.

Personnel: PhD Student Support $12 000 (1.5% of non-ARC contribution)

UNSW will also provide $6 000 funding to support each of the two PhD students (total $12 000) during their candidature. This can be applied to attending international and domestic conferences and possibly equipment to support their research. We have averaged this amount over each of the three years of the project providing $2 000 each year per student. It is expected that an additional two PhD students will be involved in the project and funded by APA or IPRS scholarships and that a further four Honours/thesis students will work on this project. These students will work on a research project aligned with one of Tasks 1-4 and contribute to Task 5, experimental evaluation, through the RoboCup@Home competition each year.

Travel: Total $54 315 (6.9% of overall non-ARC contribution)

As noted above, conference presentations are an important aspect of dissemination of research results, particularly in computer science. The travel component of the budget ensures that this dissemination and discussion with other researchers in the field will be able to occur. UNSW will fund international travel costs where costing is estimated at $6 035 per trip with one trip per year scheduled for each of the CIs. This will cover airfares, accommodation, conference registration and daily travel allowance. We justify this estimate as follows based on our previous experience of attending such conferences: return economy airfare (North America or Europe) $2 000; conference registration $1 000; accommodation for 5 days @ $252 per day = $1 260; and, daily travel allowance for 5 days @ $355 per day = $1 775 (accommodation and per diems are quoted from the Australian Taxtion Office allowances). We assume a location in Europe or the Americas as this is usual for the major conferences in our area (see Part E1). It is envisaged that this will include both conference travel and also potentially visits to other universities, coordinated with the conference travel.

Part F - Personnel and ROPE (Prof Maurice Pagnucco)

F1. Personal Details

(To update personal details, click the 'Manage Personal Details' link below. Note this will open a new browser tab. When returning to the form ensure you 'Refresh' the page to capture the changes made to your profile.)

Participation Type

Chief Investigator

Title

Prof

First Name

Maurice

Second Name

Family Name

Pagnucco

F2. Will you be residing predominately in Australia for the duration of the Project?

(This is a 'Yes' or 'No' question. Indicate whether you will be residing predominantly in Australia for the duration of the Project, taking into account any international travel. If you are applying as a CI and you answer 'No' to this question you will be prompted to contact your Research Office to check your eligibility.)

Yes

F3. Qualifications

(To update any qualifications, click on the 'Manage Qualifications' link below. Note this will open a new browser tab. When returning to the form ensure you 'Refresh' the page to capture the changes made to your profile.)

Conferral Date	AQF Level	Degree/Award Title	Discipline/Field	Awarding Organisation	Country of Award
19/12/1996	Doctoral Degree	PhD	Computer Science	The University of Sydney	Australia
14/06/1991	Bachelor Honours Degree,Graduate Certificate, Graduate Diploma	BSc (Hons I)	Computer Science	The University of Sydney	Australia

F4. Are you currently undertaking a Higher Degree by Research which will be conferred after 1 January 2018?

(This is a 'Yes' or 'No' question. If you are applying as a CI and your answer is 'Yes' to this question you will be prompted to contact your Research Office.)

No

F5. Research Opportunity and Performance Evidence (ROPE) – Current and previous appointment(s) / position(s) - during the past 10 years

(To update any details in this table, click on the 'Manage Employment Details' link below. Note this will open a new

browser tab. When returning to the form ensure you 'Refresh' the page to capture the changes made to your profile. Click on the information icon above and refer to the Instructions to Applicants for more information.)

Description	Department	Contract Type	Employment Type	Start Date	End Date	Organisation
Professor	School of Computer Science and Engineering	Permanent	Full Time	01/01/2015		The University of New South Wales
Professorial Fellow (Honorary)	iCinema Centre for Interactive Cinema Research	Permanent	Full Time	01/01/2014		The University of New South Wales
Head of School	School of Computer Science and Engineering	Contract	Full Time	19/07/2010	18/07/2020	The University of New South Wales
Deputy Dean (Education)	Engineering	Contract	Full Time	15/08/2015	14/08/2018	The University of New South Wales
Associate Professor	School of Computer Science and Engineering	Permanent	Full Time	01/01/2008	31/12/2014	The University of New South Wales
Senior Lecturer	School of Computer Science and Engineering	Permanent	Full Time	01/07/2001	31/12/2007	The University of New South Wales

F6. Employment Details as at Commencement date of Project

(This question will be used to determine your eligibility. Confirm your employment status at all organisations that you will be associated with as at the Commencement Date for the Project (1 January 2018). Enter the relevant appointment type and Full-Time Equivalent (FTE) for each organisation. Click on the information icon for further information.)

Org name	Is this an Eligible Organisation?	Please choose your appointment type for this organisation.	Please enter your FTE for this Organisation
The University of New South Wales	Yes	Employee	1.0

F7. Further Details Regarding Partner Investigator Status - Do you hold a remunerated appointment at an Eligible Organisation?

(NOTE: this question is mandatory ONLY FOR PIs WHO:
• at F2 confirmed that they will reside predominantly in Australia for the duration of the proposed Project; AND
• at F4 confirmed that they are not currently undertaking a Higher Degree by Research which will be conferred after 1 January 2018; AND
• at F6 indicated that they would hold either:
- an appointment at an Eligible Organisation equal or greater than 0.2FTE; OR
- Emeritus appointment at an Eligible Organisation

This is a 'Yes' or 'No' question. If you select 'Yes', you will be further prompted to justify your participation on this Proposal as a PI with reference to sections F7.2 and F7.3 of the Funding Rules. Click on the information icon for further information.)
Do you hold a remunerated appointment at an Eligible Organisation?

Justification of PI status

F8. Relevant Organisation for this Proposal

(Enter the Organisation that is relevant to your participation on this proposal, and that you will be associated with as at the Commencement Date for the Project (1 January 2018). The 'relevant organisation' is the primary organisation that will be supporting your involvement in this Project if it is funded. Note that the Organisation must be listed in F6 for this question to validate.)

Relevant Organisation

The University of New South Wales

F9. What is your time commitment to this Project?

(Enter your time commitment to this Project as a Full-Time Equivalent (FTE). Note that a FTE of 1.0 represents a full-time commitment (i.e. 5 days per week).)

0.2

F10. Are you applying for Teaching Relief?

(This is a 'Yes' or 'No' question.

• If you answer 'Yes' to this question a budget line will be automatically populated for the Teaching Relief in the budget table in Form Part D: Project Cost. This will allow you to enter the funding amount requested in the relevant year/s. To remove the Teaching Relief from the budget table you must return to this question and answer 'No'.

• Note: CIs may request funding for teaching relief or other duties in order to maximise the opportunity for the CI to conduct research. This question is only relevant for CIs and will not be activated for PIs. If the answer to this question is 'yes', the budget table in 'Project Costs' will automatically update with a line to add costs for Teaching Relief.)

No

F11. Are you applying for a Discovery International Award?

(This is a 'Yes' or 'No' question. If you answer 'Yes' to this question a budget line will be automatically populated for the DIA in the budget table in Form Part D: Project Cost. This will allow you to enter the funding amount requested in the relevant year/s. To remove the DIA from the budget table you must return to this question and answer 'No'. Click on the information icon for further information.)

No

F12. Research Opportunity and Performance Evidence (ROPE) - Details of your career and opportunities for research

(Write a maximum of 5250 characters (approximately 750 words). Please detail your career and opportunities.)

i) NUMBER OF YEARS SINCE HIGHEST EDUCATIONAL QUALIFICATION
Prof Pagnucco received his PhD in Computer Science from the University of Sydney 21 years ago, in 1996.

ii) RESEARCH OPPORTUNITIES IN THE CONTEXT OF EMPLOYENT SITUATION
Pagnucco has spent the last 10 years in senior academic and advisory roles at UNSW. He became Deputy Dean (Education), Engineering, in 2015; Head of the School of Computer Science and Engineering (CSE) in 2010; Deputy Director of the Creative Robotics Lab (CRL) in 2016; and is currently a Professorial Fellow at iCinema. He

is also President of the Australian Council of Deans of ICT, Chair of the NICTA University Partner Committee and Chair of the NSW Steering Committee for Digital Careers. Previous appointments include Postgraduate Research Co-ordinator and Computing Resources Co-ordinator for CSE.

Over the last 10 years at UNSW, Pagnucco has been an Investigator on 10 major grant projects including:
- 3 ARC Discovery Projects as CI;
- 1 ARC Linkage Projects as CI;
- Go8-DAAD Joint Research Cooperation Scheme (2013-14);
- major commercial research funding grant from Microsoft (2012-13);
- 3 Asian Office of Aerospace Research and Development (AOARD) projects (2011, two in 2014); and
- Google Research Award (2015).

Between 2003 and 2010, Pagnucco was an Associate Investigator and Research Leader at the ARC COE for Autonomous Systems (CE0348228).

Pagnucco has helped attract over $12.7M in competitive funding to his research projects and institutions over the last 10 years. His research at UNSW has been further supported by over $900K internal funding for establishment of a world-class robotics research and teaching laboratory facility as part of the ARC COE for Autonomous Systems. The success of resulting research outcomes has led to inclusion of “ICT, Robotics and Devices” as one of UNSW’s official Research Strengths—areas in which UNSW is recognised as having international research excellence.

As part of his research Pagnucco has been committed to mentorship, supervising 14 PhD students (9 completed), over 45 Honours students, and a Masters student.

iii) EMPLOYMENT FRACTIONS
Pagnucco is Deputy Dean (Education) and Head of CSE: 38 academic staff, 25 research staff, 10 technical support staff, and 17 administrative staff. He allocates 0.5 FTE to Research, 0.5 to Administration.

iv) CAREER INTERRUPTIONS
n/a

v) RESEARCH MENTORING AND RESEARCH FACILITIES AVAILABLE
RESEARCH MENTORING:
Pagnucco has benefitted from mentoring from leading researchers in Australia. He was mentored by his PhD supervisor Norman Foo, one of the most eminent AI researchers in Australia (recipient of an ARC Special Investigator Award) and by Hector Levesque one of the most eminent AI researchers internationally during a postdoctoral fellowship at the University of Toronto. As Associate Investigator and Research Leader in the ARC COE for Autonomous Systems he was mentored by Professor Claude Sammut (COE CI and UNSW Node Leader) and Professor Hugh Durrant-Whyte (CEO of the COE).

FACILITIES:
Through Pagnucco, UNSW has developed an internationally recognised robotics research facility that produces highly successful world-class outputs in Human–Robot Interaction, Urban Search and Rescue, and RoboCup Soccer. Through his involvement with the former ARC COE for Autonomous Systems and his affiliation with NICTA (now Data61), Pagnucco provides access to cutting-edge research facilities that house state-of-the-art technological infrastructure. These associations support CSE’s leading position in national and international rankings in Computer Science and Robotics, and provide a valuable research context for the current Proposal in terms of dialogic human-computer interaction.

Pagnucco has a long history of collaboration with CI Sammut having co-authored papers and both part of the UNSW Node of the ARC COE for Autonomos Systems, with CI Velonaki through co-authored exhibitions and co-director/director of the UNSW Creative Robotics Laboratory, and with PI Lakemeyer through co-authored papers and joint grants (DP150103034 and a DAAD-Go8 grant). These partnerships and Pagnucco’s collaborative associations with leading ICT and robotics facilities have established productive working partnerships that strengthen the overall research environment in which the current project is to be situated (C1).

vi) OTHER ASPECTS OF CAREER OR OPPORTUNITIES FOR RESEARCH
Pagnucco’s research outputs are primarily published as refereed conference papers. The quality of his outputs is evidenced by their publication, both in full and abstract, by the highest ARC ERA and Computing Research & Education (CORE) ranked conferences in the field (F13), and extensive scholarly citations (F14, F15). This publishing convention, along with citation and credit in 3 highly-regarded textbooks, and the fact that he has published scholarly book chapters, demonstrate Pagnucco’s exceptional achievements in his field. In F14 and

F15, Google Scholar is cited as it is the most appropriate index for Computer Science because it includes top-rated conferences, which figure as equal if not more important than journal publications in Pagnucco's key disciplines.

F13. Research Opportunity and Performance Evidence (ROPE) - Significant research outputs and ARC grants

(Upload a PDF of no more than four A4 pages with a list of all research outputs, such as journal articles and refereed conference papers, book and book chapters. Use asterisks to identify research outputs relevant to this Proposal. Click on the information icon or refer to the Instructions to Applicants for the required content and formatting.)

Uploaded PDF file follows on next page.

F13 SIGNIFICANT RESEARCH OUTPUTS

i) Significant research outputs

Scholarly Book Chapters

1. *de Giacomo, G. & **Pagnucco, M.** (2011). Chronolog: It's About Time for Golog. In G. Lakemeyer & S. McIlraith (Eds.), *Knowing, Reasoning and Acting: Essays in Honor of Hector J. Levesque* (pp. 239–50). London: College Publications.
2. **Pagnucco, M.** (2006). Chapter 10: Levi on Abduction. In E.J. Olsson (Ed.), *Knowledge and Inquiry: Essays on the Pragmatism of Isaac Levi* (pp. 143–56). Cambridge/NY: Cambridge University Press.

Refereed Journal Articles

3. *Vongbunyong, S., **Pagnucco, M.** & Kara, S. (2016). Vision-Based Execution Monitoring of State Transition in Disassembly Automation. *International Journal of Automation Technology,* **10**:708-16.
4. Zhuang, Z., **Pagnucco, M.** & Zhang, Y. (2016). Inter-Definability of Horn Contraction and Horn Revision. *Journal of Philosophical Logic,* **45**:1-34. [ERA: A*]
5. *Vongbunyong, S., Kara, S. & **Pagnucco, M.** (2015). Learning and Revision in Cognitive Robotics Disassembly Automation. *Robotics and Computer-Integrated Manufacturing,* **3**(Aug):79-94. [ERA: A]
6. Zhuang, Z. & **Pagnucco, M**. (2014). Entrenchment-Based Horn Contraction. *Journal of Artificial Intelligence Research,* **51**:227-54. [ERA: A; CORE: A]
7. Nakata, M., Hamacher, D., Warren, J., Byrne, A., **Pagnucco, M.**, Harley, R., Venugopal, S., Thorpe, K., Neville, R. & Bolt, R. (2014). Using Modern Technologies to Capture and Share Indigenous Astronomical Knowledge. (Special Issue: Engaging with Indigenous Knowledge, Culture and Communities.) *Australian Academic & Research Libraries,* **45**(2):101-10. [ERA: B]
8. *Vongbunyong, S., Kara, S. & **Pagnucco, M.** (2013). Application of Cognitive Robotics in Disassembly of Products. *CIRP Annals–Manufacturing Technology,* **62**(1):31–34. [ERA: A]
9. *Vongbunyong, S., Kara, S. & **Pagnucco, M.** (2013). Basic Behaviour Control of the Vision-Based Cognitive Robotic Disassembly Automation. *Assembly Automation,* **33**(1):38-56. [ERA: C]
10. *Shapiro, S., **Pagnucco, M.**, Lesperance, Y. & Levesque, H. (2011). Iterated Belief Change in the Situation Calculus. *Artificial Intelligence,* **175**(1):165-92. [ERA: A*; CORE:A*]
11. Delgrande, J.P., Nayak, A.C. & **Pagnucco, M.** (2005). Gricean Belief Change. *Studia Logica,* **79**(1):97-113. [ERA: A]

Refereed Conference Papers

12. *Rajaratnam, D., Hengst, B., **Pagnucco, M.**, Sammut, C. & Thielscher, M. (2016). Composability in Cognitive Hierarchies. In *Proceedings of the 29th Australasian Joint Conference on Artificial Intelligence (AI-16)*, *Lecture Notes in Computer Science* (pp. 42-55). Cham: Springer.
13. *Clark, K., Hengst, B., **Pagnucco, M.**, Rajaratnam, D., Robinson, P., Sammut, C. & Thielscher, M. (2016). A Framework for Integrating Symbolic and Sub-Symbolic Representations. In S. Kambhampati (Ed.), *Proceedings of the 25th International Joint Conference on Artificial Intelligence* (IJCAI-16; pp. 2486–92). Palo Alto: AAAI. [ERA: A; CORE: A*]
14. Rezvani, M., Ignjatovic, A., Pagnucco, M., and Jha, A. (2016). Anomaly-free policy composition in software-defined networks. In Proceedings of the 2016 IFIP Networking Conference (IFIP Networking) and Workshops, (IFIP Networking; pp. 28-36).
15. *Harris, S., Hengst, B. & **Pagnucco, M.** (2015). Termination Approximation: Continuous State Decomposition for Hierarchical Reinforcement Learning. In Leonetti, M., and Eaton, E. (Eds.), *In Proceedings of the AAAI Workshop on Knowledge, Skill, and Behavior Transfer in Autonomous Agents* (pp. 16–22). Palo Alto: AAAI.
16. *Hall, B., Harris, S., Hengst, B., Liu, R., Ng, K., **Pagnucco, M.**, Pearson, L., Sammut, C. & Schmidt, P. (2015). Robocup SPL 2015 Champion Team Paper. In Almeida, L., Ji, J., Steinbauer, G., and Luke, S. (Eds.), *Proceedings of RoboCup 2015: Robot World Cup XIX, Lecture Notes in Computer Science* (pp. 72–82). Cham: Springer.
17. *Ashar, J., Ashmore, J., Hall, B., Harris, S., Hengst, B., Liu, R., Mei, Z., **Pagnucco, M.**, Roy, R. & Sammut, C. (2015). RoboCup SPL 2014 Champion Team Paper. In Bianchi, R.A.C., Akin, H.L., Ramamoorthy, S., Sugiura, K. (Eds), *Proceedings of RoboCup 2014: Robot World Cup XVIII, Lecture Notes in Artificial Intelligence* (pp. 70–81). Cham: Springer.

18. Schwering, C., Lakemeyer, G. & **Pagnucco, M**. (2015). Belief Revision and Progression of Knowledge Bases in the Epistemic Situation Calculus. In Q. Yang & M. Woolridge (Eds.), Proceedings of the *International Joint Conference on Artificial Intelligence* (IJCAI-15; pp. 3214-20). Palo Alto: AAAI. [ERA: A; CORE: A*]
19. *Vongbunyong, S., Kara, S. & **Pagnucco, M.** (2015). General Plans for Removing Main Components in Cognitive Disassembly Automation. In D. Bailey, G.S. Gupta & S. Demidenko (Eds.), *Proceedings of the 6th Int. Conference on Automation, Robotics and Applications* (pp. 501-06). Danvers: IEEE.
20. *Buehler, J., & **Pagnucco, M.** (2014). Planning and Execution of Robot Tasks Based on a Platform-Independent Model of Robot Capabilities. In T. Schaub, G. Friedrich & B. O'Sullivan (Eds.), *Proceedings of the 21st European Conference on Artificial Intelligence: Proceedings* (pp. 171–76). Amsterdam: IOS. [ERA: A; CORE: A]
21. *Buehler, J. & **Pagnucco, M.** (2014). A Framework for Task Planning in Heterogeneous Multi Robot Systems Based on Robot Capabilities. In C.E. Brodley & P. Stone (Eds.), *Proceedings of the 28th AAAI Conference on Artificial Intelligence* (pp. 2527-33). Menlo Park: AAAI. [ERA: A; CORE: A*]
22. *Heap, B. & **Pagnucco, M.** (2014). Minimising Undesired Task Costs in Multi-Robot Task Allocation Problems with In-Schedule Dependencies. In C.E. Brodley & P. Stone (Eds.), *Proceedings of the 28th AAAI Conference on Artificial Intelligence* (pp. 2542-48). Menlo Park: AAAI. [ERA: A; CORE: A*]
23. *Rajaratnam, D., Levesque, H. J., **Pagnucco, M.** & Thielscher, M. (2014). Forgetting in Action. In C. Baral, G. De Giacomo & T. Eiter (Eds.), *Proceedings of the 14th Int. Conference on Principles of Knowledge Representation and Reasoning* (pp. 498–507). Menlo Park: AAAI. [ERA: A; CORE: A*]
24. Zhuang, Z., **Pagnucco, M.** & Zhang, Y. (2013). Definability of Horn Revision from Horn Contraction. In F. Rossi (Ed.), *Proceedings of the 23rd Int. Joint Conference on Artificial Intelligence* (pp. 1205-10). Menlo Park: AAAI. [ERA:A; CORE: A*]
25. *Rajaratnam, D., Levesque, H.J., **Pagnucco, M.** & Thielscher, M. (2013). Reasoning about Robot Epistemic Ability to Use the Cloud. In J. Ji, H. Strass, & X. Wang (Eds.), *Non-Monotonic Reasoning, Action, and Change: Proceedings of the 10th Int. Workshop (NRAC 2013)* (pp. 37-44). Menlo Park: AAAI. [CORE: C]
26. ***Pagnucco, M.**, Rajaratnam, D., Strass, H. & Thielscher, M. (2013). Implementing Belief Change in the Situation Calculus and an Application. In P. Cabalar & T.C. Son (Eds.), *Logic Programming and Nonmonotonic Reasoning: 12th Int. Conference* (pp. 439-51). NY: Springer. [ERA: A; CORE: A]
27. *Heap, B. & **Pagnucco, M.** (2013). Repeated Sequential Single-Cluster Auctions with Dynamic Tasks for Multi-Robot Task Allocation with Pickup and Delivery. In M. Klusch, M. Thimm & M. Paprzycki (Eds.), *Proceedings of Multiagent System Technologies: 11th German Conference* (pp. 87-100). Berlin/Heidelberg: Springer [ERA: B]
28. *Heap, B. & **Pagnucco, M.** (2013). Repeated Auctions for Reallocation of Tasks with Pickup and Delivery upon Robot Failure. In G. Boella, E. Elkind, B.T. Savarimuthu, F. Dignum, M.K. Purvis (Eds.), *Principles and Practice of Multi-Agent Systems: 16th Int. Conference, Proceedings* (pp. 461-69). NY: Springer. [ERA: C; CORE: B]
29. *Heap, B. & **Pagnucco, M.** (2012). Analysis of Cluster Formation Techniques for Multi-robot Task Allocation Using Sequential Single-Cluster Auctions. In M. Thielscher & D. Zhang (Eds.), *Advances in Artificial Intelligence, 25th Int. Australasian Joint Conference, Proceedings* (pp. 839-50). NY: Springer. [ERA: B]
30. *Heap, B. & **Pagnucco, M.** (2012). Repeated Sequential Auctions with Dynamic Task Clusters. In *Proceedings of the 26th AAAI Conference on Artificial Intelligence* (pp. 1997-2002). Menlo Park: AAAI. [ERA: A; CORE: A*]
31. Zhuang, Z. & **Pagnucco, M.** (2012). Model Based Horn Contraction. In G. Brewka, T. Eiter & S. McIlraith (Eds.), *Proceedings: 13th Int. Conference on the Principles of Knowledge Representation and Reasoning* (pp. 169-78). Menlo Park: AAAI. [ERA: A; CORE: A*]
32. *Vongbunyong, S., Kara, S. & **Pagnucco, M.** (2012). A Framework for Using Cognitive Robotics in Disassembly Automation. In D.A. Dornfeld & B.S. Linke (Eds.), *Leveraging Technology for a Sustainable World: Proceedings of the 19th CIRP Conference on Life Cycle Engineering* (pp. 173-78). NY: Springer. [ERA: A]
33. *Cerexhe, T. & **Pagnucco, M.** (2011). Executability in the Situation Calculus. In D. Wang & M. Reynolds (Eds.), *Advances in Artificial Intelligence: 24th Australasian Joint Conference, Proceedings* (pp. 677-86). NY: Springer. [ERA: B]
34. *Heap, B. & **Pagnucco, M.** (2011). Sequential Single-Cluster Auctions for Robot Task Allocation. In D. Wang & M. Reynolds (Eds.), *Advances in Artificial Intelligence: 24th Australasian Joint Conference Proceedings* (pp. 412–21). NY: Springer. [ERA: B]
35. Rajaratnam, D. & **Pagnucco, M.** (2011). From Approximate Clausal Reasoning to Problem Hardness. In D. Wang & M. Reynolds (Eds.), *Advances in Artificial Intelligence: 24th Australasian Joint Conference, Proceedings* (pp. 501–10). NY: Springer. [ERA: B]
36. ***Pagnucco, M.**, Rajaratnam, D., Strass, H. & Thielscher, M. (2011). How to Plan When Being Deliberately Misled. In S. Sariel-Talay, S.F. Smith & N. Onder (Eds.), *Automated Action Planning for Autonomous Mobile*

Robots: Papers from the 2011 AAAI Workshop (pp. 45-50). Menlo Park: AAAI.

37. Zhuang, Z. & **Pagnucco, M**. (2011). Transitively Relational Partial Meet Horn Contraction. In T. Walsh (Ed.), *Proceedings of the 22nd Int. Joint Conference on Artificial Intelligence* (pp. 1132-1139). Menlo Park: AAAI. [ERA: A; CORE: A*]
38. Zhuang, Z. & **Pagnucco, M.** (2010). Two Methods for Constructing Horn Contractions. In J. Li (Ed.), *Advances in Artificial Intelligence: 23rd Australasian Joint Conference, Proceedings* (pp. 72–81). NY: Springer. [ERA: B]
39. *Schonig, A. & **Pagnucco, M.** (2010). Evaluating Sequential Single-Item Auctions for Dynamic Task Allocation. In J. Li (Ed.), *Advances in Artificial Intelligence: 23rd Australasian Joint Conference, Proceedings* (pp. 506–15). NY: Springer. [ERA: B]
40. Ashar, J., Claridge, D., Hall, B., Hengst, B., Nguyen, H., **Pagnucco, M.**, Ratter, A., Robinson, S., Sammut, C., Vance, B., White, B. & Zhu, Y. (2010). RoboCup Standard Platform LeaguerUNSWift 2010. In G. Wyeth & B. Upcroft (Eds.), *Proceedings of the 2010 Australasian Conference on Robotics and Automation*. Red Hook: Australian Robotics & Automation Association (ARAA). [ERA: B]
41. Zhuang, Z. & **Pagnucco, M.** (2010). Horn Contraction via Epistemic Entrenchment. In T. Janhunen & I. Niemelä (Eds.), *Logics in Artificial Intelligence: 12th European Conference, Proceedings* (pp. 339–51). NY: Springer. [ERA: A; CORE: A]
42. Chamiel, G. & **Pagnucco, M.** (2009). Ontology Guided Dynamic Preference Elicitation. In D. Jannach, W. Geyer, J. Freyne, S. Singh Anand, C. Dugan, B. Mobasher & A. Kobsa (Eds.), *Proceedings of the ACM RecSys'09 Workshop on Recommender Systems & the Social Web* (pp. 41-49). NY: ACM.
43. Ströder, T. & **Pagnucco, M.** (2009). Realising Deterministic Behavior from Multiple Non-Deterministic Behaviors. In C. Boutillier (Ed.), *Proceedings of the 21st Int. Joint Conference on Artificial Intelligence* (pp. 936-41). Menlo Park: AAAI. [ERA: A; CORE: A*]
44. Zhuang, Z. & **Pagnucco, M.** (2009). Belief Contraction in the Description Logic EL. In B. Cuenca Grau, I. Harrocks, B. Motik & U. Sattler (Eds.), *Proceedings of the 22nd Int. Workshop on Description Logics* (Vol. 477). Oxford: Center for European Union Research.
45. *Chamiel, G. & **Pagnucco, M.** (2008). Exploiting Ontological Structure for Complex Preference Assembly. In W. Wobcke & M. Zhang (Eds.), *Advances in Artificial Intelligence: 21st Australasian Joint Conference on Artificial Intelligence, Proceedings* (pp. 86–92). NY: Springer. [ERA: B]
46. *Chamiel, G. & **Pagnucco, M.** (2008). Utilising Ontological Structure for Reasoning with Preferences. In T. Meyer & M.A. Orgun (Eds.), *Advances in Ontologies: Proceedings of the Knowledge Representation Ontology Workshop* (pp. 1-10). Sydney: ACS.
47. *Chamiel, G. & **Pagnucco, M.** (2008). Exploiting Ontological Information for Reasoning with Preferences. In J. Chomicki, V. Conitzer, U. Junker & P. Perny (Eds.), *Advances in Preference Handling: Papers from the AAAI Workshop* (pp. 19-24). Menlo Park: AAAI.
48. Zhuang, Z., **Pagnucco, M.** & Meyer, T. (2007). Implementing Iterative Belief Change via Prime Implicates. In M.A. Orgun & J. Thornton (Eds.), *Advances in Artificial Intelligence: 20th Australian Joint Conference on Artificial Intelligence, Proceedings* (pp. 506-18). NY: Springer. [ERA: B]
49. Rajaratnam, D. & **Pagnucco, M.** (2007). Prime Implicates for Approximate Reasoning. In Z. Zhang & J. Siekmann (Eds.), *Knowledge Science, Engineering and Management: 2nd Int. Conference, Proceedings* (pp. 61–72). NY: Springer. [ERA: B; CORE: B]
50. **Pagnucco, M.** (2006). Knowledge Compilation for Belief Change. In A. Sattar & B.H. Kang (Eds.), *Advances in Artificial Intelligence: 19th Australian Joint Conference on Artificial Intelligence, Proceedings* (pp. 90–99). NY: Springer. [ERA: B; CORE: B]
51. **Pagnucco, M.** & Rajaratnam, D. (2005). Inverse Resolution as Belief Change. In *Proceedings of the 19th Int. Joint Conference on Artificial Intelligence* (pp. 540-45). San Francisco: Elsevier. [ERA: A; CORE: A*]

Other Research Outputs

Edited Conference Proceedings

52. **Pagnucco, M**. & Thielscher, M. (Eds.) (2008). *Proceedings of the 12th Int. Workshop on Non-Monotonic Reasoning*. Sydney: UNSW.

