Robot Learning

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Creating autonomous robots that can learn to act in unpredictable environments has been a long-standing goal of robotics, artificial intelligence, and the cognitive sciences. In contrast, current commercially available industrial and service robots mostly execute fixed tasks and exhibit little adaptability. To bridge this gap, machine learning offers a myriad set of methods, some of which have already been applied with great success to robotics problems. As a result, there is an increasing interest in machine learning and statistics within the robotics community. At the same time, there has been a growth in the learning community in using robots as motivating applications for new algorithms and formalisms. Considerable evidence of this exists in the use of learning in high-profile competitions such as RoboCup and the Defense Advanced Research Projects Agency (DARPA) challenges, and the growing number of research programs funded by governments around the world. Additionally, the volume of research is increasing as shown by the number of learning papers accepted at the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) and the IEEE International Conference on Robotics and Automation (ICRA), and the corresponding number of learning sessions. The primary vision of our technical committee (TC) is as a focus for widely distributing technically rigorous results in all areas of robot learning. Without being exclusive, such areas of research interests include learning models of robots, task, or environments; learning deep hierarchies or levels of representations from sensor and motor to task abstractions; learning of plans and control policies by imitation and reinforcement learning; integrating learning with control architectures, methods for probabilistic inference from multimodal sensory information (e.g., proprioceptive, tactile, and vision), and structured spatiotemporal representations designed for robot learning such as low-dimensional embedding of movements. Examples are shown in this article. Figure 1 shows an example of a dynamic locomotion behavior learned by a robot dog by trial and error. Apprenticeship allows learning complex maneuvers for helicopters as exhibited in Figure 2. In Figure 3, we show how a motor skill can be learned by the combination of imitation and reinforcement learning.

As a result, there was a strong push toward creating a TC on robot learning (TCRL) of the IEEE Robotics and Automation Society (RAS). The TCRL was officially launched by the technical activities board on 22 May 2008 during the IEEE ICRA. The TC's organizational structure consists of the four chairs and a steering committee. The founding chairs are Nicholas Roy, Russ Tedrake [both from the Massachusetts Institute of Technology (MIT), Cambridge, MA], Jun Morimoto (ATR Department for Brain-Robot Interfaces, Kyoto, Japan), and Jan Peters (Max Planck Institute for Biological Cybernetics, Tübingen, Germany). The steering committee has 12 members, where the Americas, the Asia/Pacific region, and Europe have four members each. The American robot-learning community is represented by the steering committee

Figure 1. *Dynamic behaviors like this jumping maneuver for LittleDog are being developed using reinforcement learning by a team at MIT led by TC chairs Russ Tedrake and Nick Roy. Used with permission from Russ Tedrake.*

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Figure 2. Helicopters are hard to control because of unstable, complex dynamics. TC members Pieter Abbeel (University of California in Berkeley), Adam Coates and Andrew Ng (Stanford University) developed apprenticeship learning algorithms for learning advanced aerobatics such as this aerobatic flip with their autonomous helicopter. Here, the intent of the human presenter is discovered by learning a cost function from demonstrations and determining the optimal policy from this cost function. With permission from Abbeel, Coates & Ng.

members Michael Bowling (University of Alberta, Edmonton, Canada), Drew Bagnell (Carnegie Mellon University, Pittsburgh, PA), Chad Jenkins (Brown University, Providence, RI), and Sebastian Thrun (Stanford University, Palo Alto, CA). The TC is supported by its Asian/Pacific representatives Masamichi Shimosaka (Tokyo University, Japan), Tomohiro Shibata (Nara Institute of Science and Technology, Japan), Gordon Cheng (ATR Department of Humanoid Robotics and Computational Neuroscience, Kyoto, Japan), and Minoru Asada (Osaka University, Japan). Martin Riedmiller (University of Freiburg, Germany), Manuel Lopes (Instituto Superior Technica, Lisbon, Portugal), Marc Toussaint (Technical University of Berlin, Germany), and Paolo Fiorini (University of Verona, Italy) act as the European steering committee members and organize the TC's activities in Europe.

