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. <u>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.</u>

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 (∃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., $\varphi(s)$). 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

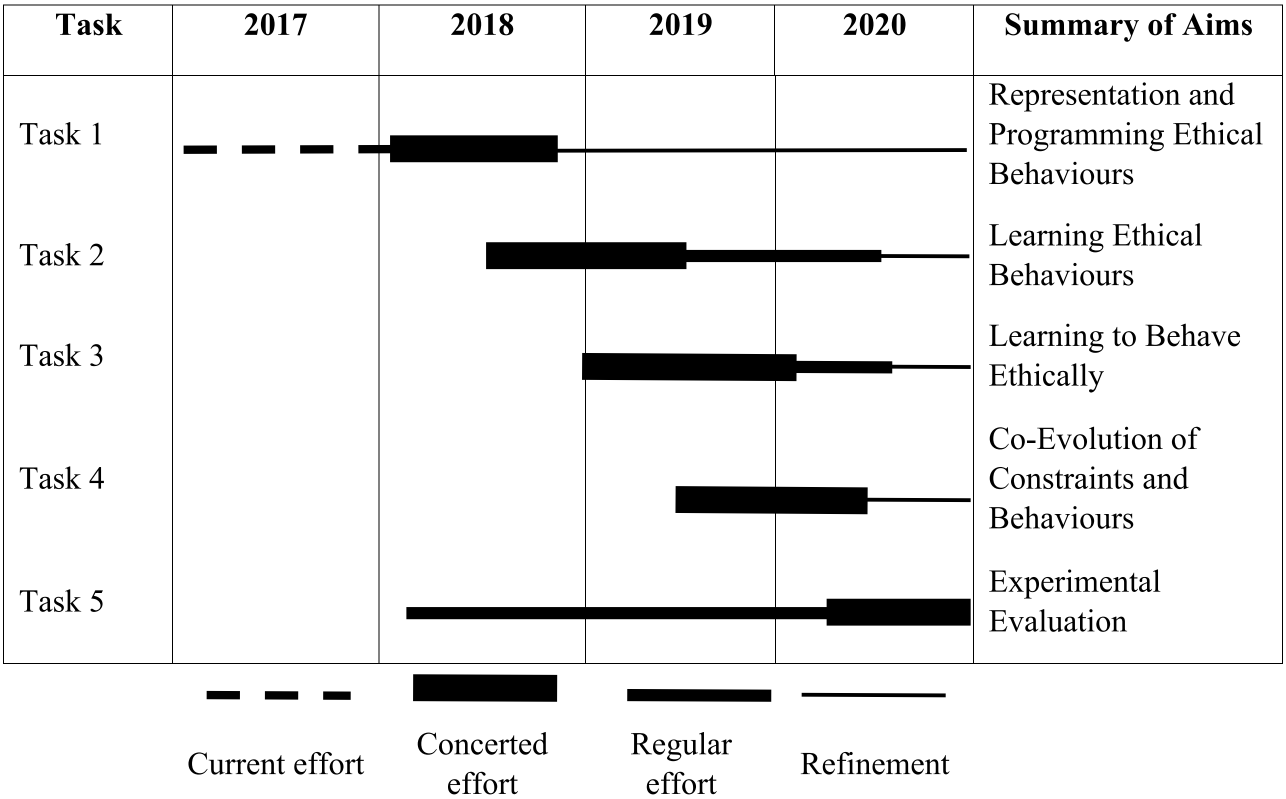
Intelligence and Image Processing (FoR 0801), the area of research relevant to this proposal, in the 2015 ERA Report.

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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