Conference Presentations

53. Del Favero, D. & **Pagnucco, M.** (2011). Artificially Intelligent Aesthetics: Recent Experimental Studies. Paper

presented at *NIEA Experimental Arts Double Conference*, UNSW, Sydney.

Exhibitions

54. Velonaki, M., **Pagnucco, M.**, Silvera-Tawil, D., Alvarez, D., Ladoucer, F. & Durrant-Whyte, H. (2013-15). *Blue Iris*. 2015: 'CUSP: Designing into the Next Decade' State Library of Queensland, Brisbane & Queen Victoria Gallery & Museum, Launceston & Mornington Peninsula Regional Gallery, Mornington Peninsula; 2014: 'CUSP: Designing into the Next Decade', Western Plains Cultural Centre, Dubbo & Glasshouse Regional Gallery, Port Macquarie & JamFactory, Adelaide; 2013: 'CUSP: Designing into the Next Decade', Casula Powerhouse, Sydney.
55. *Del Favero, D., Shaw, J., Benford, S., Goebel, J., Sewell, S. & **Pagnucco, M.** (2010-14). *Scenario*. 2014: Chronus Art Center, Shanghai, China; 'Child, Nation & World Cinema Symposium', UNSW, Sydney; 2013: 'Int. Symposium of Electronic Art (ISEA)', UNSW, Sydney; 2011: 'Sydney Film Festival', Sydney; 2010: '15th Biennial Film & History Conference FHAANZ', UNSW, Sydney.
56. Shaw, J., Del Favero, D., Brown, N., Compton, P., **Pagnucco, M.**, Van Schaik, A., Jin, C., Seah, H., Weibel, P., Kenderdine, S., Hart, T., Fritz, J. & Kuchelmeister, V. (2006-14). *PLACE-Hampi* (& *ANCIENT HAMPI MUSEUM*). 2014: Chronus Art Center, Shanghai; 2012: (Permanent Installation) Kaladham Museum, Karnataka, India; 2011: 'Inaugural Exhibition', ALiVE, City University of Hong Kong; 2009: Immigration Museum, Melbourne; 2008: 'eARTS Festival: eLANDSCAPES', Shanghai Zendai Museum of Modern Art, Shanghai; 2007: 'Panorama Festival', ZKM, Karlsruhe; 'From Spark to Pixel', Martin-Gropius-Bau, Berlin; 'i.Future Festival', Science Centre, Singapore; 2006: 'Lille3000 Festival, Bombaysers de Lille', Rotonde de L'Opera, Lille.

ii) ARC grants awarded in the last 10 years and associated outputs

Project ID	CI/PI/Fellow Names	Amount Funded	Amount of Years	Project Title	Outputs
DP150103034	Prof M.Thielscher, **Prof M.Pagnucco**, Prof T.Schaub, Prof G.Lakemeyer	$419,900	3	Representation and Reasoning for Cognitive Personal Robots	12, 13
LE150100090	A/Prof M.Velonaki, A/Prof D.Rye, Prof G.Dissanayake, Prof C.Clifford, Prof D.Liu, **Prof M.Pagnucco**, Dr F.Ramos, A/Prof S.Faux	$350,000	1	Facility for Experimental Human-Robot Interaction (HRI) Research	
DP120102144	Prof M.Thielscher, **A/Prof M.Pagnucco**, Prof H.J.Levesque	$335,000	3	Representing and Reasoning about Ability for Robots to Use the Cloud	18, 20-23, 25, 26, 27-30
DP120100332	Dr S.Sardina, **A/Prof M.Pagnucco**, Prof G.De Giacomo	$300,000	3	Optimisation of Embedded Virtual Complex Systems by Re-using a Library of Available Components	
LP0669163	Prof J.Shaw, Dr D.Del Favero, Prof N.C.Brown, Prof P.Compton, **Dr M.Pagnucco**, Dr F.van Schaik, Dr C.T.Jin, A/Prof H.Seah, Prof P.Weibel, Ms S.Kenderdine, Mr T.Hart, Dr J.Fritz	$519,264	4	Reformulating narrative in Virtual Heritage Using Co-evolutionary Model of Immersive Interactivity	56

F14. Research Opportunity and Performance Evidence (ROPE) - Ten career-best research outputs

(Please upload a PDF with a list of your ten career-best research outputs, with a brief paragraph for each research

output explaining its significance (five pages maximum).)

Uploaded PDF file follows on next page.

F14 TEN CAREER-BEST RESEARCH OUTPUTS

KEY:
ERA ranking: journals (A*, A, B, C); conferences (A, B, C)
CORE ranking: journals (A*, A, B, C); conferences (A*, A, B, C)
Times Cited: from Google Scholar (see F12 vi)

1. *Shapiro, S., **Pagnucco, M**., Lesperance, Y., & Levesque, H. J. (2011). Iterated Belief Change in the Situation Calculus. *Artificial Intelligence* 175(1): 165–92. [ERA: **A*;** CORE: **A***]

   Funded by ARC Grant CE0348228.

   Landmark paper dealing with maintaining beliefs in the situation calculus. Still benchmark output in the area of Artificial Intelligence Reasoning About Action Systems. 44 citations, 90 for original conference version.

2. Rott, H. & **Pagnucco, M.** (1999). Severe Withdrawal (and Recovery). *Journal of Philosophical Logic* 28(5): 501-47. [ERA: **A*;** CORE: **A***]

   Axiomatisation for significant class of contraction functions. Unbeknownst then, Sven Ove Hansson later credited the authors in seminal work with providing solutions for significant open problems in reasoning. 120 citations.

3. Nayak, A.C., **Pagnucco, M.,** & Peppas, P. (2003). Dynamic Belief Revision Operators. *Artificial Intelligence* 146(2): 193–228. [ERA: **A*;** CORE: **A***]

   Funded by ARC Grant DP0344192.

   Among the earliest, pioneering papers formally investigating iterated belief change, laying the groundwork for this field that today figures at the forefront of global AI research. 113 citations.

4. ***Pagnucco, M.** & Levesque, H. J. (2000). LeGolog: Inexpensive Experiments in Cognitive Robotics. In W. Horn (Ed.), *Proceedings of the 2nd Int. Cognitive Robotics Workshop at the 14th European Conference on Artificial Intelligence.* Amsterdam: IOS. Available at: http://www.cs.toronto.edu/kr/papers/crw00.pdf. [ERA: **B**]

   Funded by ARC Grant X0000179.

   Extensively used by researchers and included in syllabi at UNSW, Macquarie, Potsdam, Milan, and Sabanci universities. Describes software controlling mobile robots using the unique cognitive robotics language Golog. 64 citations.

5. Nayak, A.C., Foo, N. Y., **Pagnucco, M.,** & Sattar, A. (1996). Changing Conditional Beliefs Unconditionally. In Y. Shoham (Ed.), *Proceedings of the 6th Conference on the Theoretical Aspects of Rationality and Knowledge* (pp. 119-35). San Franscico: Morgan Kauffmann Publishers Inc. [ERA: **A**; CORE: **A***]

   First paper on iterated belief revision appearing alongside that of pioneers Darwiche and Pearl. The two papers established this important area of research. 48 citations.

6. Zhuang, Z. & **Pagnucco, M**. (2010). Horn Contraction via Epistemic Entrenchment. In T. Janhunen & I. Niemelä (Eds.), Logics in Artificial Intelligence: 12th European Conference, Proceedings (pp. 339–51). NY: Springer. [ERA: A; CORE: A]

   A pioneering paper providing a construction for the Horn fragment of belief contraction. This work has important implications for the implementation of belief change. 24 citations.

7. *Shapiro, S. & **Pagnucco, M.** (2004). Iterated Belief Change and Exogenous Actions in the Situation Calculus. In R. López de Mántaras and L. Saitta (Eds.), *Proceedings of the 16th European Conference on Artificial Intelligence* (pp. 878-82). Amsterdam: IOS. [ERA: **A;** CORE: **A***]

   Funded by ARC Grant CE0348228.

   Significantly extends the investigation into AI reasoning about action systems by focussing on exogenous actions, laying the groundwork for practical applications of developments in AI reasoning about action. 21 citations.

8. *Ströder, T. & **Pagnucco, M.** (2009). Realising Deterministic Behavior from Multiple Non-Deterministic Behaviors. In C. Boutilier (Ed.), *Proceedings of the 21st International Joint Conference on Artificial Intelligence*. (pp. 936-41). Menlo Park: AAAI. [ERA: **A**; CORE: **A***]

   Funded by ARC Grant CE0348228.

   Provides a ground-breaking progression algorithm for solving the long-standing behaviour composition problem where previous approaches failed by using regression. It also provides a Java implementation of the algorithm. 13 citations.

9. **Pagnucco, M.** & Peppas, P. (2001). Causality and Minimal Change Demystified. In B. Nebel (Ed.), *Proceedings of the 17th International Joint Conference on Artificial Intelligence*, Vol. 1 (pp.125-30). San Francisco: Morgan Kauffmann Publishers Inc. [ERA: **A;** CORE: **A***]

   Path-defining study showing where causal knowledge can be singled down to minimal change in order to solve classes of significant AI reasoning about action problems. 12 citations.

10. Delgrande, J. P., Nayak, A. C., & **Pagnucco, M.** (2004). Conservative Belief Change. In A.G. Cohn (Ed.), *Proceedings of the 19th National Conference on Artificial Intelligence* (pp. 251-56). Palo Alto: AAAI. [ERA: **A;** CORE: **A***]

    Funded by ARC Grant DP0344192.

    First ever successful attempt at applying Grice's celebrated work on pragmatics to AI belief change theory. Provides formal account of belief change incorporating Grice's maxims of conversational implicature. 10 citations.

F15. Research Opportunity and Performance Evidence (ROPE) - Further evidence in relation to research impact and contributions to the field, including those most relevant to this Proposal

(Write a maximum of 11250 characters (approximately 1500 words). Detail further evidence in relation to research impact and contributions to the field. Click on the information icon and refer to the Instructions to Applicants for the required content and formatting.)

RESEARCH IMPACT: CONTRIBUTIONS SPECIFIC TO THE PROPOSAL
Professor Pagnucco is an internationally recognised computer scientist and innovator in the field of Artificial Intelligence (AI), particularly recognised for developments in the areas of knowledge representation and reasoning, belief change, reasoning about action, and cognitive robotics. Highly respected in the field, Pagnucco has a history of collaboration with researchers on installation art and electronic media art projects that will greatly benefit the project (F13 No.53-56) including CI Velonaki (F13 No.53). With achievements that include field-first discoveries, he is well positioned to execute the development of the project's Task 1 and Task 4 (Part C1).

His contributions in the following areas will benefit the project:

*ABDUCTIVE REASONING
Pagnucco's most significant contribution to the development of AI is a project concerned with the role of abductive reasoning (a form of explanatory inference) in belief change. This is recognised as one of the pioneering works in this area. An outcome of this work was an axiomatisation for a class of contraction functions that was, unbeknownst to Pagnucco and his collaborators at the time, listed as an open problem by leading scholar, Sven Ove Hansson in 'A Textbook Of Belief Dynamics: Theory Change And Database Updating' (Dordrecht: Kluwer, 1999). Pagnucco was credited for this discovery in the published version of the text. An equivalent (but syntactically different) axiomatisation was independently discovered by Prof Hans Rott and led to a seminal joint work published in the JOURNAL OF PHILOSOPHICAL LOGIC (F14 No.2). Modelling the beliefs of AI systems will be key to encoding and reasoning about the ethical principles a robot should follow in a social setting, one of the key areas of expertise Pagnucco brings to the project.

*REASONING ABOUT ACTION:
Reasoning about action for intelligent systems is another sphere in which Pagnucco has contributed pioneering results, particularly in two areas: belief change in the situation calculus, and representations of causal knowledge. An article published by Pagnucco and colleagues in KR2000 (proceedings of the 7th International Conference on Principles of Knowledge Representation and Reasoning) was revised and extended before being published in the A* ranked journal ARTIFICIAL INTELLIGENCE (F13 No.1), and is still considered one of the cornerstones of developing a notion of belief change in the situation calculus used in planning and cognitive robotics. This project is concerned with the actions a robot should take in a social setting in which it collaborates with human co-workers, and Pagnucco's research on reasoning about action will be used to determine appropriate actions to enable this collaboration without placing the co-worker in danger.

In addition, Pagnucco's ground-breaking work on the understanding of behaviour formulation will be instrumental in the project's development of efficient methods for reasoning about AI agent belief. Pagnucco's recent paper (with Zhi Qiang Zhuang and Prof Yan Zhang) at the 23rd International Joint Conference on Artificial Intelligence (IJCAI 2013) (F13 No.24), provided further innovation in efficient reasoning techniques for modelling and reasoning about agent beliefs. These results extended previous pioneering work by Pagnucco and Zhi Qiang Zhuang and are crucial to the current Proposal.

Further, the cognitive robotics software, LEGOLOG (F14 No.4), developed by Pagnucco and Prof H. J. Levesque, has been used at universities worldwide for cognitive robotics research (e.g. University of Potsdam, Germany, Sabanci University, Turkey). The implementation techniques developed for it will also be of critical importance to the success of the proposed project.

SUMMARY: CONTRIBUTIONS SPECIFIC TO THE PROPOSAL
As evidenced by his significant impact and contributions to the field of AI, and his experience in its application to reasoning about action and robotics (e.g., DP150103034, DP120102144, DP120100332, LE150100090), Pagnucco is extremely well-placed to lead this project.

RESEARCH IMPACT: CONTRIBUTIONS TO THE FIELD
Pagnucco's publications have appeared in the foremost forums in his field, including all major international AI events. He has papers at the prestigious IJCAI, AAAI, ECAI, KR, and TARK conferences. He has also published in top-ranking journals including ARTIFICIAL INTELLIGENCE (ERA ranking A*), JOURNAL OF ARTIFCIAL INTELLIGENCE RESEARCH (ERA ranking A), the JOURNAL OF PHILOSOPHICAL LOGIC (ERA ranking A*) and STUDIA LOGICA (ERA ranking A). His research impact is in part reflected by a total of 1040 citations to his work (25/02/2017).

Pagnucco's impact and contribution to his field are further evidenced by the following achievements:

*COGNITIVE ROBOTICS:
As Professorial Fellow at UNSW's iCinema Centre, Pagnucco has developed a version of the cognitive robotics programming language Golog for controlling virtual agents in visualisation applications. This language facilitates the realistic control of virtual agents using sophisticated AI planning techniques. The techniques developed are many times more powerful than those found in current computer programs. In collaboration with iCinema, a purpose-written narrative work by acclaimed Australian playwright Stephen Sewell, SCENARIO (with CI Del Favero and PI Shaw; F13 No.55), has been developed using this language. The outcome of the project premiered at the SYDNEY FILM FESTIVAL in 2011—the very first time that such sophisticated AI techniques have been used for a work presented at a major film festival. As testimony to its lasting reputation as a pioneering project, SCENARIO continues to be exhibited internationally at prestigious events, including the INTERNATIONAL SYMPOSIUM OF ELECTRONIC ART (ISEA 2013) and, most recently, Shanghai's Chronus Art Center (2014) (F13 No.55). He and his students and collaborators have developed Golog-based controllers for other projects, in particular to control a robot arm that disassembles LCD screens for recycling (F13 Nos.3, 5, 8, 9, 19, 32).

*AUTONOMOUS SYSTEMS:
Pagnucco has been instrumental in developing technologies that have been industrially implemented as part of high-value commercialisations of research. E.g., he was lead CI on a $110K research contract with Susien Robotics Pty Ltd that developed an autonomous weeding robot for a farm southwest of Sydney. In collaboration with researchers from UNSW Engineering, he has also developed a robotic system that disassembles LCD monitors for recycling (see above). A major innovation resulting from this project was the successful incorporation of robot learning by example for the disassembly process. He is currently involved in a research project funded by Fuji Xerox, Japan with CI Velonaki.

RESEARCH ACHIEVEMENTS
Pagnucco's contributions are recognised by his appointment to the advisory board of KR Inc.—the major professional body for research in knowledge representation and AI. This commitment involved organising the 11th International Conference on Principles of Knowledge Representation and Reasoning (KR2008)—an A-ranked (ERA) conference that attracted 420 elite delegates to Sydney.

In 2014 Pagnucco was appointed an Associate Editor of ARTIFICIAL INTELLIGENCE (ERA Journal Ranking A*), the most highly regarded journal in his field of research. He has also been on the editorial board of the JOURNAL OF ARTIFICIAL INTELLIGENCE RESEARCH (ERA Journal Ranking: A) and is a current member of leading international professional bodies, including the ASSOCIATION FOR THE ADVANCEMENT OF ARTIFICIAL INTELLIGENCE (AAAI), ASSOCIATION FOR COMPUTING MACHINERY (ACM) and ASSOCIATION FOR SYMBOLIC LOCIC (ASL).

Pagnucco's standing is further evidenced by his citation in several books by international leaders in AI research. In addition to being credited with a field-first discovery (see above), Pagnucco's research on abductive reasoning (a form of explanation) and its role in belief change has been extensively discussed by leading American philosopher Isaac Levi in his book 'Mild Contraction' (Oxford:OUP, 2004), and also by E.J. Olsson and S. Enqvist in 'Belief Revision Meets Philosophy of Science' (Heidelberg:Springer, 2011).

He holds seats on various conference committees and has been conference chair for many high-ranking conferences and organisations including:

-International Joint Conf. on AI (IJCAI 2009, 2011, 2013, 2015-2017) (ERA: A); Senior Program Committee
-Association for the Advancement of AI Conf. (AAAI 2006-17) (ERA: A); Senior & Program Committee
-International Conf. on Autonomous Agents & Multiagent Systems (AAMAS-2004/2005/2013-2017) (ERA: A)
-Australasian Joint Conf. on AI (AI 1999-2012, 2015-2016) (ERA: B); General Chair & Committee
-Australasian Computer Science Conf. (ACSC 2010-2017); Programme Committee
-International Conf. on Principles of Knowledge Representation and Reasoning (KR2006, 2008, 2010) (ERA: A); Local Arrangements, Chair & Committee
-Australasian Conf. on Robotics and Automation (ACRA 2005-16) (ERA: B)
-International Workshop on Nonmonotonic Reasoning (NMR 2008); Co-Chair
-IJCAI Workshop on Nonmonotonic Reasoning, Action and Change (NRAC 2005); Co-Chair
-7th Pacific Rim Conf. on AI (PRICAI 2002); Workshop Chair

Pagnucco is highly engaged and respected in the international community of his field of research as demonstrated by numerous invitations to collaborate at leading international institutions such as the German DFG funded Hybrid Reasoning for Intelligent Systems project (fully-funded keynote invitation to Potsdam University, Germany); University of Sao Paulo, Brazil (2004: delivery of research intensive course on Cognitive Robotics); the Nippon Institute for Informatics; the renowned Banff International Research Station (2003, invitation-only); and, the

prestigious German computer science research centre, Dagstuhl (2003, 2008-10; invitation-only workshops).

Pagnucco has been invited annually (1998-2009) to deliver courses on knowledge representation at the Australian Logic Summer School (ANU), currently sponsored by Australia's largest organisation dedicated to information communications technology (ICT) research: the National ICT Research Centre of Excellence (NICTA), now Data61 (from 2010, when he became Head of School, Pagnucco was unable to continue these courses due to the time commitment). In 2016 he was the keynote speaker at the 29th Australasian Joint Conference on Artificial Intelligence and in 2012 he was invited to give a keynote address at the International Conference on Information Security and Control (Taiwan), presented by the foremost international organisation of computer scientists and engineers, the IEEE. His standing is further evidenced by research seminars he has been invited to present at institutions such as:
-City University of New York
-Dresden University of Technology
-Simon Fraser University, Vancouver
-Technical University of Aachen (RWTH)
-University of Alberta
-University of Amsterdam
-University of Leipzig
-University of Rome, La Sapienza
-University of Texas (El Paso)
-University of Toronto
-Uppsala University

F16. Currently held ARC Projects

(This information is auto-populated from your RMS profile and will include any 'active' Project which has not yet had a Final Report approved and the Project file closed by the ARC. If you have any concerns with the information recorded here, contact your Administering Organisation's Research Office. NOTE: If you hold a CI or a PI role on the Project/s listed in the table below you must ensure a progress statement is provided in G2. This requirement applies to the following schemes: Discovery Projects, Discovery Indigenous Researchers Development, Discovery Indigenous, Discovery Early Career Researcher Award, Linkage Projects, Industrial Transformation Research Hubs, Industrial Transformation Training Centres or any ARC Fellowship scheme. Please click on the information icon and refer to the Instructions to Applicants for further information.)

Identifier	Scheme Name	Investigators	Admin Organisation	Project Title	Funding	End Date
DP120100332	DP 2012 R1	A/Prof Sebastian Sardina ; Prof Maurice Pagnucco ; Prof Giuseppe De Giacomo	RMIT University	Optimisation of embedded virtual complex systems by re-using a library of available components	$300,000	31/12/2016
DP120102144	DP 2012 R1	Prof Michael Thielscher ; Prof Maurice Pagnucco ; Prof Hector Levesque	The University of New South Wales	Representing and reasoning about ability for robots to use the cloud	$335,000	30/06/2015
DP150103034	DP 2015 R1	Prof Michael Thielscher ; Prof Maurice Pagnucco ; Prof Dr Torsten Schaub ; Prof Dr Gerhard Lakemeyer	The University of New South Wales	Representation and Reasoning for Cognitive Personal Robotics	$419,900	31/12/2017

LE150100090	LE 2015 R1	A/Prof Mari Velonaki ; A/Prof David Rye ; Prof Gamini Dissanayake ; Prof Colin Clifford ; Prof Dikai Liu ; Prof Maurice Pagnucco ; A/Prof Fabio Ramos ; A/Prof Steven Faux	The University of New South Wales	Facility for Experimental Human-Robot Interaction Research	$350,000	31/12/2016

Part F - Personnel and ROPE (A/Prof Mari Velonaki)

F1. Personal Details

(To update personal details, click the 'Manage Personal Details' link below. Note this will open a new browser tab. When returning to the form ensure you 'Refresh' the page to capture the changes made to your profile.)

Participation Type

Chief Investigator

Title

A/Prof

First Name

Mari

Second Name

Family Name

Velonaki

F2. Will you be residing predominately in Australia for the duration of the Project?

(This is a 'Yes' or 'No' question. Indicate whether you will be residing predominantly in Australia for the duration of the Project, taking into account any international travel. If you are applying as a CI and you answer 'No' to this question you will be prompted to contact your Research Office to check your eligibility.)

Yes

F3. Qualifications

(To update any qualifications, click on the 'Manage Qualifications' link below. Note this will open a new browser tab. When returning to the form ensure you 'Refresh' the page to capture the changes made to your profile.)

Conferral Date	AQF Level	Degree/Award Title	Discipline/Field	Awarding Organisation	Country of Award
17/10/2003	Doctoral Degree	PhD	Experimental Interfaces	University of New South Wales	Australia
23/04/1999	Bachelor Honours Degree,Graduate Certificate, Graduate Diploma	BFA (Hons 1)	Media Arts	University of New South Wales	Australia

F4. Are you currently undertaking a Higher Degree by Research which will be conferred after 1 January 2018?

(This is a 'Yes' or 'No' question. If you are applying as a CI and your answer is 'Yes' to this question you will be prompted to contact your Research Office.)

No

F5. Research Opportunity and Performance Evidence (ROPE) – Current and previous appointment(s) / position(s) - during the past 10 years

(To update any details in this table, click on the 'Manage Employment Details' link below. Note this will open a new browser tab. When returning to the form ensure you 'Refresh' the page to capture the changes made to your profile. Click on the information icon above and refer to the Instructions to Applicants for more information.)

Description	Department	Contract Type	Employment Type	Start Date	End Date	Organisation
Adjunct Associate Professor	Intermedia Art and Science	Contract	Part Time	07/09/2015		Waseda University, Japan
Associate Professor	National Institute of Experimental Art, UNSW Art & Design	Permanent	Full Time	08/11/2011		The University of New South Wales
Director	Creative Robotics Lab, UNSW Art & Design	Permanent	Full Time	08/11/2011		The University of New South Wales
Adjunct Associate Professor	Australia Centre for Field Robotics	Contract	Part Time	01/01/2014	29/12/2017	The University of Sydney
ARF/QEII Fellow	National Institute of Experimental Arts	Permanent	Full Time	10/10/2011	31/12/2013	The University of New South Wales
APDI	Australian Centre for Field Robotics	Contract	Full Time	01/01/2004	07/10/2011	The University of Sydney

F6. Employment Details as at Commencement date of Project

(This question will be used to determine your eligibility. Confirm your employment status at all organisations that you will be associated with as at the Commencement Date for the Project (1 January 2018). Enter the relevant appointment type and Full-Time Equivalent (FTE) for each organisation. Click on the information icon for further information.)

Org name	Is this an Eligible Organisation?	Please choose your appointment type for this organisation.	Please enter your FTE for this Organisation
The University of New South Wales	Yes	Employee	1.0

F7. Further Details Regarding Partner Investigator Status - Do you hold a remunerated appointment at an Eligible Organisation?

(NOTE: this question is mandatory ONLY FOR PIs WHO:
• at F2 confirmed that they will reside predominantly in Australia for the duration of the proposed Project; AND
• at F4 confirmed that they are not currently undertaking a Higher Degree by Research which will be conferred after 1 January 2018; AND
• at F6 indicated that they would hold either:
- an appointment at an Eligible Organisation equal or greater than 0.2FTE; OR
- Emeritus appointment at an Eligible Organisation

This is a 'Yes' or 'No' question. If you select 'Yes', you will be further prompted to justify your participation on this Proposal as a PI with reference to sections F7.2 and F7.3 of the Funding Rules. Click on the information icon for further information.)
Do you hold a remunerated appointment at an Eligible Organisation?

Justification of PI status

F8. Relevant Organisation for this Proposal

(Enter the Organisation that is relevant to your participation on this proposal, and that you will be associated with as at the Commencement Date for the Project (1 January 2018). The 'relevant organisation' is the primary organisation that will be supporting your involvement in this Project if it is funded. Note that the Organisation must be listed in F6 for this question to validate.)