Thanks to the strong support by the steering committee as well as several IEEE RAS Technical Advisory Board (TAB) members; it took the TCRL only a few months to grow to more than a hundred members. Currently, it has 154 members with 54 living in the Americas, 71 in Europe, and 34 from the Asia/Pacific region. The TCRL has been very active in the first year of its existence and among the most important events that it has organized are as follows:

- *NIPS Workshop 2007*: to foster interest in machine learning community for a robotics as an application domain, Jan Peters (cochair) and Marc Toussaint (steering committee) organized a NIPS Workshop on robotics challenges for machine learning
- *IROS Workshop 2008*: upon the establishment of the TCRL at ICRA 2008, all TC chairs, Russ Tedrake, Nicholas Roy, Jun Morimoto, and Jan Peters have jointly launched an IROS workshop to kick the TCRL off
- *ICRA Workshop 2009*: Ales Ude (member; Josef-Stefan Institute, Ljubeljana, Slovenia), Tamim Asfour (member; Karlsruhe University, Germany), Jan Peters (cochair), Jun Morimoto (cochair), and Stefan Schaal (member; University of Southern California, Los Angeles, CA) organized the workshop on Approaches to Sensorimotor Learning on Humanoid Robots at ICRA 2009
- *Robotics: Science and Systems (R:SS) Workshop 2009*: Dana Kulic (member; Tokyo University, Japan), Pieter Abbeel (member; University of California in Berkeley, CA), and Jan Peters (cochair) organized a R:SS 2009 workshop on Bridging the Gap Between High-Level Representations and Low-Level Continuous Behaviors
- *Autonomous Robots special issue*: Jan Peters (cochair) and Andrew Ng (member) are the editors of a special issue on Robot Learning. They received 46 submissions out of which the eight best papers are going to be published in *Autonomous Robots*
- *Robot Learning Summer School (RLSS)*: Manuel Lopes (steering committee) and Luis Montesano (member) have organized a robot-learning summer school in Lisbon, Portugal, between Monday 20 and Friday, 24 July 2009.

More information on the TCRL can be found at our Web site http://www.learning-robots.de. We would be happy to welcome you in our TC. Current members can be reached using the moderated mailing list all@learning-robots.de.

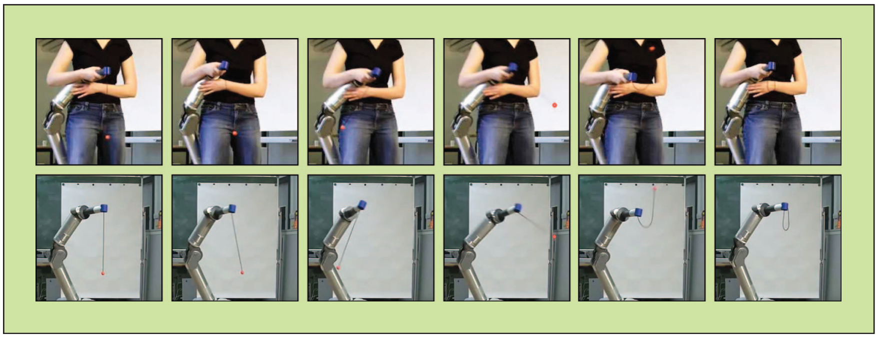

Figure 3. This ball-in-a-cup behavior was learned through the concerted action of imitation learning and reinforcement learning in the Robot Learning Laboratory headed by TC chair Jan Peters of the Department of Empirical Inference and Machine Learning at the Max Planck Institute for Biological Cybernetics. The imitation is used to initialize the policy, and it achieves satisfactory performance through reward-driven self-improvement. The learning performance compares roughly to a nine-year-old child. With permission from Kober & Peters.

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