Brain-Supported Learning Algorithms for Robots

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Roboticists have early recognized the high potential of neuro-biological control structures for robotic applications. However, limited processing power and the lack of appropriate models and tools shifted the focus of research far away from biological neural networks. Today, combined efforts in the fields of neurosciences, computer science and many other areas in interdisciplinary research projects like the Human Brain Project enable the simulation of spiking biological neural networks with millions of neurons. The computational power of these networks makes them a very promising tool for the development for brain-controlled neurorobots. Major challenges towards this goal include a meaningful mapping between tasks and neural structures as well as making the simulated brain exhibit the desired behavior. The large size and the complexity of biological neural networks make the development of learning algorithms a huge challenge. A main prerequisite for the implementation of learning algorithms for brain-controlled robots is the availability of appropriate tools like, e.g., the SpiNNaker board, which is able to simulate the neural network in real-time. On the software side, these tools should ease the development and support the researcher during the evaluation by offering a toolchain for the implementation and simulation of new algorithms (i.e. simulators able to connect and synchronize simulated brain-supported algorithms and simulated robotic platforms).

This symposium presents actual brain-supported learning techniques for robots as well as support tools for the implementation of these algorithms. In particular, the papers in this symposium provide evidence of the advantages of the proposed brain-supported learning solutions and the effectiveness of tools for the evaluation and implementation of these algorithms.

Continuous-time neural reinforcement learning of working memory tasks

Sander Bohte

As living organisms, one of our primary characteristics is the ability to rapidly process and react to unknown and unexpected events. To this end, we are able to recognize an event or a sequence of events and learn to respond properly. Despite advances in machine learning, current cognitive robotic systems are not able to rapidly and efficiently respond in the real world: the challenge is to learn to recognize both what is important, and also when to act. Reinforcement Learning (RL) is typically used to solve complex tasks: to learn the how. To respond quickly - to learn when - the environment has to be sampled often enough. For "enough", a programmer has to decide on the step-size as a time-representation, choosing between a fine-grained representation of time (many state-transitions; difficult to learn with RL) or to a coarse temporal resolution (easier to learn with RL but lacking precise timing). Here, we derive a continuous-time version of on-policy SARSA-learning in a working-memory neural network model, AuGMEnT. Using a neural working memory network resolves the "what" problem, our "when" solution is built on the notion that in the real world, instantaneous actions of a certain duration are actually impossible. We demonstrate how we can decouple action duration from the internal time-steps in the neural RL model using an action selection system. The resultant CT-AuGMEnT successfully learns to react to the events of a continuous-time task, without any pre-imposed specifications about the duration of the events or the delays between them.

Bio-inspired learning mechanisms and anticipation in humanoid robotics

Egidio Falotico

Nowadays, increasingly complex robots are being designed. As the complexity of robots increases, traditional methods for robotic control may become complex to handle. For this reason, the use of neuro-controllers, controllers based on biological learning mechanisms, have risen at a rapid pace. This kind of controllers are especially useful in the field of humanoid robotics, where it is common for the robot to perform difficult tasks (i.e. visual tracking, gaze guided locomotion) in a complex unstructured environment. In order to perform these tasks, motor control cannot be based on sensory feedback, which would be too slow. Indeed, in humans, perceptual activity is not confined to the interpretation of sensory information, but it anticipates the consequences of action. Also in robotics, the anticipatory control, generated thanks to internal models built by experience, properly combined with reactive behaviours, can greatly improve the effectiveness of perception-action loops and the overall behaviour in real-world environments. This talk will present latest results of bio-inspired learning mechanisms integrated within anticipative control architectures implemented on humanoid robots.

Cerebellar internal models for a modular robot

Silvia Tolu

The problem to solve in controlling a dynamical system is to find out the input to the system that will achieve the desired behavior as output even under disturbances or changing environments. The cerebellum acts in this sense because it adapts its output in every condition by acquiring intrinsic models through experience by a perceptual feedback that allows the motor learning to proceed. Each internal model (IM) is then instantiated based on what has been learned about a specific motor control for a specific machine. Apart from adaptation, another issue is the Central Nervous System (CNS) capability of recalling the appropriate IM and using it to make predictions during a movement. Therefore, after training and adaptation the IM becomes encoded into a long-term memory. Neurorobots have proved useful for investigating motor control, and for designing robot controllers as well. Furthermore, they can generate hypotheses and test theories of brain functions. In this work, we have designed a control system that can operate in an unknown or changing environment, when the dynamical robot model is unknown (e.g. a modular robot) inspired by how the brain works. Furthermore a cerebellar model has been developed with the aim of implementing model extraction schemes for acquisition of knowledge (forward and inverse IMs). A modular robot (Fable robot) benefits from the organization and adaptivity of IMs that are embedded into its control system architecture. Finally, we have tested the adaptation of the IMs under a given task and the robustness of the whole control system.

Sensorimotor Learning for Neural Robot Control based on the Kinematic Bézier Maps and Spiking Neural Networks

Stefan Ulbrich

The Kinematic Bézier Maps are a highly specialized model representation of robot kinematics and dynamics with related, optimal learning algorithms. By means of complex basis transformations embedding prior knowledge, these complex functions are transformed into a high-dimensional space where they can be represented in a linear form and, thus, efficiently be learned. In this work, we present our ongoing research on how this model representation and learning algorithms can be translated into a novel form based on spiking neural networks exploiting the high degree of parallelism in order to benefit from the increased performance in robotic applications when applied on neuromorphic hardware.