Relevant Organisation

The University of New South Wales

F9. What is your time commitment to this Project?

(Enter your time commitment to this Project as a Full-Time Equivalent (FTE). Note that a FTE of 1.0 represents a full-time commitment (i.e. 5 days per week).)

0.2

F10. Are you applying for Teaching Relief?

(This is a 'Yes' or 'No' question.

• If you answer 'Yes' to this question a budget line will be automatically populated for the Teaching Relief in the budget table in Form Part D: Project Cost. This will allow you to enter the funding amount requested in the relevant year/s. To remove the Teaching Relief from the budget table you must return to this question and answer 'No'.

• Note: CIs may request funding for teaching relief or other duties in order to maximise the opportunity for the CI to conduct research. This question is only relevant for CIs and will not be activated for PIs. If the answer to this question is 'yes', the budget table in 'Project Costs' will automatically update with a line to add costs for Teaching Relief.)

No

F11. Are you applying for a Discovery International Award?

(This is a 'Yes' or 'No' question. If you answer 'Yes' to this question a budget line will be automatically populated for the DIA in the budget table in Form Part D: Project Cost. This will allow you to enter the funding amount requested in the relevant year/s. To remove the DIA from the budget table you must return to this question and answer 'No'. Click on the information icon for further information.)

No

F12. Research Opportunity and Performance Evidence (ROPE) - Details of your career and opportunities for research

(Write a maximum of 5250 characters (approximately 750 words). Please detail your career and opportunities.)

i) NUMBER OF YEARS SINCE HIGHEST EDUCATIONAL QUALIFICATION
Associate Professor Velonaki completed her PhD (Experimental Interface Design) 14 years ago in 2003 at UNSW.

ii) RESEARCH OPPORTUNITIES IN THE CONTEXT OF EMPLOYENT SITUATION
CI Velonaki's research on social human-robot interaction (HRI) has focussed on exploring and understanding the degree of engagement that is possible and acceptable between a human and a technological other. Velonaki has

been awarded a total of $4.71 million in competitive and strategic funds for her research in this area over the past 10 years.

During Velonaki's first research appointment as an ARC Australian Postdoctoral Fellow at the Australian Centre for Field Robotics (ACFR), University of Sydney, she was the first-named Chief Investigator on one of the first ARC Linkage Project grants awarded for collaborative research between an artist and scientists [LP0349069, $248,514], 2003-06. In 2006, she founded the Centre for Social Robotics at ACFR, following her long advocacy for the establishment of a dedicated space for social robotics. In 2007, Velonaki was awarded the prestigious Visual Arts Fellowship by the Australia Council for the Arts. During the Fellowship, Velonaki collaborated with Professor Hiroshi Ishiguro during a residency at his laboratory at Osaka University. In 2008, Velonaki became a Senior Research Fellow at ACFR.

In 2009, Velonaki was awarded an ARC Discovery Project grant and ARF/QEII Fellowship 2009-13 [DP0988336, $753,758], to investigate the physicality that is possible and acceptable between a human and a robot. This project created a soft, flexible, touch-sensitive artificial skin and demonstrated (with her then PhD student CI Silvera-Tawil) that this skin could be used by a robot to identify social messages via classification of touch, and represented a world-first in electrical impedance tomography. In addition, Velonaki created 'Diamandini,' an interactive humanoid robot that responds to the movement of an interactant. The robot's appearance is that of a sculptural figure with a porcelain finish, introducing a new aesthetic in robotics that is far removed from a stereotypical humanoid robot.

In October of 2011, Velonaki was strategically recruited by UNSW to establish and lead a new laboratory and research group at the National Institute of Experimental Arts (NIEA) in the faculty of Art & Design. Velonaki was appointed as Associate Professor and Director of the Creative Robotics Laboratory. She was supported by a grant of $660,000 from the UNSW Deputy Vice-Chancellor (Research) in 2012 to establish the laboratory and fund a Post-Doctoral Fellow for three years.

In 2012 Velonaki established collaborative links with the cognitive science and perception laboratory of Professor Katsumi Watanabe the University of Tokyo. A formal exchange program was instituted, leading to ongoing shared experiments and associated publications.

In 2015 Velonaki was awarded a LEIF grant (LE150100090) to establish a National Facility for Human-Robot Interaction Research, in collaboration with the Schools of Computer Science & Engineering (CSE) and Psychology at UNSW; ACFR and School of IT, at USyd; Autonomous Systems at UTS and St Vincent's Hospital. Velonaki will be the Facility Director.

iii) EMPLOYMENT FRACTIONS
Velonaki commits 50% of her time to research and research leadership, 30% to research administration and 20% to research supervision and teaching.

iv) CAREER INTERRUPTIONS
Velonaki's daughter was born in September 2006; she took maternity leave until April 2007.

v) RESEARCH MENTORING AND RESEARCH FACILITIES AVAILABLE
The proposed project will be situated between R&D Square and three UNSW locations: Creative Robotics Lab (CRL); School of Computer Science & Engineering; and the National Facility for Human-Robot Interaction Research (due to open June 2016).

CRL is part of the UNSW Art & Design faculty which has the strongest concentration of interactive media researchers in Australia, providing a stimulating intellectual environment.

vi) OTHER ASPECTS OF CAREER OR OPPORTUNITIES FOR RESEARCH
Velonaki's cross-disciplinary research between robotics and interactive media arts produces interactive robotic installations that also act as ideal vehicles for the study of human-robot interaction in social spaces, a technique that she has termed "open experimentation" (see Silvera-Tawil, D., Rye, D.C. & Velonaki, M., 'Human-robot interaction with humanoid Diamandini using an open experimentation method', Proc. IEEE RO-MAN, 2015).

A significant proportion of Velonaki's research outputs are major creative works, published in the form of curated and catalogued exhibitions in some of the world's most highly regarded museums and festivals (F13, F14). These exhibitions at internationally significant venues are curated by eminent figures in the field, are recognised as equivalent to publications in A* or A ranked journals. The artistic outputs of these research projects are innovative presentations of social robotics research and products of effective transdisciplinary practice, and manifestations of significant advances in social robotics.

F13. Research Opportunity and Performance Evidence (ROPE) - Significant research outputs and ARC grants

(Upload a PDF of no more than four A4 pages with a list of all research outputs, such as journal articles and refereed conference papers, book and book chapters. Use asterisks to identify research outputs relevant to this Proposal. Click on the information icon or refer to the Instructions to Applicants for the required content and formatting.)

Uploaded PDF file follows on next page.

F13 SIGNIFICANT RESEARCH OUTPUTS

i) Significant research outputs

Edited Research Books

1. J.T. Koh, B.J. Dunstan, D. Silvera-Tawil & **M. Velonaki**, eds. *Cultural Robotics First International Workshop CR 2015.* Workshop held as part of IEEE RO-MAN 2015, Kobe, Japan, 31 August 2015. Springer, 2016.

Scholarly Book Chapters

2. K.S. Haring, **M. Velonaki**, D. Silvera-Tawil & K. Watanabe. The influence of robot appearance and interactive ability in HRI: A cross-cultural study. *Social Robotics*, Springer, 2016, pp. 392–401. Best Paper Award finalist.
3. D. Turnbull Tillman & **M. Velonaki** (2016). 'Disruption and reflection: A curatorial case study. Chapter 12 in D. England, T. Schiphorst & N. Bryan-Kinns (eds.). *Curating the Digital: Space for Art and Interaction*. Springer Series on Cultural Computing, Springer, 2016, pp. 181–201.
4. **M. Velonaki** & D. Rye. Designing robots creatively. In D. Herath, C. Kroos & Stelarc (eds), *Robots and Art: Exploring an Unlikely Symbiosis*. Springer, 2016.
5. **M. Velonaki**. Diamandini. In Mika Iwsaka (ed.), *Beyond the Display: Phenomenal Art and Design in the 21st Century*, [Japanese/English bilingual] BNN, Tokyo, Japan, pp. 96–115. ISBN 9784861009518, 2015.
6. A. Ball, D. Rye, D. Silvera-Tawil & **M. Velonaki**. Group vs. individual comfort when a robot approaches. In A. Tapus, E. André, J-C. Martin, F. Ferland & M. Ammi (eds), *Social Robotics*, LNCS 9388,, 2015, pp. 41–50.
7. A. Ball, D. Rye, D. Silvera-Tawil & **M. Velonaki**. Understanding group comfort through directional statistics. In A. Tapus, E. André, J-C. Martin, F. Ferland & M. Ammi (eds), *Social Robotics*, LNCS 9388,, 2015, pp. 51–60.
8. **M. Velonaki**. Human-robot interaction in prepared environments: Introducing an element of surprise by reassigning identities in familiar objects. In N. Lee (ed), *Digital Da Vincis*, Springer, 2014, pp. 21–64.
9. K.S. Haring, D. Silvera-Tawil, Y. Matsumoto, **M. Velonaki** & K. Watanabe. Perception of an android robot in Japan and Australia: A cross-cultural comparison. *Int. Conf. Social Robotics*, Springer, 2014, pp. 166–175,
10. A. Ball, D. Silvera-Tawil, D. Rye & **M. Velonaki**. Group comfortability when a robot approaches. In M. Beetz, B. Johnston & M.A. Williams (eds), *Social Robotics*, Springer, 2014, pp. 44–53.
11. K.S. Haring, D. Silvera-Tawil, Y. Matsumoto, **M. Velonaki** & K. Watanabe. Perception of an android robot in Japan and Australia: A cross-cultural comparison. In M. Beetz, B. Johnston & M.A. Williams (eds), *Social Robotics*, Springer, 2014, pp. 166–175.
12. **M. Velonaki** & D. Rye. Art and robotics: A brief account of eleven years of cross-disciplinary invention. In A. Dong, J. Conomos & B. Buckley (eds), *Ecologies of Invention*, pp. 55–68, Sydney University Press, 2013.
13. **M. Velonaki**, D. Rye & S. Scheding. Panel: Engagement, trust and intimacy: Are these the essential elements for a 'successful' interaction between a human and a robot? AAAI Spring Symposium, pp. 141–142, 2008.
14. **M. Velonaki**. Apples, wheelchairs and unrequited love. In C. Hart (ed.), *Can We Fall in Love With a Machine?* Pittsburgh Cultural Trust, Pittsburgh USA, pp. 85–90, 2006.

Refereed Journal Articles

15. D. Silvera-Tawil, D. Rye, M. Soleimani & **M. Velonaki**. Electrical impedance tomography for artificial sensitive robotic skin: A review. *IEEE Sensors Journal*, 15(4):2001–2016, 2015.
16. D. Silvera-Tawil, D. Rye & **M. Velonaki**. Artificial skin and tactile sensing for socially interactive robots: A review. *Robotics and Autonomous Systems*, 63(3):230–243, 2015.
17. D. Silvera-Tawil, D. Rye & **M. Velonaki**. Interpretation of social touch on an artificial arm covered with an EIT-based sensitive skin. *Int. J. of Social Robotics*, 6(4):489–505, November 2014.
18. D. Silvera Tawil, D. Rye & **M. Velonaki**. Interpretation of the modality of touch on an artificial arm covered with an EIT-based sensitive skin. *Int. J. of Robotics Research*, 31(13):1627–1642, November 2012.
19. **M. Velonaki**. Multi-objective evaluation of cross-disciplinary experimental research. *Studies in Material Thinking*, 8 (May):01/08–08/08, 2012.
20. D. Silvera Tawil, D. Rye & **M. Velonaki**. Improved image reconstruction for an EIT-based sensitive skin with multiple internal electrodes. *IEEE Trans. Robotics*, 27(3):425–435, June 2011.

21. **M. Velonaki**, D. Silvera Tawil & D. Rye. Engagement, trust, intimacy: Touch sensing for human-robot interaction. *Second Nature*, 2(1):102–119, 2010.
22. **M. Velonaki**, S. Scheding, D. Rye & H. Durrant-Whyte. Shared spaces: Media art, computing and robotics. *ACM Computers in Entertainment*, 6(4):51:1–51:12, December 2008.
23. **M. Velonaki**. Interview with Mari Velonaki, Australian Centre for Field Robotics. *Computers in Entertainment*, 6(4):1–1, December 2008. DOI=http://doi.acm.org/10.1145/1461999.1462001.
24. **M. Velonaki**, D. Rye, S. Scheding & S. Williams. Fish-Bird: A perspective on cross-disciplinary collaboration. *IEEE MultiMedia*, January–March 2008, pp. 10–12.

Refereed Conference Papers

25. D. Turnbull Tillman, J. Forseck Rauh Hain and **M. Velonaki**. An exploratory case study into curatorial intervention within the context of HCI. The 19th Int. Conf. Human-Computer Interaction, Vancouver, Canada, 9–14 July 2017. In Press, accepted 7 Dec. 2016.
26. K.S. Haring, D. Silvera-Tawil, T. Takahashi, K. Watanabe & **M. Velonaki**. How people perceive different robot types: A direct comparison of an android, humanoid, and non-biomimetic robot. *Proc. 2016 8th Int. Conf. Knowledge and Smart Technology*, pp. 265–270, 2016. DOI: 10.1109/KST.2016.7440504.
27. K.S. Haring, K. Watanabe, D. Silvera-Tawil & **M. Velonaki**. Expectations towards two robots with different interactive abilities. *Proc. 2016 11th ACM/IEEE Int. Conf. Human-Robot Interaction*, pp. 433–434, March 2016.
28. D. Silvera-Tawil, D. Rye & **M. Velonaki**. Human-robot interaction with humanoid Diamandini using an open experimentation method. *Proc. IEEE Int. Sym. Robot and Human Interactive Communication*, September 2015.
29. **M. Velonaki**, R. Thapliya, D. Rye, D. Silvera-Tawil & K. Watanabe. Social HRI: Overcoming barriers through appearance, behaviour and context-based design, *Proc. IEEE Int. Sym. Robot and Human Interactive Communication,* September 2015.
30. D. Turnbull Tillman & **M. Velonaki**. Curating: a disruptive technique for disruptive technologies. *Proc. 21st Int. Sym. Electronic Art (ISEA 2015)*. ISSN: 2451-8611 | ISBN: 978-1-910172-00-1. Vancouver, Canada, 2015.
31. K.S. Haring. D. Silvera-Tawil, K. Watanabe & **M. Velonaki**. Perception of a humanoid robot: A cross-cultural comparison. *Proc. IEEE Int. Sym. Robot and Human Interactive Communication,* September 2015.
32. K.S. Haring, K. Watanabe, D. Silvera-Tawil, **M. Velonaki** & Y. Matsumoto. Touching an android robot: Would you do it and how? *Proc. 2015 Int. Conf. Control, Automation and Robotics*, pp. 8–13, 2015, May 2015.
33. K.S. Haring, K. Watanabe, D. Silvera-Tawil, **M. Velonaki** & T. Takahashi. Changes in perception of a small humanoid robot. *Proc. 2015 6th Int. Conf. Automation, Robotics and Applications*, pp. 83–89, February 2015.
34. D.T. Tillman, **M. Velonaki** & P. Gemeinboeck. Authenticating experience: Curating digital interactive art. In *TEI 2015 - Proc. 9th Int. Conf. Tangible, Embedded, and Embodied Interaction*. pp. 429–432. 01 Jan 2015
35. K.S. Haring, D. Silvera-Tawil, K. Watanabe, **M. Velonaki** & Y. Matsumoto. Touching an android robot: Would you do it and how? *Proceedings of the. Int. Conf. Control, Automation and Robotics*, May 2015.
36. **M. Velonaki**, D. Silvera-Tawil & D. Rye. Affective human-robot interactions in social spaces: Two case studies. Presented at the Workshop on Applications for Emotional Robots, 8th ACM/IEEE Int. Conf. Human-Robot Interaction, Tokyo, Japan, 3–6 March 2013.
37. K.S. Haring, D. Silvera-Tawil, K. Watanabe, **M. Velonaki** & T. Takahashi. Changes in perception of a small humanoid robot. *Proc. IEEE Int. Conf. Automation, Robotics and Applications*, February 2015.
38. D. Silvera Tawil, D.C. Rye & **M. Velonaki**. EIT-based sensitive skin and touch interpretation for human- robot interaction. *Proc. Workshop on Advances in Tactile Sensing and Touch-Based Human- Robot Interaction*, IEEE/RSJ Int. Conf. Intelligent Robots and Systems, 7–12 October 2012, Vilamoura, Portugal.
39. D. Silvera Tawil, D.C. Rye & **M. Velonaki**. Artificial skin and the interpretation of touch for human-robot interaction. Presented at the Human Activity and Vision Summer School, 2012, Sophia Antipolis, France.
40. A. Ball, D. Rye, F. Ramos & **M. Velonaki**. Unsupervised clustering of people from "skeleton" data. *Proc. 7th ACM/IEEE Int. Conf. Human-Robot Interaction*, 5–8 March 2012, Boston, USA, pp. 225–226.
41. D. Silvera Tawil, D. Rye & **M. Velonaki**. Touch modality interpretation for an EIT-based sensitive skin. *Proc. IEEE 2011 Int. Conf. Robotics and Automation*, 10–12 May 2011, Shanghai, China, 7 pp.

42. A. Ball, D. Rye, F. Ramos & **M. Velonaki**. A comparison of unsupervised learning algorithms for gesture clustering. *Proc. 6th ACM/IEEE Int. Conf. Human-Robot Interaction*, 6–9 March 2011, Lausanne, pp. 111–112
43. **M. Velonaki** & D. Rye. Human-robot interaction in a media art environment. Presented at the Workshop 'What Do Collaborations with the Arts Have to Say about HRI?' Human-Robot Interaction 2010, Osaka, 2010.
44. **M. Velonaki**, D. Silvera Tawil & D. Rye. Engagement, trust and intimacy: Interactions between a human and a robot. *Proceedings of Super Human: Revolution of the Species*, 22–25 November 2009, Melbourne, Australia.
45. D. Silvera Tawil, D. Rye & **M. Velonaki**. Improved EIT drive patterns for a robotics sensitive skin. *Proc. 2009 Australasian Conference on Robotics and Automation*, 2–4 Dec. 2009, Sydney, Australia. [Best Student Paper]
46. D. Silvera Tawil, D. Rye & **M. Velonaki**. Artificial skin for human-robot interaction. Poster presented at Workshop on 'Tactile sensing in Humanoids', 9th IEEE-RAS Int. Conf. Humanoid Robots, 2009, Paris, France.
47. **M. Velonaki**, Scheding, S., Brown, I. & D. Rye. Physicality and synthetic reality. In *Proceedings of ISEA2008: The Fourteenth Int. Sym. Electronic Art*, Singapore, 26 July–3 August 2008, pp. 513–515.

Other Research Outputs

Major Creative Works, with Selected Exhibitions

48. **M. Velonaki**. 'Blue Iris' (2013) Interactive installation incorporating prototypes of responsive wallpaper using nano-particles, in collaboration with M. Pagnucco: scripting language development, B. Raguse: nano-particle application development & F. Ladouceur: new materials development. Touring nationally 2013–15. Exhibited in D. Robson (curator), *CUSP - Designing to the next decade*,
    1. **Casula Powerhouse**, Casula, August 2013.
    2. **Western Plains Cultural Centre**, Dubbo, 2014
    3. **Glasshouse Regional Gallery**, Port Macquarie, 2014.
    4. **JamFactory**, Adelaide, 2014.
    5. **State Library of Queensland**, Brisbane, 2015.
    6. **Queen Victoria Gallery & Museum**, Launceston, 2015.
    7. **Mornington Peninsula Regional Gallery**, Mornington, 2015.
49. **M. Velonaki**. 'Diamandini' (2009–2013) Humanoid robot, in collaboration with D. Rye: mechatronic systems design and M. Calleija: motion base design. Exhibited in
    1. L. Aceti and K. Cleland (curators), *Uncontainable / Signs of Life*, **Taksim Cumhuriyet Sanat Galerisi**, ISEA 2011, Istanbul, Turkey, 15 Sep. – 10 Oct. 2011.
    2. I. Papadimitriou (curator), *London Design Festival*, **Victoria & Albert Museum**,, UK, 14–23 Sep. 2012.
    3. J. Parsons (curator), *Robotronica*, **Old Government House**, QUT, Brisbane, Australia, 18 Aug. 2013
    4. M. Stubbs (curator), *Time & Motion: Redefining Working Life*, **FACT**, , UK, 12 Dec. 2013 – 9 Mar. 2014.
50. **M. Velonaki**. 'The Woman and the Snowman' (2013) Autokinetic responsive object arranging musical compositions in real time, linked to two video projections, in collaboration with D. Rye: mechatronic systems design and H. Ishiguro: creator of robot "Repliee 2". Exhibited in
    1. M. Feary (curator), **Artspace Visual Arts Centre**, Sydney, 2 May – 16 June 2013. ISEA 2013, Sydney.
51. **M. Velonaki**. 'Current State of Affairs' (2010) Interactive installation with mirror, water and electricity, in collaboration with D. Rye: mechatronic systems design. Exhibited in:
    1. A. Lærkesen (curator), *Unknown Territories — Between a Rock and a Hard Place*, **Cockatoo Island**, Sydney, Australia, 10 Sep. – 4 Oct. 2010.
52. **M. Velonaki**. 'Circle E: Fragile Balances' (2009) Kinetic object, in collaboration with D. Rye: mechatronic systems design. Exhibited in:
    1. V. Lynn (curator), *Double Take: Anne Landa Award for Video and New Media Arts 2009*, **Art Gallery of New South Wales**, Sydney, 7 May – 19 July 2009.
    2. M. Rackham (curator), *Super Human*, **RMIT Gallery**, Melbourne, 5 Nov. – 5 Dec. 2009.
    3. Choi, M. Lee & W.F. Wong (curators), *Fugue in the Key of Understanding*, **Osage Kwun Tong**, Kowloon, Hong Kong, 27 Mar. – 18 Apr. 2010.
    4. V. Lynn & H.J. Kim (curators), *The Trickster*, **Gyeonggi MOMA**, Ansan City, South Korea, 7 Sep. – 5 Dec.

53. **M. Velonaki**. 'Circle D: Fragile Balances' (2008) Interactive installation with two autonomous objects, in collaboration with D. Rye: mechatronic systems design & S. Scheding: software design and implementation, 2008. Exhibited in:
    1. K. Cleland & L. Muller (curators), *Mirror States*, **Moving Image Centre Toi Rerehiko**, Auckland, New Zealand, 16 May – 28 June 2008.
    2. K. Cleland & L. Muller (curators), *Mirror States*, **Campbelltown Arts Centre**, , 18 July – 24 Aug. 2008.
    3. N. Chambers (curator), *Premier of Queensland's National New Media Art Award Exhibition*, **Queensland Art Gallery - Gallery of Modern Art**, Brisbane, 1 Nov. 2008 – 8 Feb. 2009. [Award Finalist]
    4. V. Lynn (curator), *Double Take: Anne Landa Award for Video and New Media Arts 2009*, **Art Gallery of New South Wales**, Sydney, 7 May – 19 July 2009. [Award Finalist]
    5. Choi, M. Lee & W.F. Wong (curators), *Fugue in the Key of Understanding*, **Osage Kwun Tong**, Kowloon, Hong Kong, 27 Mar. – 18 Apr. 2010.
    6. V. Lynn & H.J. Kim (curators), *The Trickster*, **Gyeonggi MOMA**, Ansan City, South Korea, 7 Sep. – 5 Dec.
    7. Zhang Ga (curator), *translife, the International Triennial of New Media Art*, **National Art Museum of China**, Beijing, China, 26 Jul. – 17 Aug. 2011.
54. **M. Velonaki**. 'Fish-Bird: Circle B – Movement C' (2004–2006) Interactive installation with two robots and multi-sensor perception system, in collaboration with D. Rye: robotic systems design, S. Scheding: software system architecture & S. Williams: tracking system. Exhibited in:
    1. C. Hart & M. Horne (curators), *Can We Fall in Love With a Machine?* **Wood Street Galleries**, Pittsburgh, USA, 27 Jan. – 1 Apr. 2006.
    2. Science EXPOsed, **NSW Parliament House**, Sydney, Australia, 2004.
    3. A. Ivanova (curator), Strange Attractors, Australia Council for the Arts, Sydney, 1 Feb. – 1 May 2007.
    4. K. Cleland & L. Muller (curators), *Mirror States*, **Campbelltown Arts Centre**, , 18 July – 24 Aug. 2008.
    5. P. Dinesen & S. Harving (curators), *ENTER ACTION - Digital Art Now*, **ARoS Århus Kunstmuseum**, Århus, Denmark, 7 Feb. 2009 – 26 Apr. 2009.
    6. Australian Research Council, ARC Major Awards Ceremony, **Parliament House**, Canberra, 2008.
    7. Zhang Ga (curator), *translife, the International Triennial of New Media Art*, **National Art Museum of China**, Beijing, China, 26 July – 17 August 2011.
    8. Claire Gannaway (curator), *The Imitation Game*, **Manchester Art Gallery**, , UK, Feb. – May 2016.

(ii) Details of ARC grants awarded in the last 10 years

ARC Project ID	CI/PI/Fellow Name/s	Amount Funded	Number of Years	Project Title	Publications
LE150100090	**M. Velonaki,** D. Rye, C. Clifford, D. Lui, M. Pagnucco, F. Ramos, S. Faux	$350k	1	Facility for Experimental Human-Robot Interaction Research	
DP0988336	**M. Velonaki**	$754k	5	Physicality, tactility, intimacy: Interaction between humans and robots	1–7, 10–12, 14, 16–19 , 26
LP0349069	**M. Velonaki,** D. Rye, S. Scheding & S. Williams	$247k	3	Fish–Bird: Autonomous interactions in a contemporary arts setting	8, 9, 15, 21–24, 29–31

F14. Research Opportunity and Performance Evidence (ROPE) - Ten career-best research outputs

(Please upload a PDF with a list of your ten career-best research outputs, with a brief paragraph for each research

output explaining its significance (five pages maximum).)

Uploaded PDF file follows on next page.

F14 TEN CAREER-BEST RESEARCH OUTPUTS

Mari Velonaki's research is situated in the multi-disciplinary field of Social Robotics. Her approach to Social Robotics' research has been informed by aesthetics and design principles that stem from the theory and practice of Interactive Media Art. Velonaki has made significant contributions in the areas of Social Robotics, Human-Machine Interface Design and Media Art. Her career outputs across these fields.

1. *** M. Velonaki**. 'Diamandini'. (2009–2013). Interactive humanoid robot, in collaboration with D. Rye: mechatronic systems design and M. Calleija: motion base design. [DP0988336] Exhibited in:
   - M. Stubbs (curator), *Time & Motion: Redefining Working Life*, **FACT**, Liverpool, UK, 12 December 2013 – 9 March 2014.
   - J. Parsons (curator), *Robotronica*, **Old Government House**, Queensland University of Technology, Brisbane, Australia, 18 August 2013
   - I. Papadimitriou (curator), London Design Festival, **Victoria & Albert Museum**, London, UK, September 2012.
   - H. Durrant-Whyte (CEO NICTA). What is a robot? [Durrant-Whyte presented and demonstrated Diamandini at a prototype stage], **TEDx Sydney**, 26 May 2012.
   - L. Aceti and K. Cleland (curators), *Uncontainable / Signs of Life*, **Taksim Cumhuriyet Sanat Galerisi**, **ISEA 2011**, Istanbul, Turkey, 15 September – 10 October 2011.

   Nadia Arbach, Leader Digital Programmes, V&A: "There's something about the word 'robot' that [...] still conjures up images of a metallic, bleeping creature. Diamandini couldn't be further from that image."

2. *** M. Velonaki**. 'Fish-Bird: Circle B – Movement C'. (2004-2006). Interactive installation with two robots and multi-sensor perception system, in collaboration with D. Rye: mechatronic systems design, S. Scheding: software system architecture & S. Williams: tracking system. [LP0349069] Exhibited in:
   - Zhang Ga (curator), *translife*, *the International Triennial of New Media Art*, **National Art Museum of China**, Beijing, China, 26 July – 17 August 2011.
   - P. Dinesen & S. Harving (curators), *ENTER ACTION - Digital Art Now*, **ARoS Århus Kunstmuseum**, Århus, Denmark, 7 February 2009 – 26 April 2009.
   - K. Cleland & L. Muller (curators), *Mirror States*, **Campbelltown Arts Centre**, Sydney, 18 July – 24 August 2008.
   - Ivanova (curator), *Strange Attractors: Charm between art & science*, **Australia Council for the Arts**, Sydney, 1 February – 1 May 2007.
   - Hart & M. Horne (curators), *Can We Fall in Love With a Machine?* **Wood Street Galleries**, Pittsburgh Cultural Estate, Pittsburgh, USA, 27 January – 1 April 2006.
   - N. Tsoutas (curator), **Artspace Visual Arts Centre**, Sydney, Australia, 22 September – 19 October 2005.
   - Cavallaro (curator), *Unnatural Selection – Australian Media Art*, **Ars Electronica 2004** – TIMESHIFT – Dei Welt in 25 Jahren [TIMESHIFT – The World in 25 Years], Linz, Austria, September 2004
   - N. Tsoutas (curator), *ResArtis*, **Artspace Visual Arts Centre**, Sydney, Australia, July-August 2004.

   In 'Fish-Bird', communication through poetic text and responsive movement were used to demonstrate that humans can be drawn to and empathise with robots regardless of their strict utilitarian appearance.

3. **M. Velonaki**. Human-robot interaction in prepared environments: Introducing an element of surprise by reassigning identities in familiar objects. In N. Lee (ed), *Digital Da Vinci: Computers in the Arts and Sciences*, Springer, 2014, pp. 21–64.
4. ***** K.S. Haring, **M. Velonaki**, D. Silvera-Tawil & K. Watanabe. The influence of robot appearance and interactive ability in HRI: A cross-cultural study. *Social Robotics*, Springer, 2016, pp. 392–401. **Best Paper Award finalist**, one of three.
5. D. Silvera Tawil, D. Rye & **M. Velonaki**. Interpretation of social touch on an artificial arm covered with an EIT-based sensitive skin. *International Journal of Social Robotics*. In press, accepted 8 August 2013, DOI 10.1007/s12369-013-0223-x.

This article reports the first automatic identification of emotions and social messages through human touch alone, at accuracies comparable to those achieved by humans.

6. *** M. Velonaki**. 'Circle D: Fragile Balances'. (2008). Interactive installation with two autonomous objects, in collaboration with D. Rye: mechatronic systems design & S. Scheding: software design and implementation. [LP0349069] Exhibited in:
    - Zhang Ga (curator), *translife*, the International Triennial of New Media Art, **National Art Museum of China**, Beijing, China, 26 July – 17 August 2011.
    - V. Lynn & H.J. Kim (curators), *The Trickster*, **Gyeonggi Museum of Modern Art**, Ansan City, South Korea, 7 September – 5 December 2010.
    - A. Choi, M. Lee & W.F. Wong (curators), *Fugue in the Key of Understanding*, **Osage Kwun Tong**, Kowloon, Hong Kong, 27 March – 18 April 2010.
    - V. Lynn (curator), *Double Take: Anne Landa Award for Video and New Media Arts 2009*, **Art Gallery of New South Wales**, Sydney, Australia, 7 May – 19 July 2009. [Award Finalist]
    - N. Chambers (curator), *Premier of Queensland's National New Media Art Award Exhibition*, **Queensland Art Gallery - Gallery of Modern Art**, Brisbane, Australia, 1 November 2008 – 8 February 2009. [Award Finalist]
    - K. Cleland & L. Muller (curators), *Mirror States*, **Campbelltown Arts Centre**, Sydney, Australia, 18 July – 24 August 2008.
    - K. Cleland & L. Muller (curators), *Mirror States*, **Moving Image Centre Toi Rerehiko**, Auckland, New Zealand, 16 May – 28 June 2008.

    Emeritus Professor Anne-Marie Duguet, Sorbonne: "This demanding work is all the more remarkable because [...] the power of this interactive object resides in its exposure and mastery of vulnerability."

7. *** M. Velonaki**. 'Pin cushion'. (2008). Interactive installation utilising electrostatic control devices. Selected exhibitions:
    - S. Danzig (curator), *International Digital Art Awards 05*, **Queensland University of Technology Gallery**, Brisbane, Australia, 7 July – 4 September 2005.
    - Adriaansens, S. Diamond, Y. Shikata, P. Weibel, A. Ivanova & Z. Ga (curators), *In the Line of Flight – Transcending Urbanscapes*, Second Beijing New Media Arts Biennial, **China Millennium Art Museum**, Beijing, China, 21 June – 11 July 2005:
    - S. Danzig (curator), *International Digital Art Awards 05*, **Victoria College of the Arts Gallery**, Melbourne, Australia, April–May 2005.
    - Melbourne Art Fair, work represented by Novamedia, **Royal Exhibition Hall**, Melbourne, Australia, 29 September – 3 October 2004.
    - K. Cleland (curator), *St@rt Up*, **Te Papa Tongarewa National Museum of New Zealand**, Wellington, New Zealand, October 2002.
    - V. Lynn, L. Cooper, et al. (curators), *Converge: Where Art and Science Meet*, **The 2002 Adelaide Biennial of Australian Contemporary Art, Art Gallery of South Australia**, Adelaide, Australia, March–April 2002.
    - P. Greenaway (curator), *Heterosis*, ARCO 2002, **Conde Duque Museum**, Madrid, Spain, February–April 2002.
    - H. Noering, A. Gehling et al. (curators), **European Media Arts Festival**, Osnabrück, Germany, April–May 2001.
    - L. Grycewicz & P. Couros (curators), *Future Screen 00, Artificial Life: HARD/SOFT/WET*, **The Powerhouse Museum**, Sydney, Australia, October 2000.
    - J. Phillips (curator), *Transformers*, **Artspace Visual Arts Centre**, Sydney, Australia, 11 August – 2 September 2000.

    'Pin Cushion' is critically acclaimed for the dramatic morphological changes that each participant's touch—through her electrostatic charge—can cause to the work, and for its technological innovation.

8. *** M. Velonaki**, S. Scheding, D. Rye & H. Durrant-Whyte. Shared spaces: media art, computing and robotics. *ACM Computers in Entertainment*, vol. 6, no. 4, December 2008, pp. 51:1–51:12.

This article discusses the beneficial synergies between media art and robotics and presents a model of interdisciplinary collaboration.

9. *** M. Velonaki**, D. Rye, S. Scheding & S. Williams. Fish-Bird: a perspective on cross-disciplinary collaboration, *IEEE MultiMedia*, January–March 2008, pp. 10–12.

   This article discusses art-science collaboration in the context of the Fish-Bird project, one of the first two ARC/Australia Council Art/Science Linkage projects.

10. * D. Silvera Tawil, D. Rye & M. **Velonaki**. Interpretation of the modality of touch on an artificial arm covered with an EIT-based sensitive skin. *International Journal of Robotics Research*, vol. 31, no. 13, November 2012, pp. 1627–1642.

    This article experimentally demonstrates that the addition of electrodes within the boundary of 2D tomographic skins improves the resolution & accuracy of the skin, and increases the robustness to noise.

    This article presents experimental results showing the machine classification of touch modality on a mannequin arm at an accuracy of 71%, comparable to human classification.

F15. Research Opportunity and Performance Evidence (ROPE) - Further evidence in relation to research impact and contributions to the field, including those most relevant to this Proposal

(Write a maximum of 11250 characters (approximately 1500 words). Detail further evidence in relation to research impact and contributions to the field. Click on the information icon and refer to the Instructions to Applicants for the required content and formatting.)

Velonaki's multidisciplinary research has had significant impact in the domains of Social Robotics and Interactive Media Arts. In 2014 she was named as one of "25 women in robotics you need to know about" by RoboHub, one of the largest online robotics communities, bringing together experts in robotics business and research from around the world.

Impact
* Introduced a new aesthetic to the design of a social robot, which redefined what a robot can be.
* Expanded the scope of multidisciplinarity in social robotics by demonstrating the pressing need to include artists, designers, social scientists in the creation of robots that are intended to interact with the general public.
* Created novel interfaces between a human and a robot that include the modalities of movement as body language, touch as an encoder of human emotion and poetic text as a trigger for human engagement.
* Invited by Fuji Xerox Innovation Headquarters (Japan) to design a new robot for the company, to be publically presented at the 2020 Tokyo Olympics.
* Created interactive robots that are of human scale and have substantial presence in the physical world. Most of the experimental studies in Social Robotics to date have utilised 'toy-sized robots' such as the Nao, or even images on a computer screen, to evaluate appearance and public acceptance.
* Introduced *open experimentation* whereby robots are placed in public spaces such as major museums and not tested only in laboratory settings. Experiments set in public spaces provide an ideal platform for acquiring more representative datasets given that the participants come from more diverse socio-economic and cultural backgrounds and age groups.
* Velonaki has assembled two of the world's largest datasets (over 460,000 recorded interactions) in human-robot interaction (HRI) studies that provide valuable information on the qualitative dimensions of human-machine relations.
* Evaluation of robot appearance vs behaviour. Data collected during public exhibitions of Fish-Bird show that the majority of the participants were attracted to the Fish-Bird robots not because of the way that they look but because of the way that they behave. The Fish-Bird data set represents over 315,000 interactions recorded in Australia, Austria, China, Denmark, England, Hong Kong, Korea, USA.
* Fish-Bird is recognised internationally as a significant artwork, as a state-of-the-art distributed robotic system and as an exemplary model of fully-engaged interdisciplinary research. Fish-Bird has been exhibited 14 times in museums and festivals including the Ars Electronica Festival in Linz, Austria, National Art Museum of China, Beijing, the Wood Street Gallery and Andy Warhol Foundation, Pittsburgh, ARoS Aarhus Kunstmuseum, Denmark. Fish-Bird was demonstrated at the ARC Major Grants announcements 2009 at Parliament House, Canberra. The Fish-Bird project has also produced articles in the prestigious journals ACM Computers in Entertainment, IEEE MultiMedia, Studies in Material Thinking and seven papers in leading conferences such as the IEEE International Conference on Robotics and Automation. It has been documented in 11 books.
* Created new modalities of interaction in Human-Computer Interaction and Human-Robot Interaction, including speech (1996), breath (1997), electrostatic charge (2000), touch (1997, 2010), organic (consumption of apples; 2000), photodynamics (2003), nanoparticles incorporated in thermochromic paint (2013) as well as interfaces such as movement as body language (2004) and real-time poetic text generation (2004) developed for specific robots.
* Interview with Mari Velonaki, Australian Centre for Field Robotics. [Forty-five minute video interview; one of eight people, including Nicholas Negroponte and George Lucas, to be interviewed worldwide by CiE in 2008.] ACM Computers in Entertainment. 6(4) DOI: 10.1145/1461999.1462001.
* Best Paper Award finalist (one of three) 2016 International Conference on Social Robotics, for K.S. Haring, M. Velonaki, D. Silvera-Tawil & K. Watanabe, The influence of robot appearance and interactive ability in HRI: A cross-cultural study.
* Top 20 most downloaded papers January to July 2015, Robotics and Autonomous Systems: D. Silvera-Tawil, D. Rye & M. Velonaki. Artificial skin and tactile sensing for socially interactive robots: A review.
* Top 30 most downloaded papers January to March 2015, IEEE Sensors Journal: D. Silvera-Tawil, D. Rye, M. Soleimani & M. Velonaki. Electrical impedance tomography for artificial sensitive robotic skin: A review. This paper currently has approximately 750 downloads.
* Member of the UNSW@Home that is a finalist in the 2017 International RoboCup@home Domestic Standard Platform League competition (Sammut, Pagnucco, Thielscher, Velonaki, Hengst, Rajaratnam, Schwering, Wiley & Gratton).
* A novel omnidirectional robot motion base was created as part of the Diamandini project (DP0988336), currently the subject of a full patent application.
* New algorithms were created for tracking the position and walking speed of people, and for combining (fusing) information in data streams from a number of disparate sensors.
* Advances in electrical impedance tomography for creating flexible, stretchable two-dimensional artificial skin

sensitive to touch.

Selected Keynote Addresses
* 'Robótica y diseño: donde el arte y la ciencia se encuentran' [Robotics and design: Where art and science meet]. Address at symposium Leonardo Da Vinci, Museo Franz Mayer, Mexico City, Mexico, 30 September 2015
* 'Robótica y diseño y la intercció humano-robot' [Design and human-robot interaction] Address to Postgraduate Conference, National University of Mexico (Postgrado UNAM), Mexico City, Mexico, 1 October 2015
* 'Robots as participants and creators of culture', in Workshop: 'Cultural Robotics: Robots as Participants and Creators of Culture', IEEE RO-MAN, Kobe, Japan, 31 August 2015.
* 'Mari Velonaki - From responsive installations to autonomous robots', agIdeas International Design Forum, Creative Masters Series, Melbourne Convention and Exhibition Centre, 2 April 2014.
* 'Multidisciplinarity and creativity in the field of social robotics', Vrystaat Kunstefees Festival, Bloemfontein, South Africa, July 2014.
* 'Identification, projection, empathy: Threading the space around human-robot interaction', Incubator Workshop, The Geurlac Room, AD Whitehouse, Cornell University, Ithaca, USA, 11 November 2012.
* 'Art and robotics: Creation and interaction', International Conference on Robotics and Automation, Shanghai, 13 May 2011.
* University of Athens, School of Communication and Media Arts: 'Time and space in interactive robotic installations', 11 March 2010.
* Keynote address presented at 'RAISE YOUR VOICE: The Fourth National Public Galleries Summit, Australian Museums and Galleries Association, Townsville, 17 October 2009.
* 'Multidisciplinary in contemporary art practice', ARoS Museum of Contemporary Art, Aarhus, Denmark, 2009.
* 'Art, science and society', presentation at ARC Major Awards Ceremony, Australian Research Council, Australian Parliament House, Canberra, 2008.

Selected Invited Events
* Black Dog Institute Symposium 'Humans and machines: A quest for better mental health': Address: 'Social HRI and wellbeing - an approach', Sydney, 15 September 2016.
* Sydney Democracy Network Lecture Series: Robots: The unfinished revolution. 'Social robotics: Thinking collaboratively'. The Great Hall, University of Sydney, 7 August 2015.
* Hawke Research Institute Workshop: 'Robotics: Artificial Intelligence and the Future of Employment': Address: 'People and robots in socially empowered spaces', University of South Australia, Adelaide, 3 August 2016.
* Incubator Workshop, Cornell University, Ithaca, USA: Conducted one week workshop on Robotics Interaction Theory supported by a grant from the Society for the Humanities, Cornell University, 2012.
* Victoria & Albert Museum, London UK: Conducted robotics workshop 'Behind the scenes with humanoid robot Diamandini', London Design Festival, 2012.
* Athens Polytechnic, Superior School of Fine Arts: Address to School - 'Media art and cross-disciplinary collaborations', 16 March 2010.
* Australian Government and Australia-Japan Foundation: One of three artists invited to participate in a one-week workshop 'Australia-Japan Media Art Meeting' at Osaka Electro-Communications University, June 2010.
* University of Paris I (Panthéon-Sorbonne), Department of Art History: Address - 'From the early kinetic sculptures to autonomous interactive robots', February 2010.
* Federation of Australian Scientific and Technological Societies: Invited by the ARC to speak on cross-disciplinary research at the ACFR Centre for Social Robotics, 2009.
* Fuel 4 Arts: Expert Panellist, 'Customer as Collaborator' think tank, London & Sydney, 2007
* 'Scaling up for Greater Impact', CHASS Conference for Directors of University-based Centres. Invited speaker & panel member: Sydney, July 2006.

Awards and Nominations
* Future Everything Award, Manchester UK, 2011, finalist.
* Anne Landa Award for Video and New Media Arts 2009, finalist, Art Gallery of New South Wales, Sydney, for the interactive work Fragile Balances.
* Premier of Queensland's National New Media Art Award Exhibition, finalist, Queensland Art Gallery - Gallery of Modern Art, Brisbane, 2009, for the interactive work Fragile Balances.

Research Funding
Mari Velonaki has received over $5.71m in research funding since her first academic appointment in 2004. Her UNSW strategic funding includes an allocation of $1.40m for building works associated with construction of the National Facility for Human-Robot Interaction Research.

Competitive Research Grants and Industry Funding
* Fuji Xerox (Japan); Velonaki: Collaborative research project 'Robots at work'; 2016-18; $360,000
* Air Force Research Laboratory [USA] (AOARD); Velonaki & Pagnucco, joint CIs: 'Eliciting emotions from tactile

surfaces and kinetic agents'; 2015-17; $460,000
* Australia Council for the Arts; Velonaki: Experimental Arts Grant for a community-linked residency in the Department of Medicine, University of Free State, South Africa'; 2014; $25,000
* Australia Japan Foundation; Velonaki: 'Cross-cultural aspects of social human-robot interaction in Australia and Japan'; 2014-15; $25,000
* National ICT Australia; Velonaki, Pagnucco, Durrant-Whyte: 'Blue Iris' project; 2013-15; $180,000
* Australia Council for the Arts; Velonaki: Visual Arts Fellowship 2007; 2007-08; $90,000
* Australia Council for the Arts; Velonaki: Grant to promote Fish-Bird, Wood Street Galleries, Pittsburgh USA; 2006; $9,250

Media Coverage
Velonaki has a strong international media presence, including articles about her work in BBC News Financial Times, New York Times, the Guardian, New Scientist.

Professional Standing, not including Academic Roles
* Member, Institute of Electrical and Electronics Engineers (IEEE).
* Member, Association for the Advancement of Artificial Intelligence (AAAI).
* Member, Association of Computing Machinery (ACM).
* Australia Council for the Arts: Appointed Member, Visual Arts and Craft Board, 2012-14.

F16. Currently held ARC Projects

(This information is auto-populated from your RMS profile and will include any 'active' Project which has not yet had a Final Report approved and the Project file closed by the ARC. If you have any concerns with the information recorded here, contact your Administering Organisation's Research Office. NOTE: If you hold a CI or a PI role on the Project/s listed in the table below you must ensure a progress statement is provided in G2. This requirement applies to the following schemes: Discovery Projects, Discovery Indigenous Researchers Development, Discovery Indigenous, Discovery Early Career Researcher Award, Linkage Projects, Industrial Transformation Research Hubs, Industrial Transformation Training Centres or any ARC Fellowship scheme. Please click on the information icon and refer to the Instructions to Applicants for further information.)

Identifier	Scheme Name	Investigators	Admin Organisation	Project Title	Funding	End Date
LE150100090	LE 2015 R1	A/Prof Mari Velonaki ; A/Prof David Rye ; Prof Gamini Dissanayake ; Prof Colin Clifford ; Prof Dikai Liu ; Prof Maurice Pagnucco ; A/Prof Fabio Ramos ; A/Prof Steven Faux	The University of New South Wales	Facility for Experimental Human-Robot Interaction Research	$350,000	31/12/2016

Part F - Personnel and ROPE (Prof Claude Sammut)

F1. Personal Details

(To update personal details, click the 'Manage Personal Details' link below. Note this will open a new browser tab. When returning to the form ensure you 'Refresh' the page to capture the changes made to your profile.)

Participation Type

Chief Investigator

Title

Prof

First Name

Claude

Second Name

Anthony

Family Name

Sammut

F2. Will you be residing predominately in Australia for the duration of the Project?

(This is a 'Yes' or 'No' question. Indicate whether you will be residing predominantly in Australia for the duration of the Project, taking into account any international travel. If you are applying as a CI and you answer 'No' to this question you will be prompted to contact your Research Office to check your eligibility.)

Yes

F3. Qualifications

(To update any qualifications, click on the 'Manage Qualifications' link below. Note this will open a new browser tab. When returning to the form ensure you 'Refresh' the page to capture the changes made to your profile.)

Conferral Date	AQF Level	Degree/Award Title	Discipline/Field	Awarding Organisation	Country of Award
06/10/1981	Doctoral Degree	PhD	Artificial Intelligence	University of New South Wales	Australia
15/12/1977	Bachelor Degree	B.Sc. (Hons 1)	Computer Science	The University of New South Wales	Australia

F4. Are you currently undertaking a Higher Degree by Research which will be conferred after 1 January 2018?

(This is a 'Yes' or 'No' question. If you are applying as a CI and your answer is 'Yes' to this question you will be prompted to contact your Research Office.)

No

F5. Research Opportunity and Performance Evidence (ROPE) – Current and previous appointment(s) / position(s) - during the past 10 years

(To update any details in this table, click on the 'Manage Employment Details' link below. Note this will open a new browser tab. When returning to the form ensure you 'Refresh' the page to capture the changes made to your profile.

Click on the information icon above and refer to the Instructions to Applicants for more information.)

Description	Department	Contract Type	Employment Type	Start Date	End Date	Organisation
Professor	School of Computer Science and Engineering	Permanent	Full Time	01/01/1999		The University of New South Wales

F6. Employment Details as at Commencement date of Project

(This question will be used to determine your eligibility. Confirm your employment status at all organisations that you will be associated with as at the Commencement Date for the Project (1 January 2018). Enter the relevant appointment type and Full-Time Equivalent (FTE) for each organisation. Click on the information icon for further information.)

Org name	Is this an Eligible Organisation?	Please choose your appointment type for this organisation.	Please enter your FTE for this Organisation
The University of New South Wales	Yes	Employee	1

F7. Further Details Regarding Partner Investigator Status - Do you hold a remunerated appointment at an Eligible Organisation?

(NOTE: this question is mandatory ONLY FOR PIs WHO:
• at F2 confirmed that they will reside predominantly in Australia for the duration of the proposed Project; AND
• at F4 confirmed that they are not currently undertaking a Higher Degree by Research which will be conferred after 1 January 2018; AND
• at F6 indicated that they would hold either:
- an appointment at an Eligible Organisation equal or greater than 0.2FTE; OR
- Emeritus appointment at an Eligible Organisation

This is a 'Yes' or 'No' question. If you select 'Yes', you will be further prompted to justify your participation on this Proposal as a PI with reference to sections F7.2 and F7.3 of the Funding Rules. Click on the information icon for further information.)
Do you hold a remunerated appointment at an Eligible Organisation?

Justification of PI status

F8. Relevant Organisation for this Proposal

(Enter the Organisation that is relevant to your participation on this proposal, and that you will be associated with as at the Commencement Date for the Project (1 January 2018). The 'relevant organisation' is the primary organisation that will be supporting your involvement in this Project if it is funded. Note that the Organisation must be listed in F6 for this question to validate.)

Relevant Organisation

The University of New South Wales

F9. What is your time commitment to this Project?

(Enter your time commitment to this Project as a Full-Time Equivalent (FTE). Note that a FTE of 1.0 represents a full-time commitment (i.e. 5 days per week).)

0.2

F10. Are you applying for Teaching Relief?

(This is a 'Yes' or 'No' question.

• If you answer 'Yes' to this question a budget line will be automatically populated for the Teaching Relief in the budget table in Form Part D: Project Cost. This will allow you to enter the funding amount requested in the relevant year/s. To remove the Teaching Relief from the budget table you must return to this question and answer 'No'.

• Note: CIs may request funding for teaching relief or other duties in order to maximise the opportunity for the CI to conduct research. This question is only relevant for CIs and will not be activated for PIs. If the answer to this question is 'yes', the budget table in 'Project Costs' will automatically update with a line to add costs for Teaching Relief.)

No

F11. Are you applying for a Discovery International Award?

(This is a 'Yes' or 'No' question. If you answer 'Yes' to this question a budget line will be automatically populated for the DIA in the budget table in Form Part D: Project Cost. This will allow you to enter the funding amount requested in the relevant year/s. To remove the DIA from the budget table you must return to this question and answer 'No'. Click on the information icon for further information.)

No

F12. Research Opportunity and Performance Evidence (ROPE) - Details of your career and opportunities for research

(Write a maximum of 5250 characters (approximately 750 words). Please detail your career and opportunities.)

(i) I was awarded my PhD 35 years ago.

(ii) During the last ten years I have been continuously employed as a Professor of Computer Science and Engineering at the University of New South Wales. I was the UNSW node director for the ARC Centre of Excellence for Autonomous Systems, which was funded from 2003 to 2011. The Centre continues as an unfunded entity, with individual projects funded by their own grants.

(iii) My duties include a mixture of teaching (50%), research (40%) and administration (10%). Generally, I have taught one subject per semester and I have been the research director for the School of Computer Science and Engineering for the past four years.

(iv) My research output in 2007 and 2008 was limited due to a personal illness and the grave illness and death of an immediate family member. I am now fully recovered from the illness and my research output since then has also recovered.

(v) The research facilities available to me have been excellent, largely due to the funding provided by the earlier ARC Centre of Excellence for Autonomous Systems (2003 - 2011) and the infrastructure funding contributed by the university, which has allowed us to maintain and expand the equipment acquired through the CoE. We have a dedicated robotics laboratory in which includes a Rethink Robotics Baxter, several rescue robots, Aldebaran Nao robots for RoboCup soccer and robots for research in human-robot interaction.

(vi) There are no other aspects of my career or opportunities for research that are relevant that have not been already detailed elsewhere.

F13. Research Opportunity and Performance Evidence (ROPE) - Significant research outputs and ARC grants

(Upload a PDF of no more than four A4 pages with a list of all research outputs, such as journal articles and refereed conference papers, book and book chapters. Use asterisks to identify research outputs relevant to this Proposal. Click on the information icon or refer to the Instructions to Applicants for the required content and

formatting.)

Uploaded PDF file follows on next page.

F13: RESEARCH OPPORTUNITY AND PERFORMANCE EVIDENCE (ROPE) – SIGNIFICANT RESEARCH OUTPUTS AND ARC GRANTS

Scholarly Books

1. Claude **Sammut** and Geoffrey I. Webb, editors. *Encyclopedia of Machine Learning*. Springer, 2010. (2nd edition in press)

Scholarly Book Chapters

2. * Ashar, J., Ashmore, J., Hall, B., Harris, S., Hengst, B., Liu, R., Mei (Jacky), Z., Pag nucco, M., Roy, R., **Sammut**, C., Sushkov, O., Teh, B., and Tsekouras, L. (2015). Robocup SPL 2014 champion team paper. In Bianchi, R. A. C., Akin, H. L., Ramamoorthy, S., and Sugiura, K., editors, *RoboCup 2014: Robot World Cup XVIII*, volume 8992 of Lecture Notes in Computer Science, pages 70–81. Springer International Publishing.
3. * Brown, S. and **Sammut**, C. (2013). A Relational Approach to Tool-use Learning in Robots. In *Inductive Logic Programming*, pages 1–15. Springer Berlin Heidelberg.
4. * Claude **Sammut** and Tak Fai Yik. (2010). Multistrategy learning for robot behaviours. In Jacek Koronacki, Zbigniew W Ras, Slawomir T Wierzchon, and Janusz Kacprzyk, editors, *Advances in Machine Learning I*, volume 262 of *Studies in Computational Intelligence*, pages 457–476. Springer.
5. * Hengst, B., Pham, S. B., Ibottson, D., and Sammut, C. (2002). Omnidirectional locomotion for quadruped robots. In *RoboCup 2001: Robot Soccer World Cup V*, pages 368–373. Springer, Berlin.
6. * Bain, M. and **Sammut**, C. (1999). A framework for behavioural cloning. In Furukawa, K., Michie, D., and Muggleton, S., editors, *Machine Intelligence 15*, pages 103–129. Oxford University Press.
7. * Sammut, C. (1994). Recent progress with BOXES. In Furukawa, K., Michie, D., and Muggleton, S., editors, *Machine Intelligence 13*, pages 363–383. Clarendon Press, Oxford.
8. * Sammut, C. A. and Banerji, R. B. (1986). Learning concepts by asking questions. In Michalski, R. S., Carbonell, J., and Mitchell, T., editors, *Machine Learning: An Artificial Intelligence Approach, Vol 2*, pages 167–192. Morgan Kaufmann, Los Altos, California.

Refereed Journal Articles

9. Hwong, Y. L., Oliver, C., Van Kranendonk, M., **Sammut**, C., & Seroussi, Y. (2017). What makes you tick? The psychology of social media engagement in space science communication. *Computers in Human Behavior*, *68*, 480-492.
10. Moses, D., **Sammut**, C., and Zrimec, T. (2016). Automatic segmentation and analysis of the main pulmonary artery on standard post-contrast CT studies using iterative erosion and dilation. *International Journal of Computer Assisted Radiology and Surgery*, **11**:381–395.
11. * Wiley, T., **Sammut**, C., Hengst, B., and Bratko, I. (2016). A planning and learning hierarchy using qualitative reasoning for the on-line acquisition of robotic behaviors. *Advances in Cognitive Systems*, **4**:93–111.
12. Maghrebi, M., waller, S., and Sammut, C. (2016). Matching experts' decisions in concrete delivery dispatching centers by ensemble learning algorithms: Tactical level. *Automation in Construction*, **46**:146 – 155.
13. Maghrebi, M., Waller, S., and Sammut, C. (2015). Optimality gap of experts' decisions in concrete delivery dispatching. J*ournal of Building Engineering*, **2**:17–23.
14. * Reza Farid, R. and C. **Sammut** (2014). Plane-based object categorisation using relational learning. *Machine Learning*. **94:** 3–23.

15. * Haber, A. and C. **Sammut** (2012). Towards a Cognitive Architecture for Extended Robot Autonomy. *Advances in Cognitive Systems*. P. Langley. Palo Alto, CA.
16. Jamali, N. and **Sammut**, C. (2011). Majority voting: Material classification by tactile sensing using surface texture. *IEEE Transactions on Robotics*, **27**(3):508–521.
17. Milstein, A., McGill, M., Wiley, T., Salleh, R., and **Sammut**, C. (2011). A method for fast encoder-free mapping in unstructured environments. *Journal of Field Robotics*. **28**(6):817–831.
18. * Claire D'Este and Claude **Sammut**. Learning and generalising semantic knowledge from object scenes. *Robotics and Autonomous Systems*, **56**(11):891–900, November 2008.
19. * Kadous, M. W. and C. **Sammut** (2005). Classification of Multivariate Time Series and Structured Data using Constructive Induction. *Machine Learning*. **58**: 179-216.
20. * Potts, D. and Sammut, C. (2005). Incremental learning of linear model trees. *Machine Learning*, **6**(1-3):5–48.
21. Managing context in a conversational agent. *Electronic Transactions on Artificial Intelligence*, **5**(B):189–202.
22. Harries, M., Sammut, C., and Horn, K. (1998). Extracting hidden context. *Machine Learning*, **32**(2):101–126.
23. * Sammut, C. and Michie, D. (1991). Controlling a 'black-box' simulation of a spacecraft. *AI Magazine*, **12**(1):56–63.
24. Sammut, C. A. and Sammut, R. A. (1983). The implementation of UNSW Prolog. *Australian Computer Journal*, **15**(2).
25. * Cohen, B. L. and Sammut, C. A. (1982). Object recognition and concept learning with CONFUCIUS. *Pattern Recognition Journal*, **15**(4):309–316.

Refereed Conference Papers

26. * Hengst, B., Keith, C., Pagnucco, M., Rajaratnam, D., Robinson, P., Sammut, C., and Thielscher, M. (2016). A framework for integrating symbolic and sub-symbolic representations. In *25th International Joint Conference on Artificial Intelligence IJCAI-16*. New York, New York, USA.
27. Ratter, A. and Sammut, C. (2015). Fused 2d/3d position tracking for robust slam on mobile robots. In *IEEE/RSJ International Conference on Intelligent Robots and Systems*, pages 1962–1969, Hamburg, Germany.
28. * Wiley, T., Sammut, C., Hengst, B., and Bratko, I. (2015). A multi-strategy architecture for on-line learning of robotic behaviours using qualitative reasoning. In *Proceedings of the Third Annual Conference on Advances in Cognitive Systems*, pages 1–16, Atlanta, USA
29. * Wiley, T., C. **Sammut** and I. Bratko (2014). Qualitative Simulation with Answer Set Programming. *European Conference on Artificial Intelligence*. Prague**:** 915 – 920.
30. * Wiley, T., C. **Sammut** and I. Bratko (2014). Qualitative planning with quantitative constraints for online learning of robotic behaviours. *AAAI Conference on Artificial Intelligence*, AI Access Foundation. **4:** 2578–2584.
31. * Brown, S. and C. **Sammut** (2013). A Relational Approach to Tool-use Learning in Robots. *Inductive Logic Programming*, Springer Berlin Heidelberg**:** 1–15.
32. Ratter, A. and C. **Sammut** (2013). GPU Accelerated Parallel Occupancy Voxel Based ICP for Position Tracking. *Proceedings of the 2013 Australasian Conference on Robotics & Automation*, Australian Robotics and Automation Association.
33. Ratter, A., C. **Sammut** and M. McGill (2013). GPU Accelerated Graph SLAM and Occupancy Voxel Based ICP for Encoder-Free Mobile Robots. *IEEE/RSJ International Conference on Intelligent Robots and Systems*. Tokyo**:** 1–8.

34. * Wiley, T., C. **Sammut** and I. Bratko (2013). Planning with Qualitative Models for Robotic Domains. *Second Annual Conference on Advances in Cognitive Systems*.

35. * Wiley, T., C. **Sammut** and I. Bratko (2013). Using Planning with Qualitative Simulation for Multi-Strategy Learning of Robotic Behaviours. *27th International Workshop on Qualitative Reasoning*. M. Bhatt, P. Struss and C. Freksa. Bremen**:** 24–30.

36. * Brown, S. and C. **Sammut** (2012). A Relational Approach to Tool-Use Learning in Robots. *International Conference on Inductive Logic Programming*. Dubrovnik.

37. * Farid, R. and C. **Sammut** (2012). Plane-based Object Categorization using Relational Learning. *International Conference on Inductive Logic Programming.* Dubrovnik.

38. * Haber, A., M. McGill and C. **Sammut** (2012). jmeSim: An Open Source, Multi Platform Robotics Simulator. *Proceedings of Australasian Conference on Robotics and Automation*. Victoria University of Wellington, New Zealand.

39. McGill, M., R. Salleh, T. Wiley, A. Ratter, R. Farid, C. **Sammut** and A. Milstein (2012). Virtual Reconstruction Using an Autonomous Robot. *International Conference on Indoor Positioning and Indoor Navigation*.

40. * Sushkov, O. O. and C. **Sammut** (2012). Active Robot Learning of Object Properties. *IEEE/RSJ International Conference on Intelligent Robots and Systems*. E. Guglielmelli.

41. Wiley, T., M. McGill, A. Milstein, R. Salleh and C. **Sammut** (2012). Spatial Correlation of Multi-sensor Features for Autonomous Victim Identification. *RoboCup 2011: Robot Soccer World Cup XV*. Graz, Austria**:** 538–549.

42. Jamali, N. and **Sammut**, C. (2012). Slip prediction using hidden Markov models: Multidimensional sensor data to symbolic temporal pattern learning. In *IEEE International Conference on Robotics and Automation*.

43. * Brown, S. and **Sammut**, C. (2011). Learning tool use in robots. In Langley, P., editor, *Advances in Cognitive Systems*, Arlington, Virginia.

44. Milstein, A., McGill, M. J., Wiley, T. C., Salleh, R., and **Sammut**, C. (2011). Occupancy voxel metric based iterative closest point for position tracking in 3D environments. In *IEEE International Conference on Robotics and Automation*.

45. * Sheh, R., Hengst, B., and **Sammut**, C. (2011). Behavioural cloning for driving robots over rough terrain. In *International Conference on Intelligent Robots and Systems* (IROS), pages 732–737, San Francisco, CA.

46. Sheh, R. and **Sammut**, C. (2011). Simulating range cameras for complex terrain robot mobility. In *IEEE International Symposium on Safety, Security, and Rescue Robotics*, Kyoto.

47. O. Sushkov and C. **Sammut**. Local image feature matching for object recognition. In *International Conference on Control, Automation, Robotics and Vision*, 2010.

48. N. Jamali and C. **Sammut**. Material classification by tactile sensing using surface textures. In *International Conference on Robotics and Automation*, pages 2336–2341, 2010.

49. Sheh, R., K. M.W., C. Sammut and B. Hengst (2007). Extracting Terrain Features from Range Images for Autonomous Random Stepfield Traversal. *IEEE International Conference on Safety, Security and Rescue Robotics*. D. Nardi. Rome.

50. * Sammut, C., W. Kadous and R. Sheh (2007). Learning to Drive Over Rough Terrain. *International Symposium on Skill Science*. K. Furukawa. Tokyo.

51. Rudzyn, B., W. Kadous and C. Sammut (2007). Real time robot audition system incorporating both 3D sound source localisation and voice characterisation. *International Conference on Robotics and Automation*.

52. Kadous, W., R. Sheh and C. Sammut (2006). Effective User Interface Design for Rescue Robotics. *Human-Robot Interaction*. Salt Lake City, Utah, USA: 250-257.

53. * Kadous, W., C. Sammut and R. Sheh (2006). Autonomous Traversal of Rough Terrain Using Behavioural Cloning. *The 3rd International Conference on Autonomous Robots and Agents*.

54. * Kadous, M. W., R. Sheh and C. Sammut (2006). Controlling Heterogeneous Semi-autonomous Rescue Robot Teams. *2006 IEEE International Conference on Systems, Man, and Cybernetic*. Taipei.

55. Kadous, M. W. and Sammut, C. (2004). Inca: A mobile conversational agent. In Zhang, C., Guesgen, H. W., and Yeap, W. K., editors, *8th Pacific Rim International Conference on Artificial Intelligence*, pages 644 – 653, Auckland, New Zealand. Springer.

56. * Isaac, A. and Sammut, C. (2003). Goal-directed learning to fly. In Fawcett, T. and Mishra, N., editors, *Proceedings of the Twentieth International Conference on Machine Learning*, pages 258–265, Washington, D.C.

57. * Sammut, C. (1998). Prolog, refinements and RLGGs. In Page, D., editor, *Proceedings of the Eighth International Conference on Inductive Logic Programming*, pages 225–235, Madison, Wisconsin. Springer.

58. Sammut, C. and Zrimec, T. (1998). Learning to classify x-ray images using relational learning. In Nedellec, C. and Rouveirol, C., editors, *Machine Learning; ECML-98,* pages 55–60, Chemnitz, Germany. Springer-Verlag.

59. Squires, B. and Sammut, C. (1995). Automatic speaker recognition: An application for machine learning. In Prieditis, A. and Russel, S. J., editors, *Twelfth International Conference on Machine Learning*, pages 515–521, Tahoe City, California. Morgan Kaufmann.

60. * Sammut, C., Hurst, S., Kedzier, D., and Michie, D. (1992). Learning to fly. In Sleeman, D. and Edwards, P., editors, *Proceedings of the Ninth International Conference on Machine Learning*, pages 385–393, Aberdeen. Morgan Kaufmann.

61. Compton, P., Edwards, G., Kang, B., Lazarus, L., Malor, R., Menzies, T., Preston, P., Srinivasan, A., and Sammut, C. (1991). Ripple Down Rules: Possibilities and Limitations. In *Sixth AAAI Knowledge Acquisition for Knowledge-Based Systems Workshop*, pages 6–27, Banff, Canada. University of Calgary.

62. * Sammut, C. A. (1981). Concept learning by experiment. In *Seventh International Joint Conference on Artificial Intelligence*, pages 104–105, Vancouver.

ARC GRANTS AWARDED IN LAST TEN YEARS

Project ID	CI/PI Names	Amount Funded	Amount of Years	Project Title	Publications
CE0348228	H. Durrant-Whyte, C. **Sammut**, G. Dissanayake, E. Nebot.	$15,400,000	8	ARC Centre of Excellence for Autonomous Systems	3, 4, 14, 15, 17, 18, 19, 20, 27, 31, 32, 33, 36. 37, 38, 39, 40, 43, 44, 45, 46, 47, 49, 50, 52, 53, 54
TS0669860	M. Breakspear, J. Morley, J. Harris, C. **Sammut**, G. Goodhill, G. Paxinos, N. Lovell, S. Knock, J. Lagopoulos, G. Malhi, V. Macefield.	$3,300,000	5	Optimizing autonomous system control with brain-like hierarchical control systems.	16, 42, 48
DP130102351	C. **Sammut**, I. Bratko	$378,000	3	Learning and Planning with Qualitative Models	11, 28, 29, 34, 35, 41

F14. Research Opportunity and Performance Evidence (ROPE) - Ten career-best research outputs

(Please upload a PDF with a list of your ten career-best research outputs, with a brief paragraph for each research output explaining its significance (five pages maximum).)

Uploaded PDF file follows on next page.

TEN CAREER BEST PUBLICATIONS

Citations counts from Google Scholar (checked by hand).

1. * C. **Sammut**, S. Hurst, D. Kedzier & D. Michie. Learning to fly. In D. Sleeman & P. *Proceedings of the Ninth International Conference on Machine Learning,* pp. 385-393, Aberdeen, UK, July 1992.
   [309 citations] *One of the first papers in behavioural cloning: learning to control a dynamic system by observing human behaviour.*

2. * C. **Sammut** & R. Banerji. Learning concepts by asking questions. In R.S. Michalski, J. Carbonell & T.M. Mitchell (eds), *Machine Learning,* **2**:167–192, Morgan Kaufmann, 1986.
   [284 citations] *Describes some of the earliest work in relational learning; a seminal paper in inductive logic programming.*

3. C. **Sammut** and G.I. Webb, editors. *Encyclopedia of Machine Learning*. Springer, 2010.
   [252 citations] *The first encyclopedia of its kind that organises several hundred diverse topics in machine learning. This has become one of Springers top five best selling encyclopedias. A second edition has been commissioned.*

4. * M.B. Harries, C. **Sammut** & K. Horn. Extracting hidden context. *Machine Learning*, **32**(2):101–126, 1998.
   [189 citations] *In a dynamic system, the concept that a learner must acquire changes over time. This paper presented significant new approach to this problem.*

5. * M.W. Kadous & C. **Sammut**. Classification of multivariate time series and structured data using constructive induction. *Machine Learning*, **58**:179–216, February 2005.
   [75 citations] *A new approach to a problem neglected because of its difficulty. This method successfully learned to classify complex multivariate time-series, including recognition of human gestures.*

6. Waleed Kadous, Raymond Sheh, and Claude **Sammut**. Effective user interface design for rescue robotics. In *Human-Robot Interaction*, pages 250–257, Salt Lake City, Utah, USA, 2006.
   [87 citations] *This paper describes user interface design for rescue robots. This work also won a special award at RoboCup 2009 for innovation in human-robot interaction.*

7. * D. Potts & C. **Sammut**. Incremental learning of linear model trees. *Machine Learning*, **61**:5–48, November 2005. (CE0348228)
   [86 citations] *Develops a machine learning approach to system identification.*

8. * M. Bain and C. **Sammut**. A framework for behavioural cloning. In Koichi Furukawa, Donald Michie, and Stephen Muggleton, editors, Machine Intelligence 15, pages 103–129. Oxford University Press, 1999.
   [85 citations] *Introduced the concept of goal-directed learning in behavioural cloning. This improved the robustness of learning by imitation.*

9. * B. Hengst, S.B. Pham, D. Ibottson & C. **Sammut**. Omnidirectional locomotion for quadruped robots. Proceedings of RoboCup 2001: Robot Soccer World Cup V, pp. 368–373, Springer, Berlin, 2002.
   [82 citations] *Introduced a revolutionary locomotion system for quadruped robots. The impact went beyond citations because software was also published and became widely used by other researchers in the field.*

10. * Jamali, N., & Sammut, C. A. (2011). Majority Voting: Material Classification by Tactile Sensing Using Surface Texture. *IEEE Transactions on Robotics*, **27**(3), 508-521.
    [78 citations] *The most successful use, to date, of machine learning in tactile sensing.*

F15. Research Opportunity and Performance Evidence (ROPE) - Further evidence in relation to research impact and contributions to the field, including those most relevant to this Proposal

(Write a maximum of 11250 characters (approximately 1500 words). Detail further evidence in relation to research impact and contributions to the field. Click on the information icon and refer to the Instructions to Applicants for the required content and formatting.)

(1) Research outputs other than publications

RoboCup is a major initiative in robotics aimed at stimulating research through competitions in robot soccer and robot rescue. Under my leadership, the UNSW team was world champion three times in the quadruped robot soccer league. In 2014, UNSW became the champions of the Standard Platform League, which uses the Nao humanoid robot. My research includes robots for urban search and rescue. In 2009, the team I led won the award for best autonomous robot in the Rescue Robot League. We placed 2nd in the mobility challenge and we also won a special award for innovation in the operator's interface. In 2010, we again won the award for best autonomous robot and won the mobility challenge. We repeated winning the award for best autonomous robot for the third year running in 2011. As many of the best laboratories in the world compete in RoboCup, our methods must be superior to those of the other teams but they must also be implemented so that they are practical, efficient and reliable. Thus, mounting a successful RoboCup team is an indication of significant research and the ability to translate that research into practice. I served on the executive board of the RoboCup Federation from 2003 to 2009 and in 2012 I was elected to the Board of Trustees, the federation's highest governing body.

Because of my experience and breadth of knowledge in the field of Machine Learning, I was invited by Springer to be Editor-in-Chief for the Encyclopedia of Machine Learning. I later recruited co-editor Geoffrey I. Webb. We were responsible for determining the content of the encyclopedia, recruiting more than 100 experts to contribute articles, writing many of the articles ourselves, reviewing and editing all the entries, with the help of area chairs, and doing the final cross-referencing. This was a major undertaking, over five years resulting in over 1,000 pages and approximately 300 entries. The encyclopedia was published in November 2010 and is also available online. It is now one of the top five of Springer's reference works and second edition is about to be commissioned.

My research on rescue robots has applications beyond this one field. We currently have a contract with a consortium of farmers in the Southern Tablelands to develop a weeding robot. Being organic farmers, they cannot use pesticides and, at present, can only remove weeds by manual labour, which is expensive. We are developing a robot that is able to drive between rows plants, eliminating weeds that may encroach on the crops area. The hardware and software used in the rescue robots has translated directly to the agricultural robot.

From 2001 to 2004, I was a project leader, then program manager for the Smart Internet Technology CRC. In addition to publications, our project developed an extensive suit of software for multi-modal human-machine interaction. As well as being used within the CRC, this software has carried over to research on human-robot interaction.

Over my career, 33 PhD students have graduated under my supervision, twelve graduating in the last five. I currently supervise six PhD students, two of whom are will submit in 2016.

(2) Evidence of quality of research

I have a career total of 181 peer reviewed research papers. Google Scholar reports 2,808 career citations and an h-index of 26. The majority of the journal publications are in A* or A journals. International conferences are A and we also contribute to local conferences, which are mostly ranked B.

I have been an ERA assessor in both rounds, 2012 and 2015.

Prizes

I was the team leader of entries in the RoboCup Rescue Robot League and mentor for
the RoboCup Standard Platform League

2003 1st place, RoboCup four-legged robot soccer league
1st place, RoboCup four-legged robot league technical challenges
2006 3rd place, RoboCup Rescue Robot Competition
2007 2nd place, RoboCup Rescue Autonomous Robot Challenge
2009 1st place, RoboCup Rescue Autonomous Robot Challenge

2nd place, RoboCup Rescue Mobility Challenge
RoboCup Rescue Special award for innovative operator interface
2010 1st place, RoboCup Rescue Autonomous Robot Challenge
1st place, RoboCup Rescue Mobility Challenge
1st place, RoboCup Standard Platform League technical challenges
2nd place, RoboCup Standard Platform League soccer competition
2011 1st place, RoboCup Rescue Autonomous Robot Challenge
2014 1st place, RoboCup Standard Platform League
2015 1st place, RoboCup Standard Platform League

Keynote Addresses and Invited Talks

- Australian Joint Conference on Artificial Intelligence:
Perth, 3-5 December 2003. Keynote address.

- Soft Computing and Intelligent Systems: Yokohama, Japan,
21-24 September 2004. Keynote address.

- March 2004: Invited by Yonsei University, Hanyang University,
SungKyunKwan University and the Korean Institute of Science and Technology
to visit their robotics laboratories and give presentations on our work at
the ARC Centre of Excellence for Autonomous Systems.

- International Symposium on Skill Science: Tokyo, Japan,
18-20 September 2007. Keynote address.

- International Rescue Robot Workshop: Bangkok, Thailand,
December 2009. Keynote address.

- International Rescue Robot Workshop: Perth, Australia,
December 2013. Keynote address.

- Response Robot Summer Symposium: Perth, Australia,
December 2014. Keynote address.

- AAAI Conference on Artificial Intelligence: Austin, Texas
January, 2015. Tutorial on robotics competitions

Conference Organisation

2002: Conference Chair, International Conference on Machine Learning, Sydney.
2002: Conference Co-Chair: International Conference on
Inductive Logic Programming, Sydney.
2004: Program Co-Chair: RoboCup Symposium, Lisbon.
2005: Conference Chair, Australasian Conference on Robotics and Automation,
Sydney.
2007: General Chair: International Conference on Machine Learning, Corvalis,
Oregon.

Editorial Boards and Technical Committees

2003 – 2009: Member of executive board of International RoboCup Federation
2002 – 2009: Member of technical committee for RoboCup four-legged robot league.
2002 – 2007: Action Editor, Journal of Machine Learning Research
2001 – present: Editorial board member, New Generation Computing
1999 – 2010: Editorial board member, Machine Learning Journal
2012 - present: Trustee, International RoboCup Federation

(3) Impact and Relevance to the Proposal

I have been a founder of two areas relevant to this proposal. My early work in machine learning helped to lay the foundations of what has become known as “Inductive Logic Programming” or learning concept descriptions expressed as first-order logic. My group has continued to use this form of learning in applications to robotics. In particular, learning actions models for planning and for tool use.

I also made a significant impact in learning by imitation, or “behavioural cloning” in robotics. That is, a robot learns to perform a new task by observing another agent and then generalising from that demonstration to be able to perform the skill in new situations.

My two most highly cited papers are in these two areas and are directly relevant to this proposal as it concerns learning by demonstration and, because of the complexity of the domain, the most suitable form of machine learning to be applied is inductive logic programming.

F16. Currently held ARC Projects

(This information is auto-populated from your RMS profile and will include any ‘active’ Project which has not yet had a Final Report approved and the Project file closed by the ARC. If you have any concerns with the information recorded here, contact your Administering Organisation’s Research Office. NOTE: If you hold a CI or a PI role on the Project/s listed in the table below you must ensure a progress statement is provided in G2. This requirement applies to the following schemes: Discovery Projects, Discovery Indigenous Researchers Development, Discovery Indigenous, Discovery Early Career Researcher Award, Linkage Projects, Industrial Transformation Research Hubs, Industrial Transformation Training Centres or any ARC Fellowship scheme. Please click on the information icon and refer to the Instructions to Applicants for further information.)

Identifier	Scheme Name	Investigators	Admin Organisation	Project Title	Funding	End Date
DP130102351	DP 2013 R1	Prof Claude Sammut ; Prof Ivan Bratko	The University of New South Wales	Learning and planning with qualitative models	$378,000	31/12/2016

Part F - Personnel and ROPE (Prof Katsumi Watanabe)

F1. Personal Details

(To update personal details, click the 'Manage Personal Details' link below. Note this will open a new browser tab. When returning to the form ensure you 'Refresh' the page to capture the changes made to your profile.)

Participation Type

Partner Investigator

Title

Prof

First Name

Katsumi

Second Name

Family Name

Watanabe

F2. Will you be residing predominately in Australia for the duration of the Project?

(This is a 'Yes' or 'No' question. Indicate whether you will be residing predominantly in Australia for the duration of the Project, taking into account any international travel. If you are applying as a CI and you answer 'No' to this question you will be prompted to contact your Research Office to check your eligibility.)

No

F3. Qualifications

(To update any qualifications, click on the 'Manage Qualifications' link below. Note this will open a new browser tab. When returning to the form ensure you 'Refresh' the page to capture the changes made to your profile.)

Conferral Date	AQF Level	Degree/Award Title	Discipline/Field	Awarding Organisation	Country of Award
15/06/2001	Doctoral Degree	PhD	Computation and Neural Systems	California Institute of Technology	United States of America
28/03/1997	Masters Degree	M.A.	Cognitive Science	The University of Tokyo	Japan
28/03/1995	Bachelor Degree	B.A.	Experimental Psychology	The University of Tokyo	Japan

F4. Are you currently undertaking a Higher Degree by Research which will be conferred after 1 January 2018?

(This is a 'Yes' or 'No' question. If you are applying as a CI and your answer is 'Yes' to this question you will be prompted to contact your Research Office.)

No

F5. Research Opportunity and Performance Evidence (ROPE) – Current and previous appointment(s) / position(s) - during the past 10 years

(To update any details in this table, click on the 'Manage Employment Details' link below. Note this will open a new browser tab. When returning to the form ensure you 'Refresh' the page to capture the changes made to your profile. Click on the information icon above and refer to the Instructions to Applicants for more information.)

Description	Department	Contract Type	Employment Type	Start Date	End Date	Organisation
Professor	Faculty of Science and Engineering	Permanent	Full Time	01/04/2015		Waseda University, Japan
Associate Professor	Research Center for Advanced Science and Technology	Contract	Full Time	01/04/2006		University of Tokyo
Research Scientist	Human Technology Research Institute	Permanent	Full Time	01/09/2003	31/03/2011	National Institute of Advanced Industrial Science and Technology
Group Leader	ERATO Shimojo Implicit Brain Function Project	Contract	Part Time	01/10/2005	31/03/2010	Japan Science and Technology Agency

F6. Employment Details as at Commencement date of Project

(This question will be used to determine your eligibility. Confirm your employment status at all organisations that you will be associated with as at the Commencement Date for the Project (1 January 2018). Enter the relevant appointment type and Full-Time Equivalent (FTE) for each organisation. Click on the information icon for further information.)

Org name	Is this an Eligible Organisation?	Please choose your appointment type for this organisation.	Please enter your FTE for this Organisation
Waseda University, Japan		Employee	1.0

F7. Further Details Regarding Partner Investigator Status - Do you hold a remunerated appointment at an Eligible Organisation?

(NOTE: this question is mandatory ONLY FOR PIs WHO:
• at F2 confirmed that they will reside predominantly in Australia for the duration of the proposed Project; AND
• at F4 confirmed that they are not currently undertaking a Higher Degree by Research which will be conferred after 1 January 2018; AND
• at F6 indicated that they would hold either:
- an appointment at an Eligible Organisation equal or greater than 0.2FTE; OR
- Emeritus appointment at an Eligible Organisation

This is a 'Yes' or 'No' question. If you select 'Yes', you will be further prompted to justify your participation on this Proposal as a PI with reference to sections F7.2 and F7.3 of the Funding Rules. Click on the information icon for further information.)

Do you hold a remunerated appointment at an Eligible Organisation?

Justification of PI status

F8. Relevant Organisation for this Proposal

(Enter the Organisation that is relevant to your participation on this proposal, and that you will be associated with as at the Commencement Date for the Project (1 January 2018). The 'relevant organisation' is the primary organisation that will be supporting your involvement in this Project if it is funded. Note that the Organisation must be listed in F6 for this question to validate.)

Relevant Organisation

Waseda University, Japan

F9. What is your time commitment to this Project?

(Enter your time commitment to this Project as a Full-Time Equivalent (FTE). Note that a FTE of 1.0 represents a full-time commitment (i.e. 5 days per week).)

0.2

F10. Are you applying for Teaching Relief?

(This is a 'Yes' or 'No' question.

• If you answer 'Yes' to this question a budget line will be automatically populated for the Teaching Relief in the budget table in Form Part D: Project Cost. This will allow you to enter the funding amount requested in the relevant year/s. To remove the Teaching Relief from the budget table you must return to this question and answer 'No'.

• Note: CIs may request funding for teaching relief or other duties in order to maximise the opportunity for the CI to conduct research. This question is only relevant for CIs and will not be activated for PIs. If the answer to this question is 'yes', the budget table in 'Project Costs' will automatically update with a line to add costs for Teaching Relief.)

F11. Are you applying for a Discovery International Award?

(This is a 'Yes' or 'No' question. If you answer 'Yes' to this question a budget line will be automatically populated for the DIA in the budget table in Form Part D: Project Cost. This will allow you to enter the funding amount requested in the relevant year/s. To remove the DIA from the budget table you must return to this question and answer 'No'. Click on the information icon for further information.)

No

F12. Research Opportunity and Performance Evidence (ROPE) - Details of your career and opportunities for research

(Write a maximum of 5250 characters (approximately 750 words). Please detail your career and opportunities.)

i) NUMBER OF YEARS SINCE HIGHEST EDUCATIONAL QUALIFICATION Watanabe received his PhD in Computation and Neural Systems from California Institute of Technology 16 years ago in 2001. ii) RESEARCH OPPORTUNITIES IN THE CONTEXT OF EMPLOYENT SITUATION Watanabe is renowned for his research into cross-modal perception in humans (F14: 1), neuroscience of motivation and reward (F14: 2,3,6), affective science (F14: 8,10), social neuroscience (F14: 7) and vision science (F14: 4,5,9). After his PhD, he was awarded a Research Fellowship by the Japan Society for the Promotion of Science in 2001, followed by a Research Fellowship at the National Eye Institute (National Institutes of Health, USA) in 2002, and then an appointment as Research Scientist with the prestigious National Institute of Advanced Science and Technology (AIST, 2003–05), Japan. From 2005–2010 Watanabe was also the Project Group

Leader (Decision Making Research Group) for the Shimojo Implicit Brain Function Project, ERATO, Japan Science and Technology Agency. In 2006, Watanabe was appointed as Associate Professor at the Research Center for Advanced Science and Technology, the University of Tokyo. He is currently a Full Professor at Waseda University in Japan. CI Watanabe has been the founder and leader of the Watanabe Lab for more than 10 years.

At the Watanabe Lab, Watanabe's research is characterized by interdisciplinary investigations underpinned by cognitive science. The emphasis of his research is to produce real-world outcomes through investigations on explicit and implicit processes in human perception, cognition and action. Watanabe's research is substantiated by prolific publication of his findings. In his research carrier, he has published more than 40 book chapters, 144 journal articles and delivered more than 60 refereed conference papers. Through the numerous 'barrier free' and 'intermedia art and science' research activities situated in his lab, he collaborates on diverse projects including the perceptual distortion of space and time; psychophysical investigations of audio-visual integration; automation process of learned sequential actions; implicit processes for decision making based on preference; cognitive analysis on media contents; eye movement study on visual cognition and attention; implicit learning of visual context; implicit motor synchronization; cognitive neuroscience on interaction between digital media and children; and postdictive decision making.

Of his recent research focuses, Watanabe has been involved in the cognitive evaluation of human-robot interaction, including building on his previous work of cultural differences in perception (e.g., F13: 4, 5, 6, 9, 19, 21, 66, 67, 68, 71, 74), social cognition (e.g., F13: 1, 2, 3, 7, 11, 12, 16, 19, 23, 29, 33, 36, 37, 40, 41, 44, 49, 52, 73, 75, 78) and motivation/reward (F13: 3, 31, 38, 42, 57, 61, 63, 77). As part this research, he travelled to the Creative Robotics Lab (CRL), UNSW in 2013 to conduct research into cultural difference in human response to robots using Geminoid F, an android robot from the Hiroshi Ishiguro Laboratory, Osaka University.

iii) EMPLOYMENT FRACTIONS
Watanabe's current appointment comprises approximately 60% research, 20% administration, 20% supervision and teaching.

iv) CAREER INTERRUPTIONS
n/a

v) RESEARCH MENTORING AND RESEARCH FACILITIES AVAILABLE
The Watanabe Lab is currently part of Faculty of Science and Engineering, Waseda University. It focuses on real-world outcomes by engaging industry and international collaborations. It receives more than half of its research funding from external contract sources.

In research mapping terms, Watanabe Lab is 'barrier free' and 'intermeida art and science' meaning that its activities extend across the Centre's research fields of Environment and Energy, Information, Social Science and Chemical Biomedicine. The Watanabe Lab has fully equipped experimental rooms for up to ten people simultaneously; four infra-red eye trackers, two motion capture systems, a 3D visual stimulus system, a transcranial direct current stimulation (tDCS) system, a galvanic skin response (GSR) measurement system, an electroencephalography (EEG) system, and direct access to neuroimaging facilities including transcranial magnetic stimulation (TMS), magnetoencephalography (MEG), and functional magnetic resonance imaging (fMRI) systems.

vi) OTHER ASPECTS OF CAREER OR OPPORTUNITIES FOR RESEARCH
Not applicable.

F13. Research Opportunity and Performance Evidence (ROPE) - Significant research outputs and ARC grants

(Upload a PDF of no more than four A4 pages with a list of all research outputs, such as journal articles and refereed conference papers, book and book chapters. Use asterisks to identify research outputs relevant to this Proposal. Click on the information icon or refer to the Instructions to Applicants for the required content and formatting.)

Uploaded PDF file follows on next page.

F13 SIGNIFICANT RESEARCH OUTPUTS

i) Significant research outputs

Scholarly book chapters

1. Watanabe, K. (2016) Teaching and Learning as interpersonal and innerpersonal phenomena: Where bodies and minds meet. In Mind, Brain and Education at Erice: Ten Years. Battro AM, Fischer KW & Majdalani ML (eds.) Ettore Majorana Foundation and Centre for Scientific Culture, pp. 165-169.
2. Kashino, M., Shimojo, S., & Watanabe, K. (2016) Critical Roles of Implicit Interpersonal Information in Communication. Human-Harmonized Information Technology, vol. 1, pp. 271-290. Nishida, T. (Ed.).
3. Watanabe, K. (2015) Effects of successful experience and positive feedback on learning and rehabilitation. In Clinical Systems Neuroscience (pp. 291-302), Kansaku, K., Cohen, L., & Birbaumer, N. (eds), Springer.
4. Haring, K. S., Silvera-Tawil, D., Matsumoto, Y., Velonaki, M., & Watanabe, K. (2014) Perception of an Android Robot in Japan and Australia: A Cross-Cultural Comparison. In Social Robotics (pp. 166-175), Springer International Publishing.
5. Haring, K.S., Matsumoto, Y., & Watanabe, K. (2014). Perception and trust towards a lifelike android robot in Japan. Transactions on Engineering Technologies (pp. 485-497). H. K. Kim et al. (eds.)
6. Mougenot, C., & Watanabe, K. (2013) Sensory stimulation of designers. In Fukuda, S. (ed), Emotional Engineering. vol. 2, ch. 5, 63–71, Springer, London.
7. Takahashi, K., Mitsuhashi, H., Murata, K., Norieda, S., & Watanabe, K. (2012) Abstract feelings emerging from haptic stimulation. In Haptics Rendering and Applications, InTech.
8. Watanabe, K. (2011) Exceeding the limits: Behavioral enhancement via external influence. In Kansaku, K., & Cohen, L. (eds), Systems Neuroscience and Rehabilitation, pp. 117–129, Springer.
9. Mougenot C., Watanabe, K. (2010) Verbal stimuli in design creativity: a case study with Japanese sound- symbolic words. In Toshiharu Taura and Yukari Nagai (eds) Design Creativity 2010, Springer. ISBN 978-0-85729-223-0.
10. Watanabe, K., & Shimojo, S. (2005) Crossmodal attention in event perception. In Itti, L., Rees,G., Tsotsos, J. (eds), Neurobiology of Attention, Academic Press/Elsevier.

Refereed journal articles

11. Aucouturier, J.-J., Johansson, P., Hall, L., Segnini, R., Mercadié, L. & Watanabe, K. (2016) Covert digital manipulation of vocal emotion alter speakers' emotional state in a congruent direction. Proceedings of the National Academy of Science, 13(4), 948-953.
12. Ikeda, H. & Watanabe, K. (2016). Action congruency influences crowding when discriminating biological motion direction. Perception, 45(9), 1046-1059.
13. Tanaka, K., & Watanabe, K. (2016) Impacts of visuomotor sequence learning methods on speed and accuracy: Starting over from the beginning or from the point of error. Acta Psychologica, 164, 169-180.
14. Ohyama, J., & Watanabe, K. (2016) Temporal and spatial predictability of an irrelevant event differently affect detection and memory of items in a visual sequence. Frontiers in Psychology, 7:65.
15. Kitamura, M., Watanabe, K., & Kitagawa, M. (2016) Positive emotion facilitates audiovisual binding. Frontiers in Integrative Neuroscience, 9:66.
16. Saegusa, C., & Watanabe. K. (2016) Judgments of facial attractiveness as a combination of facial parts information over time: Social and aesthetic factors. Journal of Experimental Psychology: Human Perception and Performance, 42(2), 173-179.
17. Tanaka, K., & Watanabe, K. (2015) Effects of learning duration on implicit transfer. Experimental Brain Research, 233 (10), 2767-2776.
18. Takahashi K, & Watanabe, K. (2015) Synchronous motion modulates animacy perception. Journal of Vision, 15(8), 17.
19. Saegusa, C., Namatame, M. & Watanabe, K. (2015) Interpreting text messages with graphic facial expression by deaf and hearing people. Frontiers in Psychology, 6, 383.

20. Tanaka, K., & Watanabe, K. (2014) Implicit transfer of spatial structure in visuomotor sequence learning. Acta Psychologica, 153, 1-12.
21. Haring, K.S., Mougenot, C., Ono, F., & Watanabe, K. (2014) Cultural Differences in Perception and Attitude towards Robots. International Journal of Affective Engineering, 13 (3), 149-157.
22. Ueda, H, Takahashi, K., & Watanabe, K. (2014) Effects of direct and averted gaze on the subsequent saccadic response. Attention, Perception, & Psychophysics, 76(4), 1085-1092.
23. Matsuyoshi, D., Kuraguchi, K., Tanaka, Y., Uchida, S., Ashida, H., & Watanabe, K. (2014) Individual differences in autistic traits predict the perception of direct gaze for males, but not for females. Molecular Autism, 5(12), 1-3.
24. Duan, F., Watanabe, K., Yoshimura, Y., Kikuchi, M., Minabe, Y., & Aihara, K. (2014) Relationship between brain network pattern and cognitive performance of children revealed by MEG signals during free viewing of video. Brain and Cognition, 86, 10-16.
25. Ueda, H., Takahashi, K., & Watanabe, K. (2014) Influence of removal of invisible fixation on the saccadic and manual gap effect. Experimental Brain Research, 232(1), 329-336.
26. Ono, F., & Watanabe, K. (2014) Shape-assimilation effect: Retrospective distortion of visual shapes. Attention, Perception & Psychophysics, 76(1), 5-10.
27. Tanaka, K., & Watanabe, K. (2013) Implicit transfer of reversed temporal structure in visuomotor sequence learning. Cognitive Science, 1–15.
28. Tanaka, K., & Watanabe, K. (2013) Effects of learning with explicit elaboration on implicit transfer of visuomotor sequence learning. Experimental Brain Research, 228(4):411–425.
29. Takahashi, K. & Watanabe, K. (2013) Gaze cueing by pareidolia faces. i-Perception, 4(8):490–492.
30. Tsubomi, H., Fukuda, K., Watanabe, K., & Vogel, E. K. (2013) Neural limits to representing objects still within view. Journal of Neuroscience, 33(19):8257–8263.
31. Watanabe, K. (2013) Teaching as a dynamic phenomenon with interpersonal interactions. Mind, Brain and Education, 7(2):91–100.
32. Au, R. K. C., & Watanabe, K. (2013) Object motion continuity and the flash-lag effect. Vision Research, 92:19–25.
33. Kondo, A., Takahashi, K., & Watanabe, K. (2013) Influence of gender membership on sequential decision of face attractiveness. Attention, Perception, & Psychophysics, 75(7):1347–1352.
34. Ikeda, H, Watanabe, K., & Cavanagh, P (2013) Crowding of biological motion stimuli. Journal of Vision, 13(4), 20:1–6.
35. Chien, S., Ono, F., & Watanabe, K. (2013) A transient auditory signal shifts the perceived offset position of a moving visual object. Frontiers in Psychology, 4(70):1–10.
36. Yonemura, K., Ono, F., & Watanabe, K. (2013) Back view of beauty: A bias in attractiveness judgment. Perception, 42(1):95–102.
37. Yun, K., Watanabe, K., & Shimojo, S. (2012) Interpersonal body and neural synchronization as a marker of implicit social interaction. Scientific Reports, 2:959.
38. Sugawara, S.K, Tanaka, S., Okazaki, S., Watanabe, K., & Sadato, N. (2012) Social rewards enhance offline improvements in motor skill. PLoS ONE, 7(11):e48174.
39. Iwayama, K., Hirata, Y., Takahashi, K., Watanabe, K., Aihara, K. & Suzuki, H. (2012) Characterizing global evolutions of complex systems via intermediate network representations. Scientific Reports, 2 (423).
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58. Ikeda, H., Blake, R., & Watanabe, K. (2005) Eccentric perception of biological motion is unscalably poor. Vision Research, 45:1935–1943.
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64. Watanabe, K., & Shimojo, S. (2001) When sound affects vision: effects of auditory grouping on visual motion perception. Psychological Science, 12(2), 109-116.
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27(9), 1041-1054.

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66. Haring, K. S., Watanabe, K., Silvera-Tawil, D., & Velonaki, M. (2016/03/07-10) Expectations towards two robots with different interactive abilities. 2016 ACM/IEEE International Conference on Human-Robot Interaction (HRI 2016), Christchurch, New Zealand.
67. Haring, K.S., Silvera-Tawil, D., Takahashi T., Velonaki M., & Watanabe, K. (2015/9/3). Perception of a humanoid robot: A cross-cultural comparison. The 24th International Symposium on Robot and Human Interactive Communication (ROMAN 2015), Kobe International Conference Center, Japan.
68. Haring, K.S., Silvera-Tawil, D., Matsumoto, Y., Velonaki, M., & Watanabe, K. (2014/10/29) Perception of an Android Robot in Japan and Australia: A Cross-Cultural Comparison. International Conference in Social Robotics, Sydney, Australia.
69. Duan, F., Phothisonothai, M., Kikuchi, M., Yoshimura, Y., Minabe, Y., Watanabe, K., & Aihara, K. (2013/7/3–7) Boosting specificity of MEG artifact removal by weighted support vector machine. The 35th Annual International Conference of the IEEE Engineering Medicine and Biology Society (EMBC'13), Osaka, Japan.
70. Iwayama, K., Hirata, Y., Kondo, A., Tsubomi, H., Takahashi, K., Yoshimura, Y., Ueno, S., Kikuchi, M., Minabe, Y., Watanabe, K., Suzuki, H., & Aihara, K. (2013/7/3–7) Temporal dynamics of functional networks from multivariate electrophysiological time series. The 35th Annual International Conference of the IEEE Engineering Medicine and Biology Society (EMBC'13), Osaka, Japan.
71. Haring, K. S, Watanabe, K., & Mougenot C. (2013/3/3–6) The influence of robot appearance on assessment. 8th Annual Conference for Basic and Applied Human-Robot Interaction Research (HRI 2013), Tokyo, Japan.
72. Ikeda, H., Fukui, T., Tagai, K., Takata, S., & Watanabe, K. (2012, May) Politeness perception in action: Subjective impression of handing actions by professional sales persons. International Conference on Kansei Engineering and Emotion Research, Penghu, Taiwan.
73. Takahashi, K., Mitsuhashi, H., Norieda, S., Murata, K., & Watanabe, K. (9–12, Oct, 2011) Feelings of animacy and pleasantness from tactile stimulation: Effect of stimulus frequency and stimulated body part. 2011 IEEE International Conference on Systems, Man, and Cybernetics (IEEE SMC 2011), Anchorage, Alaska.
74. Mougenot, C,. Watanabe, K., Bouchard, C., & Aoussat, A. (March 2–4, 2010) Kansei information processing in product design: Exploring the role of visual information in designers' activity. International Conference on Kansei Engineering and Emotion Research, Paris.
75. Ariga, A., Kitamura-Suzuki, M., Watanabe, K., & Yoshikawa, S. (March 2–4, 2010) Perceiving the faces of Buddha statues: On the relation with viewpoint and affective evaluation. International Conference on Kansei Engineering and Emotion Research, Paris.
76. Seya, Y. Sato, K., Kimura, Y., Ookubo, A., Yamagata, H., Kasahara, K., Fujikake, H., Yamamoto, Y., Ikeda, H., & Watanabe, K. (September 1–4, 2009) Effects of peripheral visual information on performance of video game with hemi-spherical immersive projection screen. DiGRA2009, London.

Other Research Outputs

Exhibitions

77. Watanabe, K. 'Money: 10 Experiments' Exhibition at Miraikan National Museum of Emerging Science and Innovation, Tokyo, Japan, 9 March – 24 June 2013.
78. Watanabe, K. 'One, Everyone, and You'. Permanent exhibition at Miraikan National Museum of Emerging Science and Innovation, Tokyo, Japan, December 2012–.
79. Watanabe, K. 'Fear Research: Science in "Haunted House"' Exhibition at Miraikan National Museum of Emerging Science and Innovation, Tokyo, Japan, 22 April – 22 June 2009.

F13 (ii) ARC Grants Awarded in the last 10 Years

N/A

F14. Research Opportunity and Performance Evidence (ROPE) - Ten career-best research outputs

(Please upload a PDF with a list of your ten career-best research outputs, with a brief paragraph for each research

output explaining its significance (five pages maximum).)

Uploaded PDF file follows on next page.

F14 TEN CAREER-BEST RESEARCH OUTPUTS

KEY:
ERA ranking: journals (A*, A, B, C); conferences (A, B, C)
CORE ranking: journals (A*, A, B, C); conferences (A*, A, B, C)
Times Cited: from Google Scholar (see F12 vi)

1. **Watanabe, K**., & Shimojo, S. (2001) When sound affects vision: Effects of auditory grouping on visual motion perception. *Psychological Science*, 12(2):109–116. [ERA C; Citations: 127 Google, 96 Scopus]

   This study showed that audiovisual event perception is modulated by auditory context and that the effect is based on perceived, rather than physical, saliency.

2. Lauwereyns, J., **Watanabe, K**., Coe, B., & Hikosaka, O. (2002) A neural correlate of response bias in monkey caudate nucleus. *Nature*, 418:413–417. [ERA A*; Citations: 269 Google, 206 Scopus]

   This is the first single-neuron study of neural substrates on response bias: that is, biased motivation.

3. **Watanabe, K**., Lauwereyns, J., & Hikosaka, O. (2003) Neural correlates of rewarded and unrewarded eye movements in the primate caudate nucleus. *Journal of Neuroscience*, 23(31):10051–10057. [ERA A*; Citations: 90 Google, 70 Scopus]

   This study showed the primate caudate nucleus contains neurons responsible for rewarded eye movements as well as unrewarded (i.e. recultant) eye movements.

4. Ikeda, H., Blake, R., & **Watanabe, K**. (2005) Eccentric perception of biological motion is unscaleably poor. *Vision Research*, 45:1935–1943.

   Perception of point-light biological motion can be achieved only at the foveal region, contrary to our subjective feeling of detection of human action in the peripheral visual field.

5. **Watanabe, K**. (2008) Behavioral speed contagion: Automatic modulation of movement timing by observation of body movements. *Cognition*, 106 (3):1514–1524.

   This study showed that observing fast-forward (i.e. slowed-down) biological motion may facilitate (slow down) observers' responses of unrelated tasks.

6. Sugawara, S.K, Tanaka, S., Okazaki, S., **Watanabe, K**., & Sadato, N. (2012) Social rewards enhance offline improvements in motor skill. *PLoS ONE*, 7(11):e48174.

   This is the first empirical study showing that praise (i.e. social reward) has positive effects on offline consolidation of fine motor skills.

7. Yun, K., **Watanabe, K**., & Shimojo, S. (2012) Interpersonal body and neural synchronization as a marker of implicit social interaction. *Scientific Reports*, 2:959

   By simultaneously measuring activity in the brains of two participants, this study identified the brain regions responsible for increased bodily synchronization between the pair.

8. Haring, K.S., Matsumoto, Y., & **Watanabe, K**. (2013) How do people perceive and trust a lifelike robot? *Proceedings of the World Congress on Engineering and Computer Science 2013,* pp. 425–430, ISBN: 978-988-19252-3-7.

   This study examined how people trust different types of robots, and provides one of the bases for the current

proposal. Best Student Paper Award.

9. Tsubomi, H., Fukuda, K., **Watanabe, K**., & Vogel, E. K. (2013) Neural limits to representing objects still within view. *Journal of Neuroscience*, 33(19):8257–8263.

This study examined the perceptual limit of visual perception. Contrary to expectations, visual awareness is highly linked to visual working memory; we see only a few items in the visual field.

10. Aucouturier, J.-J., Johansson, P., Hall, L., Segnini, R., Mercadié, L. & **Watanabe, K**. (2016) Covert digital manipulation of vocal emotion alter speakers' emotional state in a congruent direction. *Proceedings of the National Academy of Science USA*, 13(4), 948-953.

This study showed that changing vocal emotion can change speakers' emotion implicitly by using online digital filters.

F15. Research Opportunity and Performance Evidence (ROPE) - Further evidence in relation to research impact and contributions to the field, including those most relevant to this Proposal

(Write a maximum of 11250 characters (approximately 1500 words). Detail further evidence in relation to research impact and contributions to the field. Click on the information icon and refer to the Instructions to Applicants for the required content and formatting.)

15.1 RESEARCH ACHIEVEMENTS OTHER THAN RESEARCH OUTPUTS

Prof Watanabe is active in research leadership, providing advice to several high level government panels and serving on the editorials boards of prestigious journals. The Watanabe Lab collaborates closely with Research Center for Advanced Science and Technology, the University of Tokyo, Miraikan National Museum of Emerging Science and Innovation in Tokyo (Japan), National Institutes of Advanced Science and Technology, Japan, Japan Science and Technology Agency, National Center for Child Health and Development (Japan), California Institute of Technology (USA), Creative robotics Lab at the University of New South Wales, University of London, and Fribourg University (Switzerland). As the Project Group Leader of the ERATO Grant, Watanabe proposed the concept of implicit brain functions and explored various related concepts and scientific underpinnings; one of those was implicit interpersonal information (information that is unconsciously exchanged between persons) and developed methods to measure this information, which has become the foundation of his recent project "Intelligent Information Processing Systems based on Implicit Ambient Surface Information."

Communication of scientific outcomes:
Watanabe has worked closely with the Miraikan National Museum of Emerging Science and Innovation in Tokyo on exhibitions related to cognitive science. Together with museum staff, Watanabe has developed three exhibitions: 'Fear Research: Science in "Haunted House"' (22 April – 22 June 2009) that allows visitors to explore how is fear created and how it remains in memory; 'Money – 10 Experiments' (9 March – 24 June 2013); and 'One, Everyone, and You' which explores how an individual interacts with others, and individuals form societies, and has been part of the museum's permanent displays since December 2012. Recently, he has started to open a new laboratory/exhibition space in Miraikan, where various experiments will be conducted as parts of exhibitions and event in Miraikan.

Government advisory roles:
Since 2004 Watanabe has been a member of the following Japanese Government panels: 'Consumer decision making' (Cabinet Office), 'Digital Museum' (Ministry of Education, Culture, Sports, Science and Technology), 'Brain Science and Innovation' (Ministry of Economy, Trade and Industry). He is the organiser of the URCF (Ultra-Realistic Communication Forum), a working group into super-experience design, and the Super Sensing Forum

Government research funding bodies:
Prof. Watanabe has been a reviewer for National Science Foundation (NSF, USA), Biotechnology and Biological Sciences Research Council (BBSRC, UK), Japan Society for the Promotion of Science (JSPS, Japan).

Editorial and academic review roles:
CI Watanabe is on the editorial or review boards of the journals: Cognitive Science, Cognitive Processing, PLoS One, Cyberpsychology, Behavior and Social Networking. He is also a reviewer for the following journals: Vision Research, Journal of Experimental Psychology: Human Perception & Performance, Journal of Experimental Psychology: Learning, Memory & Cognition, Cognition, Perception, Experimental Brain Research, Psychological Science, Nature, Nature Neuroscience, Neuron, Journal of Neuroscience, Journal of Neurophysiology, Perception & Psychophysics, Attention, Psychological Bulletin, Psychonomic Bulletin & Review, Journal of Vision: PLoS Biology, PLoS One, Proceedings for the National Academy of Sciences, Neuropediatrics, Neuroscience Letters, International Journal of Psychology, Cognitive Science, Biology Letters, Vision, Human Brain Mapping, Royal Society of London, Acta Psychologia, etc.

15.2 RESEARCH IMPACT IN CONTEXT OF DISCIPLINE/END USER BENEFITS
CI Watanabe's research into human-robot interaction (HRI) has contributed in three areas: cross-cultural perception; gender perception and robot appearance. In relation to robot appearance, Watanabe has conducted studies on the functional expectations of robot appearance and found that appearance is very important in shaping people's expectations (F13: 4, 21, 66, 71) of what type of behaviour the robot would exhibit. In addition, his research has lead him to investigate the notions of trust with an android robot (Geminoid F) in an attempt to understand the perception of the "uncanny valley" (an effect of eeriness or revulsion created by a near lifelike appearance of a robot) by testing the responses of participants meeting an android robot for the first time. Trust was measured through a series of standard questionnaires (Eysneck, Godspeed), the measurement of proximity to the robot, and an economic trust game. At the Creative Robotics Lab (CRL), UNSW, Watanabe conducted the same experiments with Geminoid F in order to research cross cultural variations in responses (F13: 67, 68).

In the next phase of testing directly related to this proposal, Watanabe will test four robot appearances in relation to trust. He will contribute to devising experimental procedures, development of appropriate measurements,

analyses and interpretation of the data from the perspective of experimental psychology, cognitive science, and brain science. For the first time, the unobtrusive sensing of the robot room will allow more comprehensive analysis of HRI.

F16. Currently held ARC Projects

(This information is auto-populated from your RMS profile and will include any 'active' Project which has not yet had a Final Report approved and the Project file closed by the ARC. If you have any concerns with the information recorded here, contact your Administering Organisation's Research Office. NOTE: If you hold a CI or a PI role on the Project/s listed in the table below you must ensure a progress statement is provided in G2. This requirement applies to the following schemes: Discovery Projects, Discovery Indigenous Researchers Development, Discovery Indigenous, Discovery Early Career Researcher Award, Linkage Projects, Industrial Transformation Research Hubs, Industrial Transformation Training Centres or any ARC Fellowship scheme. Please click on the information icon and refer to the Instructions to Applicants for further information.)

Part F - Personnel and ROPE (Prof Dr Gerhard Lakemeyer)

F1. Personal Details

(To update personal details, click the 'Manage Personal Details' link below. Note this will open a new browser tab. When returning to the form ensure you 'Refresh' the page to capture the changes made to your profile.)

Participation Type

Partner Investigator

Title

Prof Dr

First Name

Gerhard

Second Name

Family Name

Lakemeyer

F2. Will you be residing predominately in Australia for the duration of the Project?

(This is a 'Yes' or 'No' question. Indicate whether you will be residing predominantly in Australia for the duration of the Project, taking into account any international travel. If you are applying as a CI and you answer 'No' to this question you will be prompted to contact your Research Office to check your eligibility.)

No

F3. Qualifications

(To update any qualifications, click on the 'Manage Qualifications' link below. Note this will open a new browser tab. When returning to the form ensure you 'Refresh' the page to capture the changes made to your profile.)

Conferral Date	AQF Level	Degree/Award Title	Discipline/Field	Awarding Organisation	Country of Award
28/11/1990	Doctoral Degree	Ph.D.	Computer Science	University of Toronto	Canada
01/04/1982	Masters Degree	Dipl.-Inf. (German Masters Degree)	Computer Science	TU Dortmund	Germany

F4. Are you currently undertaking a Higher Degree by Research which will be conferred after 1 January 2018?

(This is a 'Yes' or 'No' question. If you are applying as a CI and your answer is 'Yes' to this question you will be prompted to contact your Research Office.)

No

F5. Research Opportunity and Performance Evidence (ROPE) – Current and previous appointment(s) / position(s) - during the past 10 years

(To update any details in this table, click on the 'Manage Employment Details' link below. Note this will open a new browser tab. When returning to the form ensure you 'Refresh' the page to capture the changes made to your profile.

Click on the information icon above and refer to the Instructions to Applicants for more information.)

Description	Department	Contract Type	Employment Type	Start Date	End Date	Organisation
Professor	Computer Science	Permanent	Full Time	05/07/1997		RWTH Aachen University of Technology, Germany

F6. Employment Details as at Commencement date of Project

(This question will be used to determine your eligibility. Confirm your employment status at all organisations that you will be associated with as at the Commencement Date for the Project (1 January 2018). Enter the relevant appointment type and Full-Time Equivalent (FTE) for each organisation. Click on the information icon for further information.)

Org name	Is this an Eligible Organisation?	Please choose your appointment type for this organisation.	Please enter your FTE for this Organisation
RWTH Aachen University of Technology, Germany		Employee	1.0

F7. Further Details Regarding Partner Investigator Status - Do you hold a remunerated appointment at an Eligible Organisation?

(NOTE: this question is mandatory ONLY FOR PIs WHO:
• at F2 confirmed that they will reside predominantly in Australia for the duration of the proposed Project; AND
• at F4 confirmed that they are not currently undertaking a Higher Degree by Research which will be conferred after 1 January 2018; AND
• at F6 indicated that they would hold either:
- an appointment at an Eligible Organisation equal or greater than 0.2FTE; OR
- Emeritus appointment at an Eligible Organisation

This is a 'Yes' or 'No' question. If you select 'Yes', you will be further prompted to justify your participation on this Proposal as a PI with reference to sections F7.2 and F7.3 of the Funding Rules. Click on the information icon for further information.)
Do you hold a remunerated appointment at an Eligible Organisation?

Justification of PI status

F8. Relevant Organisation for this Proposal

(Enter the Organisation that is relevant to your participation on this proposal, and that you will be associated with as at the Commencement Date for the Project (1 January 2018). The 'relevant organisation' is the primary organisation that will be supporting your involvement in this Project if it is funded. Note that the Organisation must be listed in F6 for this question to validate.)

Relevant Organisation

RWTH Aachen University of Technology, Germany

F9. What is your time commitment to this Project?

(Enter your time commitment to this Project as a Full-Time Equivalent (FTE). Note that a FTE of 1.0 represents a full-time commitment (i.e. 5 days per week).)

0.2

F10. Are you applying for Teaching Relief?

(This is a 'Yes' or 'No' question.

• If you answer 'Yes' to this question a budget line will be automatically populated for the Teaching Relief in the budget table in Form Part D: Project Cost. This will allow you to enter the funding amount requested in the relevant year/s. To remove the Teaching Relief from the budget table you must return to this question and answer 'No'.

• Note: CIs may request funding for teaching relief or other duties in order to maximise the opportunity for the CI to conduct research. This question is only relevant for CIs and will not be activated for PIs. If the answer to this question is 'yes', the budget table in 'Project Costs' will automatically update with a line to add costs for Teaching Relief.)

F11. Are you applying for a Discovery International Award?

(This is a 'Yes' or 'No' question. If you answer 'Yes' to this question a budget line will be automatically populated for the DIA in the budget table in Form Part D: Project Cost. This will allow you to enter the funding amount requested in the relevant year/s. To remove the DIA from the budget table you must return to this question and answer 'No'. Click on the information icon for further information.)

No

F12. Research Opportunity and Performance Evidence (ROPE) - Details of your career and opportunities for research

(Write a maximum of 5250 characters (approximately 750 words). Please detail your career and opportunities.)

i) NUMBER OF YEARS SINCE HIGHEST EDUCATIONAL QUALIFICATION
Prof Lakemeyer received his PhD in Computer Science from the University of Toronto 27 years ago, in 1990.

ii) RESEARCH OPPORTUNITIES IN THE CONTEXT OF EMPLOYENT SITUATION
Over the past 20 years Lakemeyer has been employed as Professor of Computer Science (with tenure) at RWTH Aachen University, where he heads the Knowledge-Based Systems Group. In the past 15 years he has also visited the Department of Computer Science, University of Toronto, regularly (about one month per year), where he collaborates with Prof. Hector J. Levesque and Prof. Sheila McIlraith. In 2013 he was appointed Professor (status-only) at the Department of Computer Science, University of Toronto.

Over the past 10 years he has received research grants from the European Union and the German Science Foundation (DFG) in the order of $5.8 Million. Currently he is also the Chair of the DFG Research Unit "Hybrid Reasoning for Intelligent Systems" (FOR 1513) with partners from six universities in Germany and 10 Ph.D. students and 2 Post-Docs. He was also the PI of a DAAD-Go8 project, which he led together with CI Pagnucco, and he is currently a PI on the ARC grant DP150103034 with CIs Pagnucco and Thielscher and PI Schaub.

iii) EMPLOYMENT FRACTIONS
His duties at RWTH Aachen University include research (45%), teaching (40%), and administrative duties (15%). Since 2000 he has been the Graduate Coordinator of the International Master Program "Software Systems Engineering" at RWTH Aachen University.

iv) CAREER INTERRUPTIONS
n/a

v) RESEARCH MENTORING AND RESEARCH FACILITIES AVAILABLE
RESEARCH MENTORING:
Lakemeyer has benefited from mentoring from leading researchers in Australia, in particular, Prof. Maurice Pagnucco and Prof. Michael Thielscher, both at UNSW. He was mentored by his PhD supervisor Hector Levesque, one of the most eminent AI researchers internationally at the University of Toronto.

FACILITIES:

RWTH Aachen University is one of eleven "Excellence Universities" in Germany and the Computer Science Department has ranked among the top three CS Departments in Germany for the past 15 years. RWTH Aachen University has extensive research facilities to which I have full access to. As part of research mentoring the Computer Science Department at RWTH Aachen University holds a 2-day retreat every year. Research facilities in Lakemeyer's own lab include 15 workstations and several robotic platforms, including a wheeled service robot operating in a home environment, a FESTO Robotino 3 mobile robot, and 2 Jaco robotic arms.

vi) OTHER ASPECTS OF CAREER OR OPPORTUNITIES FOR RESEARCH
Lakemeyer is currently the President of the European Association for Artificial Intelligence.

F13. Research Opportunity and Performance Evidence (ROPE) - Significant research outputs and ARC grants

(Upload a PDF of no more than four A4 pages with a list of all research outputs, such as journal articles and refereed conference papers, book and book chapters. Use asterisks to identify research outputs relevant to this Proposal. Click on the information icon or refer to the Instructions to Applicants for the required content and formatting.)

Uploaded PDF file follows on next page.

F13 SIGNIFICANT RESEARCH OUTPUTS

i) Significant Research Outputs

Scholarly Books

1. Hector J.Levesque and **Gerhard Lakemeyer** (2001). The Logic of Knowledge Bases. MIT Press.

Refereed Journal Articles

2. *V. Belle and **G. Lakemeyer** (2015) Semantical considerations on multiagent only knowing. *Artificial Intelligence*, **223**: 1–26. [ERA: **A***/CORE: **A***]

3. V. Belle and Gerhard Lakemeyer (2014). Multiagent Only Knowing in Dynamic Systems. *Journal of Artificial Intelligence Research (JAIR)*, **49**, 363–402.

4. *G. Rens, T. Meyer, and **G. Lakemeyer** (2014). SLAP: Specification logic of actions with probability. *J. Applied Logic*, **12**(2), 128–150.

5. T. Goeckel, H. Führ, **G. Lakemeyer**, and H. Wagner (2014). Side peak suppression in responses of an across-frequency integration model to stimuli of varying bandwidth as demonstrated analytically and by implementation. *Journal of Computational Neuroscience*, **36**(1), 1–17.

6. *A. Küstenmacher, N. Akhtar, P. Plger, and **G. Lakemeyer** (2014). Towards Robust Task Execution for Domestic Service Robots. *Journal of Intelligent and Robotic Systems*, **76**(1), 5–33.

7. *Daniel Beck, and **Gerhard Lakemeyer** (2012). Reinforcement learning for Golog programs with first-order state-abstraction. *Logic Journal of the IGPL*, **20**(5):909–942.

8. *Stefan Schiffer, Alexander Ferrein, and **Gerhard Lakemeyer** (2012). Caesar: An Intelligent Domestic Service Robot. *Intelligent Service Robotics*, **5**(4):259–273.

9. *Stefan Schiffer, Alexander Ferrein, and **Gerhard Lakemeyer** (2012). Reasoning with Qualitative Positional Information for Domestic Domains in the Situation Calculus. *Journal of Intelligent and Robotic Systems*, **66**(1-2):273–300.

10. *Jens Claßen, Gabriele Röger, **Gerhard Lakemeyer**, and Bernhard Nebel (2012). Platas—Integrating Planning and the Action Language Golog. *Künstliche Intelligenz (KI)*, **26**(1):61–67.

11. ***Gerhard Lakemeyer**, and Hector J. Levesque (2011). A Semantic Characterization of a Useful Fragment of the Situation Calculus with Knowledge. *Artificial Intelligence*, **175**(1):142–164. [ERA: **A***]

12. **Gerhard Lakemeyer** (2010). The Situation Calculus: A Case for Modal Logic. *Journal of Logic, Language and Information*, **19**(4): 431–450.

13. Yongmei Liu, and **Gerhard Lakemeyer** (2008). On the Expressiveness of Levesque's Normal Form. *Journal of Artificial Intelligence Research (JAIR)*, **31**:259–272. [ERA: **A**]

14. *Alexander Ferrein, and **Gerhard Lakemeyer** (2008). Logic-based Robot Control in Highly Dynamic Domains. *Robotics and Autonomous Systems*, **56**(11):980–991. [ERA: **A**]

Refereed Conference Papers

15. C. Schwering, and **G. Lakemeyer** (2016). Decidable Reasoning in a First-Order Logic of Limited Conditional Belief. *Proceedings of the European Conference on Artificial Intelligence (ECAI)*, 1379 -1387.

16. *G. Gierse, T. Niemueller, J. Claßen, and **G. Lakemeyer** (2016). Interruptible Task Execution with Resumption in Golog. *Proceedings of the European Conference on Artificial Intelligence (ECAI)*, 1265–1273.

17. V. Belle, **G. Lakemeyer**, H. J. Levesque (2016). A First-Order Logic of Probability and Only Knowing in Unbounded Domains. *Proceedings of the AAAI Conference on Artificial Intelligence*, 893–899.

18. *T. Hofmann, T. Niemueller, J. Claßen, and **G. Lakemeyer** (2016). Continual Planning in Golog. *Proceedings of the AAAI Conference on Artificial Intelligence*, 3346–3353.

19. **G. Lakemeyer**, H. J. Levesque (2016). Decidable Reasoning in a Logic of Limited Belief with Function Symbols. *Proceedings of the International Conference on Knowledge Representation and Reasoning (KR)*, 288–297.

20. V. Belle and **G. Lakemeyer**, Only Knowing Meets Common Knowledge (2015). *Proceedings of the International Joint Conference on Artificial Intelligence (IJCAI)*, 2755–2761.

21. *Ch. Schwering, **G. Lakemeyer**, and M. Pagnucco (2015). Belief Revision and Progression of Knowledge Bases in the Epistemic Situation Calculus. *Proceedings of the International Joint Conference on Artificial Intelligence (IJCAI)*, 3214–3220.

22. *Ch. Schwering and **G. Lakemeyer** (2015). Projection in the Epistemic Situation Calculus with Belief Conditionals. *Proceedings of the AAAI Conference on Artificial Intelligence*.

23. *Ch. Schwering and **G. Lakemeyer** (2014). A Semantic Account of Iterated Belief Revision in the Situation Calculus. *Proceedings of the European Conference on Artificial Intelligence (ECAI)*.

24. ***G. Lakemeyer** and H. J. Levesque (2014). Decidable Reasoning in a Fragment of the Epistemic Situation Calculus. *Proceedings of the International Conference on Knowledge Representation and Reasoning (KR)*.

25. V. Belle and **G. Lakemeyer** (2014). On the Progression of Knowledge in Multiagent Systems. *Proceedings of the International Conference on Knowledge Representation and Reasoning (KR)*.

26. * J. Claßen, M. Liebenberg, G. Lakemeyer, and B. Zarrieß (2014). Exploring the Boundaries of Decidable Verification of Non-Terminating Golog Programs. *Proceedings of the AAAI Conference on Artificial Intelligence*, 1012–1019.

27. *Gavin Rens, Thomas Meyer, and **Gerhard Lakemeyer** (2013). A Logic for Specifying Stochastic Actions and Observations. *Proceedings of the International Symposium on Foundations of Information and Knowledge Systems (FoIKS)*, Bordeaux, France, pages 305–323.

28. *Alexander Ferrein, Tim Niemueller, Stefan Schiffer, and **Gerhard Lakemeyer** (2013). Lessons Learnt from Developing the Embodied AI Platform CAESAR for Domestic Service Robotics. *AAAI Spring Symposium: Designing Intelligent Robots*.

29. *Tim Niemueller, and **Gerhard Lakemeyer**, Alexander Ferrein (2013). Incremental Task-Level Reasoning in a Competitive Factory Automation Scenario. *AAAI Spring Symposium: Designing Intelligent Robots*.

30. ***Gerhard Lakemeyer**, and Hector J. Levesque (2013). Decidable Reasoning in a Logic of Limited Belief with Introspection and Unknown Individuals. *Proceedings of the International Joint Conference on Artificial Intelligence (IJCAI)*. [ERA: **A**/CORE: **A***]

31. Tim Niemueller, Daniel Ewert, Sebastian Reuter, Ulrich Karras, Alexander Ferrein, Sabina Jeschke, and **Gerhard Lakemeyer** (2013). Towards Benchmarking Cyber-Physical Systems in Factory Automation Scenarios. *Künstliche Intelligenz (KI)*, pages 296–299.

32. Hector J. Levesque, and **Gerhard Lakemeyer** (2012). The Truth about Defaults. *Correct Reasoning*, pages 422–435.

33. **Gerhard Lakemeyer** (2012). Multi-agent Only-Knowing. *International Workshop on Computational Logic in Multi-Agent Systems (CLIMA)*, 25.

34. Daniel Beck, and **Gerhard Lakemeyer** (2012). Representing Value Functions with Recurrent Binary Decision Diagrams. *Proceedings of the European Conference on Artificial Intelligence (ECAI)*, pages 139–144. [ERA: **A**/CORE: **A**]

35. **Gerhard Lakemeyer**, and Yves Lespérance (2012). Efficient Reasoning in Multiagent Epistemic Logics. *Proceedings of the European Conference on Artificial Intelligence (ECAI)*, pages 498–503. [ERA: **A**/CORE: **A**]

36. *Stefan Schiffer, Niklas Hoppe, and **Gerhard Lakemeyer** (2012). Flexible Command Interpretation on an Interactive Domestic Service Robot. *Proceedings of the International Conference on Agents and and Artificial Intelligence (ICAART)*, (1), pages 26–35.

37. *Tim Niemueller, **Gerhard Lakemeyer**, and Siddhartha S. Srinivasa (2012). A generic robot database and its application in fault analysis and performance evaluation. *International Conference on Intelligent Robots and Systems (IROS)*, pages 364–369. [ERA: **A**]

38. *Christoph Schwering, Daniel Beck, Stefan Schiffer, and **Gerhard Lakemeyer** (2012). Plan Recognition by Program Execution in Continuous Temporal Domains. *Künstliche Intelligenz (KI)*, pages 156–167.

39. **Gerhard Lakemeyer**, and Hector J. Levesque (2012). Only-Knowing Meets Nonmonotonic Modal Logic. *Proceedings of the International Conference on Knowledge Representation and Reasoning (KR)*. [ERA: **A**/CORE: **A***]

40. *Gavin Rens, **Gerhard Lakemeyer**, and Thomas Meyer (2012). A Logic for Specifying Agent Actions and Observations with Probability. *Proceedings of the Starting AI Researchers' Symposium (STAIRS)*, pages 252–263.

41. *Vaishak Belle, and **Gerhard Lakemeyer** (2011). A Semantical Account of Progression in the Presence of Uncertainty. *Proceedings of the AAAI Conference on Artificial Intelligence*. [ERA: **A**/CORE: **A***]

42. *Stefan Schiffer, Alexander Ferrein, and **Gerhard Lakemeyer** (2011). Fuzzy Representations and Control for Domestic Service Robots in Golog. *International Conference on Intelligent Robotics and Applications (ICIRA)*, (2), pages 241–250.

43. *Stefan Schiffer, Tobias Baumgartner, **Gerhard Lakemeyer** (2011). A Modular Approach to Gesture Recognition for Interaction with a Domestic Service Robot. *International Conference on Intelligent Robotics and Applications (ICIRA)*, (2), pages 348–357.

44. Vaishak Belle, **Gerhard Lakemeyer** (2011). On Progression and Query Evaluation in First-Order Knowledge Bases with Function Symbols. *Proceedings of the International Joint Conference on Artificial Intelligence (IJCAI)*, pages 744–749. [ERA: **A**/CORE: **A***]

45. Vaishak Belle, **Gerhard Lakemeyer** (2010). Reasoning about Imperfect Information Games in the Epistemic Situation Calculus. *Proceedings of the AAAI Conference on Artificial Intelligence*. [ERA: **A**/CORE: **A***]

46. Dominik Schmitz, Thomas Arzdorf, Matthias Jarke, **Gerhard Lakemeyer** (2010). Analyzing Agent-Based Simulations of Inter-organizational Networks. *International Workshop on Agents and Data Mining Interaction (ADMI)*, pages 87–102.

47. *Jens Claßen, **Gerhard Lakemeyer** (2010). On the Verification of Very Expressive Temporal Properties of Non-terminating Golog Programs. *Proceedings of the European Conference on Artificial Intelligence (ECAI)*, pages 887–892. [ERA: **A**/CORE: **A**]

48. Vaishak Belle, **Gerhard Lakemeyer** (2010). Multi-Agent Only-Knowing Revisited. *Proceedings of the International Conference on Knowledge Representation and Reasoning (KR)*. [ERA: **A**/CORE: **A***]

49. Tim Niemller, Alexander Ferrein, Daniel Beck, **Gerhard Lakemeyer** (2010). Design Principles of the Component-Based Robot Software Framework Fawkes. *Proceedings of the International Conference on Simulation, Modelling, and Programming for Autonomous Robots (SIMPAR)*, pages 300–311.

50. **Gerhard Lakemeyer**, Hector J. Levesque (2009). A Semantical Account of Progression in the Presence of Defaults. *Conceptual Modelling: Foundation and Applications - Essays in Honor of John Mylopoulos*, pages 82–98.

51. *Alexander Ferrein, Stefan Schiffer, **Gerhard Lakemeyer** (2009). Embedding fuzzy controllers in golog. *International Conference on Fuzzy Systems (FUZZ-IEEE)*, pages 894–899. [ERA: **A**/CORE: **A**]

52. **Gerhard Lakemeyer**, Hector J. Levesque (2009). A Semantical Account of Progression in the Presence of Defaults. *Proceedings of the International Joint Conference on Artificial Intelligence (IJCAI)*, pages 842–847. [ERA: **A**/CORE: **A***]

53. *Yongmei Liu, **Gerhard Lakemeyer** (2009). On First-Order Definability and Computability of Progression for Local-Effect Actions and Beyond. *Proceedings of the International Joint Conference on Artificial Intelligence (IJCAI)*, pages 860–866. [ERA: **A**/CORE: **A***]

54. *Stefan Jacobs, Alexander Ferrein, Stefan Schiffer, Daniel Beck, **Gerhard Lakemeyer** (2009). Robust Collision Avoidance in Unknown Domestic Environments. *Papers from the annual RoboCup International Symposium*, pages 116–127. [ERA: B/CORE: B]

55. Tim Niemller, Alexander Ferrein, **Gerhard Lakemeyer** (2009). A Lua-based Behavior Engine for Controlling the Humanoid Robot Nao. *Papers from the annual RoboCup International Symposium*, pages 240–251. [ERA: B/CORE: B]

56. Aristama Roesli, Dominik Schmitz, **Gerhard Lakemeyer**, Matthias Jarke (2008). Modelling Actor Evolution in Agent-Based Simulations. *International Workshop on Organized Adaption in Multi-Agent Systems (AAMAS-OAMAS)*, pages 126–144.

57. Alexander Ferrein, Stefan Schiffer, **Gerhard Lakemeyer** (2008). A Fuzzy Set Semantics for Qualitative Fluents in the Situation Calculus. *International Conference on Intelligent Robotics and Applications (ICIRA)*, (1), pages 498-509.

58. Matthias Jarke, Ralf Klamma, **Gerhard Lakemeyer**, Dominik Schmitz (2008). Continuous, Requirements-Driven Support for Organizations, Networks, and Communities. *Proceedings of the International i* Workshop (iStar)*, pages 47–50.

59. *Christoph Mies, Alexander Ferrein, **Gerhard Lakemeyer** (2008). Repairing Decision-Theoretic Policies Using Goal-Oriented Planning. *Künstliche Intelligenz (KI)*, pages 267–275.

60. *Jens Claßen, **Gerhard Lakemeyer** (2008). A Logic for Non-Terminating Golog Programs. *Proceedings of the International Conference on Knowledge Representation and Reasoning (KR)*, pages 589–599. [ERA: **A**/CORE: **A***]

61. *Stavros Vassos, **Gerhard Lakemeyer**, Hector J. Levesque (2008). First-Order Strong Progression for Local-Effect Basic Action Theories. *Proceedings of the International Conference on Knowledge Representation and Reasoning (KR)*, pages 662–672. [ERA: **A**/CORE: **A***]

ii) ARC grants awarded in the last 10 years and associated outputs

DP150103034	Prof M. Thielscher, Prof M. Pagnucco, Prof T.Schaub, **Prof G. Lakemeyer**	$ 419,900	3	Representation and Reasoning for Cognitive Personal Robots	21

F14. Research Opportunity and Performance Evidence (ROPE) - Ten career-best research outputs

(Please upload a PDF with a list of your ten career-best research outputs, with a brief paragraph for each research output explaining its significance (five pages maximum).)

Uploaded PDF file follows on next page.

F14 TEN CAREER-BEST RESEARCH OUTPUTS

ERA ranking: journals (A*, A, B, C); conferences (A, B, C)
CORE ranking: journals (A*, A, B, C); conferences (A+, A, B, C)

1. *W. Burgard, A. B. Cremers, D. Fox, D. H¨ahnel, **G. Lakemeyer**, D. Schulz,W. Steiner, and S. Thrun (1998). Experiences with an interactive museum tour-guide robot. Artificial Intelligence, 114(1): 3–55. [ERA: A*/CORE: A*]

A landmark paper that describes the first mobile robot where the action programming language Golog was deployed. The conference version of the paper won the AAAI 2016 Classic Paper Award. 840 citations; 608 for the conference version.

2. *A. Ferrein and **G. Lakemeyer** (2008). Logic-based robot control in highly dynamic domains. Robotics and Autonomous Systems, 56(11): 980–991. [ERA: A/CORE: A]

The paper describes the robot programming language Readylog developed for the control of mobile robots. The language supports stochastic actons and decision-theoretic planning, among other things. 77 citations.

3. *H. Levesque and **G. Lakemeyer** (2007). Cognitive robotics. Handbook of Knowledge Representation, Elsevier, pages 869–886.]

The paper gives the first overview of the logic-based account of cognitive robotics. 84 citations.

4. ***G. Lakemeyer** and H. J. Levesque (2011). A Semantic Characterization of a Useful Fragment of the Situation Calculus with Knowldge. Artificial Intelligence, 175(1): 142–164. [ERA: A*/CORE: A*]

The paper introduces a modal variant of the situation calculus. 32 citations.

5. V. Belle and **G. Lakemeyer** (2015) Semantical considerations on multiagent only knowing. Artificial Intelligence, 223: 1–26. [ERA: A*/CORE: A*]

The first paper to give a logical account of multi-agent only-knowing in a first-order setting. 1 citation.

6. J. Y. Halpern and **G. Lakemeyer** (2001). Multi-Agent Only Knowing. Journal of Logic and Computation, 11(1): 41–71. [ERA: A/CORE: A]

The first paper to give a logical account of propositional multi-agent only-knowing. 78 citations.

7. J. Y. Halpern and **G. Lakemeyer** (1995). Levesque's Axiomatization of Only Knowing is Incomplete. Artificial Intelligence, 74(2): 381–387. [ERA: A*/CORE: A*]

The paper solves a long-standing question about the logic of only-knowing proposed by Levesque. 31 citations.

8. *Y. Liu and **G. Lakemeyer** (2009). On First-Order Definability and Computability of Progression for Local-Effect Actions and Beyond. Proceedings of the International Joint Conference on Artificial Intelligence (IJCAI), pages 860–866.[ERA: A/CORE:A*]

The paper describes an important class of action theories which can be progressed effectively. 39 citations

9. *J. Claßen and **G. Lakemeyer** (2008). A Logic for Non-Terminating Golog Programs. Proceedings of the International Conference on Knowledge Representation and Reasoning (KR), AAAI Press, pages 589–599.[ERA: A/CORE: A*]

The paper describes, for the first time, how to specify the verification of temporal properties of non-terminating Golog programs within a logic. 49 citations.

10. *J. Claßen, P. Eyerich, **G. Lakemeyer**, and B. Nebel (2007). Towards an Integration of Golog and Planning. Proceedings of the International Joint Conference on Artificial Intelligence (IJCAI), pages 1846–1851. [ERA: A/CORE: A*]

The paper shows how to combine the action language Golog with state-of-the-art planners. 41 citations.

F15. Research Opportunity and Performance Evidence (ROPE) - Further evidence in relation to research impact and contributions to the field, including those most relevant to this Proposal

(Write a maximum of 11250 characters (approximately 1500 words). Detail further evidence in relation to research impact and contributions to the field. Click on the information icon and refer to the Instructions to Applicants for the required content and formatting.)

RESEARCH IMPACT: CONTRIBUTIONS SPECIFIC TO THE PROPOSAL

Professor Lakemeyer is a leading international scientist in the area of knowledge representation and reasoning (KR&R), a sub-field of Artificial Intelligence, and their application to the control of autonomous robots (cognitive robotics). He has already successfully collaborated with Prof. Pagnucco in the context of a Go8-DAAD grant in 2013-2014 and as PI of the ARC grant DP150103034.

Regarding this proposal, the following contributions will be of benefit:

REASONING ABOUT ACTION AND CHANGE:
For more than 20 years Lakemeyer has developed variants and extensions of the robot programming language Golog, which was originally proposed by Hector Levesque and the late Ray Reiter at the University of Toronto. Key extensions include decision-theoretic planning tailored towards highly dynamic domains (F14,No.2) and the incorporation of classical planning techniques into Golog (F14,No.10). Moreover, Lakemeyer also addressed the problem of verifying temporal properties of Golog programs (F14,No.9). Lakemeyer has also contributed to the foundations of reasoning about action and change by giving a semantical account of the situation calculus (F14,No.4), considering a form of tractable reasoning in the situation calculus (F13,No.24), and developing effective forms of progressing (updating) a knowledge base as a result of actions (F14,No. 8;F13,No. 61).

HIGH-LEVEL CONTROL OF MOBILE ROBOTS/COGNITIVE ROBOTICS:
Besides the foundational work on reasoning about action and change Lakemeyer has a long history of applying logic-based techniques to the high-level control of mobile robots, beginning with the seminal museum tour-guide robot RHINO, which was the first robot controlled by Golog. (The publication based on this project (F14,No.1) won the AAAI 2016 Classic Paper Award in recognition of the impact the paper has had on the field of Artificial Intelligence and Robotics.) This work was instrumental in establishing the field of cognitive robotics in the sense of developing formal, logic-based underpinnings of robot control (F14,No. 3).
In 2006 and 2007 Lakemeyer and his team became world champions in the Robocup@Home League, where service robots interact with humans in a home environment (F13,No.8). More recently, in 2014, 2015, and 2016, Lakemeyer and his team became world champions in the Robocup Logistics League (RCLL), where teams of robots compete in production logistics scenarios (F13,No.29). Again, the focus of the work has been on high-level control, especially regarding online planning interleaved with execution and monitoring. Lakemeyer's team also developed a simulation environment for the RCLL to be used as part of a benchmark competition at the International Conference on Automated Planning and Scheduling (ICAPS).

RESEARCH IMPACT: CONTRIBUTIONS TO THE FIELD:

Besides the areas mentioned above, Lakemeyer has made significant contributions to the following areas:

LIMITED REASONING:
Starting with his Ph.D. thesis at the University of Toronto, Lakemeyer, together with his co-worker and former advisor Hector J. Levesque, has significantly advanced the state of the art in semantical approaches to limited and often tractable reasoning in expressive knowledge bases. Recent work along these lines includes (F13,No. 15,19,24,30,35).

THE LOGIC OF KNOWLEDGE BASES:
For many years, Lakemeyer has explored, again in collaboration with Levesque, the logic behind what a fully introspective knowledge base knows. Early work on this topic was summarized in the book "The Logic of Knowledge Bases" (F13,No. 1). Fundamental to this work is the concept of only-knowing, which was explored and analyzed in a number of publications, including (F14,No. 5,6,7;F13, No. 17,20,25,32,39,50).

The impact of Lakemeyer's work is evidenced by numerous publications in both top-rated journals and conferences. The journals include "Artificial Intelligence" and "The Journal of Artificial Intelligence Research," which are regarded as the leading journals in the field of artificial intelligence. The conferences include the International Joint Conference on Artificial Intelligence (IJCAI), the Conference of the Association for the Advancement of Artificial Intelligence (AAAI), the European Conference on Artificial Intelligence (ECAI), and the International Conference on Knowledge Representation and Reasoning (KR). Again, these are regarded as the

top venues for research in Artificial Intelligence and KR&R. Overall, Lakemeyer's publications have received 4684 citations with an h-index of 32 (Google Scholar, February 27, 2017).

Lakemeyer received four best paper awards, most recently in 2016, when he was the recipient of the AAAI Classic Paper Award for a paper which originally appeared at AAAI in 1998.

His group won the world championship in Robocup@Home in 2005 and 2006, and the world championship in the Robocup Logistics League in 2014, 2015, and 2016. (Robocup@Home and the Robocup Logistics League are disciplines within the Robocup Federation, where robots from all over the world compete in tasks involving service robots in home environments and production logistics scenarios, respectively.)

Lakemeyer is Associate Editor of the Journal Artificial Intelligence (AIJ) (since 2011), and a member of the Editorial Board of Computational Intelligence (since 2007) and the Journal of Applied Logic (since 2005). He was a member of the Editorial Board, Associate Editor, and member of the Advisory Board of the Journal of Artificial Intelligence Research (JAIR) (1999-2011).

He is the Chair of the Cognitive Robotics Steering Committee (since 2000).

He was Program co-Chair of the German Conference on Artificial Intelligence (2002), Robocup (2006) and Commonsense (2009). He also served as Area Chair for IJCAI, AAAI, and ECAI. Moreover, he has been a member of the program committee of these and numerous other international conferences and workshops.

Since 2009 he is a Fellow of the European Association for Artificial Intelligence (EurAI). Since 2012 he also serves on the Board and since 2016 he is the President of the European Association for Artificial Intelligence.

F16. Currently held ARC Projects

(This information is auto-populated from your RMS profile and will include any 'active' Project which has not yet had a Final Report approved and the Project file closed by the ARC. If you have any concerns with the information recorded here, contact your Administering Organisation's Research Office. NOTE: If you hold a CI or a PI role on the Project/s listed in the table below you must ensure a progress statement is provided in G2. This requirement applies to the following schemes: Discovery Projects, Discovery Indigenous Researchers Development, Discovery Indigenous, Discovery Early Career Researcher Award, Linkage Projects, Industrial Transformation Research Hubs, Industrial Transformation Training Centres or any ARC Fellowship scheme. Please click on the information icon and refer to the Instructions to Applicants for further information.)

Identifier	Scheme Name	Investigators	Admin Organisation	Project Title	Funding	End Date
DP150103034	DP 2015 R1	Prof Michael Thielscher ; Prof Maurice Pagnucco ; Prof Dr Torsten Schaub ; Prof Dr Gerhard Lakemeyer	The University of New South Wales	Representation and Reasoning for Cognitive Personal Robotics	$419,900	31/12/2017

Part G - Research Support and Statements on Progress (DP180101103)

G1. Research support for all Participants

(For each participant on this Proposal, provide details of:
i) current submitted ARC proposals (i.e. for which the outcome has not yet been announced);
ii) any newly funded ARC Projects which are not yet showing in the Participant's question (Currently held ARC Projects); and
iii) research funding from non-ARC sources (in Australia and overseas). For research funding from non-ARC sources, list all projects/proposals/awards/fellowships awarded or requests submitted involving that participant for funding for the years 2017 to 2022 inclusive.)

Uploaded PDF file follows on next page.

G1: Research support for all Participants

Current ARC Proposals and newly funded ARC Projects which are not yet active									
Description (all named investigators on any proposal or grant/ project/ fellowship in which a Participant is involved, project title, source of support, scheme and round)	**Same Research Area** (Yes/No)	**Support Status** (Requested/Current/Past)	**Proposal / Project ID**	**2017** ($'000)	**2018** ($'000)	**2019** ($'000)	**2020** ($'000)	**2021** ($'000)	**2022** ($'000)
Prof Maurice Pagnucco, **A/Prof Mari Velonaki**, **Prof Claude Sammut, Prof Katsumi Watanabe, Prof Dr Gerhard Lakemeyer.** *Learning Ethical Behaviours by Demonstration in Social Robot.* Australian Research Council (ARC), Discovery Project, 2018.	Y	R	DP18010 1103		239	244	256		
Prof Dennis Del Favero, **Prof Maurice Pagnucco,** Dr Sussane Thurow, Prof Peter Weibel, Prof Jeffrey Shaw. *Reformulating visual narrative in art using a cross-platform framework* Australian Research Council (ARC), Discovery Project, 2018.	N	R	DP18010 2958		153	158	163		
Prof.Claude Sammut, Prof	N	R	DP18010 1208		190	195	200		

Ivan Bratko, Prof Stephen Muggleton. *Machine learning for programming autonomous systems operating in dynamic environments.* Australian Research Council (ARC), Discovery Project, 2018.									
Funding from non-ARC sources									
Description (all named investigators on any proposal or grant/ project/ fellowship in which a Participant is involved, project title, source of support, scheme and round)	**Same Research Area** (Yes/No)	**Support Status** (Requested/Current/Past)	**Proposal / Project ID**	**2017** ($'000)	**2018** ($'000)	**2019** ($'000)	**2020** ($'000)	**2021** ($'000)	**2022** ($'000)
Prof Mari Velonaki. *Robots in the office.* Fuji Xerox.	Y	C		120	120	120			
Prof Claude Sammut, **Prof Maurice Pagnucco**, Prof Travis Waller, Prof Dennis Del Favero, **A/Prof Mari Velonaki**, Prof Sarah Kenderdine, Dr Carol Oliver, Prof Marin Van Kranendonk, Prof Steven Sherwood, Prof Stephanie Hemlryk Donald, AProf Claudia Tazreiter.	Y	C		97					

Interdisciplinary Robotics and Visualisation Facilities. UNSW, Research Infrastructure Scheme: Supporting Collaborative Research, 2017.									
Prof Dennis Del Favero, Prof Sarah Kenderdine, **Prof Claud Sammut**, Dr Nalini Pather, Dr Carol Oliver. *Virtual Field Trips* UNSW, Strategic Education Fund Grant, 2016.	N	C		179.5					
Dr Bernhard Hengst, **A/Prof Maurice Pagnucco**, **Prof Claude Sammut,** Prof Michael Thielscher; Dr Nadine Marcus; Dr David Rajaratnam. *Autonomous Adaptation and Trust.* US Air Force Research Laboratory, Asian Office of Aerospace Research and Development (AOARD) 2014	Y	C		134					
A/Prof Maurice Pagnucco, A/Prof Mari Velonaki, A/Prof David Rye, Dr David	Y	C		137					

Silvera-Tawil. *Eliciting Emotions from Tactile Surfaces and Kinetic Agents.* US Air Force Research Laboratory, Asian Office of Aerospace Research and Development (AOARD) 2014									
Prof Katsumi Watanabe; Prof Makio Kashino, Prof Kimitaka Nakazawa, Prof Shinsuke. Shimojo. *Intelligent Information Processing Systems based on Implicit Ambient Surface Information.* Japan Science and Technology Agency Scheme: Core Research for Evolutionary Science and Technology Round: FY2014-FY2019	N	C		290	290	290			
Prof Katsumi **Watanabe**, Prof Roberto Caldara. *Tracing cultural diversity for the decoding of facial expressions of emotion: From visual intake to neural signature.* Japan Society for Promotion of Science, Joint	N	C		116	116	116			

Research Projects with SNSF Round: FY2017-FY2019									
Prof Alexander Ferrein **Prof Gerhard Lakemeyer,** *Constraint-based transformation of abstract plans into executable actions of autonomous robots.* DFG (German Science Foundation), DFG Project.	Y	C		220	220	220			
Prof Franz Baader, **Prof Gerhard Lakemeyer.** *Verification of non-terminating Golog programs.* DFG (German Science Foundation), Project within DFG Research Unit.	Y	C		220	220				
Prof Wolfram Burgard, **Prof Gerhard Lakemeyer,** Prof Bernhard Nebel. *Planning and Action Control under Uncertainty for Mobile Manipulation Tasks.* DFG (German Science Foundation), Project within DFG Research Unit.	Y	C		330	330				
Prof Claude	No	C		50					

Sammut. *Autonomous, Situation Aware Surface Vessels.* Innovations Connections (Partner: Ocius Technology).									

G2. Statements on Progress for ARC-funded Projects

(A progress statement must be provided for any currently funded ARC Project that involves a Participant on this Proposal as a CI or PI. This requirement only applies to funding held under the Discovery Projects, Discovery Indigenous Researchers Development, Discovery Indigenous, Discovery Early Career Researcher Award, Linkage Projects, Industrial Transformation Research Hubs, Industrial Transformation Training Centres or any ARC Fellowship scheme. Click on the information icon or refer to the Instructions to Applicants for further information.)

Project ID

DP150103034

First Named Investigator

Prof Michael Thielscher

Scheme

Discovery Projects

Statement

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Project ID: DP150103034 (2015 – 2017)

Project Title: Representing and Reasoning for Cognitive Personal Robotics

Investigators: Prof. Dr. Michael Thielscher, Prof. Maurice Pagnucco, Prof. Dr. Torsten Schaub, Prof. Dr. Gerhard Lakemeyer.

Project Description and Objectives

Robotic systems are becoming increasingly more sophisticated and prevalent. Developing complex and maintainable robot programs to control these systems remains a significant challenge particularly given the diversity of robot platforms and application areas. This project builds on advances in problem solving and programming paradigms in Artificial Intelligence, applying them to learning sophisticated robot programs. These techniques provide for elaboration tolerance, knowledge/program maintenance and optimisation of performance. The aim of the project is to develop techniques for building sophisticated declarative robot programs. It will achieve this by learning procedural robot programs and turning them into maintainable declarative robot programs.

Progress and Outcomes

This project was awarded at the end of 2014 and a research associate was employed early in 2015. Both PIs Profs Lakemeyer and Schaub have visited CIs Profs Thielscher and Pagnucco in February/March 2015 and 2016 to work on the project outcomes. The project is progressing as planned.

We have developed and implemented a cognitive robotic framework for the integration of symbolic and sub-symbolic representations within a cognitive hierarchy [2,3]. This framework addresses the problem of how to derive high-level facts and actions, suitable for the declarative representation of robot behaviours, from stochastic and noisy sensors and actuators. Importantly it provides a highly principled integration of declarative robot programs, such as the Golog programs being learned and refined as part of Task 1 of the project proposal, into research and commercial robot platforms. It is also the basis on which we have tightly coupled declarative Answer Set Programs (ASP) to provide high-level robot control [1] and to translate procedural robot programs into ASP, as outlined in Task 2.

The development of a domestic robot demonstrator, outlined in Task 4, continues with the acquisition of a Toyota Human Support Robot (HSR), to be delivered in April 2017. This robot was acquired through a competitive application process and is the platform that will be used as part of the recently established Robocup@Home Standard Platform League (SPL) competition. Human-robot interaction is a critical aspect of any general purpose domestic robot platform and we have extended the cognitive hierarchy with a notion of context [4] to provide the facilities to enable this level of rich interaction. Context allows higher level cognitive processes to directly influence the lower-levels, for example priming a recognition system to track human operator movements, and is therefore important in developing real-time human-robot interaction capabilities. This is also important to the on-going work, outlined in Task 3, of optimising robot behaviour using ASP robot programs.

CIs Profs Lakemeyer and Schaub are visiting in February/March 2017 to continue to work on the project. Further publications from this phase of the project are being planned.

Selected Publications

1. B. Andres, D. Rajaratnam, O. Sabuncu, T. Schaub: Integrating ASP into ROS for Reasoning in Robots. In: Proc. of the International Conference on Logic Programming and Nonmonotonic Reasoning (LPNMR), pp. 69-82, Lexington 2015.
2. K. Clark, B. Hengst, M. Pagnucco, D. Rajaratnam, P. Robinson, M. Thielscher, C. Sammut. A Framework for Integrating Symbolic and Sub-symbolic Representations. Proc. of the International Joint Conference on Artificial Intelligence (IJCAI), pp. 2486-2492, New York 2016.
3. D. Rajaratnam, B. Hengst, M. Pagnucco, M. Thielscher, C. Sammut. Composability in Cognitive Hierarchies. Proc. of the Australasian Conference on Artificial Intelligence (AI), pp. 42-55, Hobart 2016.
4. B. Hengst, M. Pagnucco, D. Rajaratnam, M. Thielscher, C. Sammut. Context in Cognitive Hierarchies. Submitted to: Proc. of the International Joint Conference on Artificial Intelligence (IJCAI), Melbourne. Submitted on 20 Feb 2017.

Project ID

DP120100332

First Named Investigator

Dr Sebastian Sardina

Scheme

Discovery Projects

Statement

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Project ID: DP120100332 (2012 – 2014)
Project Title: Optimisation of Embedded Virtual Systems by Re-using a Library of Available Components
Investigators: Dr Sebastian Sardina, A/Prof Maurice Pagnucco, Prof. Giuseppe De Giacomo.

Project Description and Objectives

This project aims at developing techniques for realising a complex virtual component (e.g., a smart house surveillance system) by suitably combining a set of available modules (e.g., cameras, blinds, phones, etc.). The project is significant in that it focusses on cases where perfect realisations are either impossible or too difficult to synthesise automatically, thus going beyond all existing techniques.

Progress and Outcomes

While the project suffered delays in its final year with the early departure of the research fellow, it is on track for completion in the first half of 2017. The project has been very successful and produced many outputs in high-quality scientific venues, notably: two articles in the *Artificial Intelligence Journal (AIJ)* (the top AI journal) and a best paper award at JELIA'12 conference. Overall, the project produced 15 articles exclusively in premier scientific outlets spanning several subareas of AI (e.g., IJCAI, AAAI, ICAPS and KR). The key technical contributions are:

- We showed, for the first time, a characterization of "best possible" solution for the composition task. The account is simple by relying on the well-known formal notion of simulation (JELIA'12).
- Against all our intuitions, we found that a solution is always unique (JELIA'12 and IJCAI'13).
- We developed an effective technique to compute the best possible solution that provides a complexity upper bound to the problem (IJCAI'13).
- We demonstrated experimentally that effective state-of-the-art planning techniques (a technology that has enjoyed remarkable advances in the last decade) can be applied to the composition problem (ICAPS'13).
- We adapted the composition framework to the manufacturing domain (IJCAI'16), in collaboration with researchers at the University of Nottingham, UK, involved in an EU project (see below).
- We found out that the ICAPS'13 approach to composition can be generalized beyond the problem itself, we developed a directed model-checking approach for solving *general* non-deterministic planning problems (ICAPS'14) that is able to compete with state-of-the-art planners.

More importantly, the project has led us to a new perspective and techniques on how to specify and build complex behaviours from primitive ones in terms of networks of goals, leading to an AIJ (2016) paper.

Work from the project has been cited in the large 2012-2018 EU project EP/K018205/1 "Evolvable Assembly Systems: Towards open, adaptable and Context-aware equipment and systems," (http://tinyurl.com/hmos9kt) which aims at developing highly adaptable manufacturing systems and includes 11 large industries such as Airbus, Siemens, and GE. The project states that it will resort to our synthesis techniques and extend (our) "agent composition approaches to incorporate task deadlines and priorities." A paper at IJCAI'16 on the topic was published with Dr. Brian Logan (University of Nottingham), one of the project's investigators.

Selected Publications

1. Felli, P., Yadav, N., and Sardina, S., Supervisory Control for Behavior Composition. IEEE Transactions on Automatic Control, **62**(2):986-991,2017.
2. De Giacomo, G., Gerevini, A., Patrizi, F., Saetti, A., and Sardina, S., Agent planning programs. Artificial Intelligence **231**:64-106, 2016.
3. Felli, P., Logan, B., and Sardina, S., Parallel Behavior Composition for Manufacturing, in Proceedings of the 25th International Joint Conference on Artificial Intelligence (IJCAI-16), pp. 271-278, 2016.
4. Sardina, S., and D'Ippolito, N., Towards Fully Observable Non-Deterministic Planning as Assumption-based Automatic Synthesis, in Proc. of the 24th Int. Joint Conference on Art. Int. (IJCAI-15), pp. 3200-3206, 2015.
5. De Giacomo, G., Patrizi, F., and Sardina, S., Building Virtual Behaviors from Partially Controllable Available Behaviors in Nondeterministic Environments, in Proceedings of the Twenty-Fourth International Conference on Automated Planning and Scheduling (ICAPS-14), 2014.
6. Yadav, N., Felli, P., De Giacomo, G., and Sardina, S., Supremal Realizability of Behaviors with Uncontrollable Exogenous Events, in Proc. of the 23rd Int. Joint Conf. on Art. Int., pp. 1176-1182, 2013.
7. De Giacomo, G., Patrizi, F., and Sardina., Automatic behavior composition synthesis, Artificial Intelligence **196**:106-142, 2013.
8. Ramírez, M., Yadav, N., and Sardina, S., Behavior Composition as Fully Observable Non-Deterministic Planning, in Proc. of the 23rd Int. Conference on Automated Planning and Scheduling (ICAPS-13), 2013.
9. Yadav, N., and Sardina, S., Qualitative Approximate Behavior Composition, in Proceedings of the 13th European Conference Logics in Artificial Intelligence (JAIR-12), pp. 450-462, 2012.

Project ID

DP130102351

First Named Investigator

Prof Claude Sammut

Scheme

Discovery Projects

Statement

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Project ID: DP130102351

Project Title: Learning and Planning with Qualitative Models

Investigators: Prof. Claude Sammut and Prof. Ivan Bratko

Project Description and Objectives

The project *Learning and Planning with Qualitative Models* is largely completed and has achieved its goal of developing a theory and implementation for a system that learns qualitative models to describe a robot's behaviours and uses these models to generate plans of actions to achieve given goals. The results have been published in the journal *Advances in Cognitive Systems* and the *Qualitative Reasoning Workshop* and the *Cognitive Systems Conferences*.

The actions of the plan are not immediately operational and must be refined by trial-and-error learning. However, the search space is greatly reduced by applying information from the qualitative actions as constraints on the search. The final stage of this project is now underway, namely, the implementation of the trial-and-error learning system and experimental evaluation. This is demonstrated on a rescue robot maintained in our lab.

Progress and Outcomes

An unexpected benefit of this work has been a demonstration of the use of Answer Set Programming (ASP) in qualitative modelling. The qualitative simulation, originally written in Prolog, was computationally very expensive. When the problem was reformulated as an ASP, we obtained very dramatic speed improvements. These results were presented at *AAAI* and *ECAI*.

CI Sammut used his study leave in October 2015 to visit PI Bratko in the University of Ljubljana and during that time, we were able to make substantial progress on the final stage. This follows a previous visit by PI Bratko to UNSW. Another visit by Bratko was scheduled in 2016 but he was unable to come to UNSW due to previously unplanned teaching commitments. We sought and received approval to convert the travel funds to buy spare parts for the Negotiator robot used in the experimental evaluation for the project. This turned out to be fortunate as we had a major breakdown the required custom parts to be sourced. This delayed the final experiments but they are now complete. Unfortunately, the delay also held up PhD candidate Timothy Wiley for several months but he will now submit his thesis no later than March 2017.

Publications

1. Wiley, T., Sammut, C., Hengst, B., and Bratko, I. (2016). A planning and learning hierarchy using qualitative reasoning for the on-line acquisition of robotic behaviors. *Advances in Cognitive Systems*, **4**:93–111.
2. Wiley, T., Sammut, C., Hengst, B., and Bratko, I. (2015). A multi-strategy architecture for on-line learning of robotic behaviours using qualitative reasoning. In *Proceedings of the Third Annual Conference on Advances in Cognitive Systems*, 1–16, Atlanta, USA
3. Wiley, T., C. Sammut and I. Bratko (2014). Qualitative planning with quantitative constraints for online learning of robotic behaviours. *AAAI Conference on Artificial Intelligence*, AI Access Foundation. **4:** 2578--2584.
4. Wiley, T., C. Sammut and I. Bratko (2014). Qualitative Simulation with Answer Set Programming. *European Conference on Artificial Intelligence*. Prague**:** 915 – 920.
5. Wiley, T., C. Sammut and I. Bratko (2013). Using Planning with Qualitative Simulation for Multi-Strategy Learning of Robotic Behaviours. *27th International Workshop on Qualitative Reasoning*. M. Bhatt, P. Struss and C. Freksa. Bremen**:** 24- –30.
6. Wiley, T., C. Sammut and I. Bratko (2013). Planning with Qualitative Models for Robotic Domains. *Second Annual Conference on Advances in Cognitive Systems*.

Project ID

DP120102144

First Named Investigator

Prof Michael Thielscher

Scheme

Discovery Projects

Statement

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Project ID: DP120102144 (2012 – 2015)
Project Title: *Representing and Reasoning About Ability for Robots to Use the Cloud*
Project Investigators: Professor Michael Thielscher, Professor Maurice Pagnucco, Professor Hector Levesque

The final report for this project was submitted to the ARC on 30/06/16

Project Aims:
The aim of this research project has been to develop formal techniques for representing and reasoning about robot abilities and to provide implementations of these techniques that enhance the facilities provided by cloud platforms and robot middleware. The expected research outcomes were: (1) develop languages for describing robot behaviours, problems, and goals to be achieved; (2) a logic of physical ability to reason about what a robot can immediately achieve; (3) a logic of epistemic ability to reason about what a robot knows and what it can achieve; (4) a high-level cognitive robotics language with beliefs so that the robot can develop plans that can be achieved using its abilities; (5) an abstract model of sensing that utilises the facilities provided by the cloud but hides this from the programmer; (6) the use of off-board and cloud-based reasoning resources. All objectives have been fully achieved.

Project to date agains Aims:
Objectives 2, 3 & 5: Reasoning about physical and epistemic ability, and models of sensing.

• Based on existing formalisms for logics of action, we have provided methods to enable a robot to reason introspectively about gaps in its knowledge and abilities [2]. This provides a formal framework for reasoning about robot abilities and a principled approach to the utilisation of cloud computing resources.

• We have developed an abstract model of sensing that includes a notion of forgetting [5]. Forgetting is critical to resource constrained agents (e.g., robots) when accessing large, cloud-based resources. We provide a systematic analysis of the conditions under which this form of forgetting is desirable and can be guaranteed.

Objectives 1, 4 & 6: Cognitive robotics language

• We have developed a practical implementation of belief change able to deal with mistaken or misleading information [1]. The formalism allows a robot to be imbued with a form of commonsense knowledge, providing flexible and robust behaviour in response to unexpected changes to its environment.

• We have extended existing *general-game-playing* methods to encompass *general-game-playing robots* [4]. Many robotic challenges have game-like properties, for example, where a robot is required to anticipate the behaviour of other participants. Furthermore, our extension allows the leveraging of existing general game playing technologies to provide external and cloud-based reasoning resources to the robot. Finally, we developed a robot *execution monitoring* framework that enables the use of the standard *game description language* to specify recovery strategies and behaviours that allow a robot to reason about and recover from errors and unexpected changes to its environment [7].

• We have integrated the reactive reasoning system *oClingo* with the popular robotic middleware *ROS* [3,6], allowing for the specification and control of robot behaviour in terms of high-level cognitive primitives.

Selected Publications:

1. M. Pagnucco, D. Rajaratnam, H. Strass, M. Thielscher. Implementing belief change in the situation calculus and an application. In: *Proc. of the International Conference on Logic Programming and Nonmonotonic Reasoning (LPNMR)*, pp. 219-232, Corunna 2013.
2. D. Rajaratnam, H. Levesque, M. Pagnucco, M. Thielscher. Reasoning about robot epistemic ability to use the cloud. In: *Proc. of the International Workshop on Nonmonotonic Reasoning, Action and Change at IJCAI (NRAC)*, pp. 37-44, Beijing 2013.
3. B. Andres, P. Obermeier, O. Sabuncu, T. Schaub, D. Rajaratnam. ROSoClingo: A ROS package for ASP-based robot control. In: *ICLP Workshop on Knowledge Representation and Reasoning in Robotics*, Istanbul 2013.
4. D. Rajaratnam and M. Thielscher. Towards general game-playing robots: models, architecture and game controller. In: *Proc. of the Australasian Joint Conference on AI*, pp. 271-276, Dunedin 2013.
5. D. Rajaratnam, H. Levesque, M. Pagnucco, M. Thielscher. Forgetting in action. In: *Proc. of the International Conference on Knowledge Represenation and Reasoning (KR),* pp. 498-507, Vienna 2014.
6. B. Andres, D. Rajaratnam, O. Sabuncu, T. Schaub. Integrating ASP into ROS for reasoning in robots. In: *Proc. of the International Conference on Logic Programming and Nonmonotonic Reasoning (LPNMR)*, pp. 69-82, Lexington 2015.
7. D. Rajaratnam, M. Thielscher. Execution monitoring as meta-games for general game-playing robots. In: *Proc. of the International Joint Conference on Artificial Intelligence (IJCAI),* pp. 3178-3185, Buenos Aires 2015.