Workshop

Advances in Biologically Inspired Brain-Like Cognition and Control for Learning Robots

Organisers:
Florian Walter, Florian Röhrbein, Stefan Ulbrich, Rüdiger Dillmann

http://www.neurorobotics.net/workshop/iros-workshop/

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Objectives

Even today's most advanced robots perform poorly at simple everyday tasks carried out routinely by humans and animals. This has very early motivated researchers to adopt neurobiological principles of cognition and control in robotics, yielding numerous approaches based on artificial neural networks and machine learning. However, many of the originally proposed methods employ neural networks solely for the purpose of approximating and replicating standard control architectures. At the same time, research focusing more on biological plausibility severely suffered from limitations on size and accuracy of the neural simulations imposed by hardware constraints.

In recent years, new theoretical insights and the increasing availability of cheap processing power have brought new momentum to the field of neural learning, which has evolved into two tracks of research with different goals and methods. In the new and emerging discipline of neurorobotics, the focus is on a close correspondence to experimental findings from neuroscience. Detailed simulations of spiking neural networks and the use of biologically plausible neural learning rules are therefore more important than mathematical tractability or implementation efficiency. This enables a seamless exchange of results between both disciplines. In contrast, other approaches like deep learning techniques build on the theory of classical artificial neural networks but apply it at larger scales or to novel network architectures.

This workshop seeks to provide a platform to present and discuss advances in biologically inspired brain-like cognition and control for robotics. By bringing together experts from the fields of neurorobotics, artificial neural networks and machine learning, we intend to foster a fruitful exchange between the different communities. The global scope of the workshop makes participation equally attractive for researchers new to the field. It is a must-attend event for everyone interested in a fresh view on cognitive robotics. Interactive demonstrations of tools and implementations give all attendants the chance to get actively involved. A dedicated poster session additionally offers enough room for individual discussion.

Topics of interest

- Neurorobotics
- Spiking Neural Networks for Robotic Applications
- Bio-Inspired Learning
- Self-Organization
- Embodiment
- Applications of Neuromorphic Hardware in Robotics
- Reservoir Computing
- Deep Learning

Invited Speakers

1. Joni Dambre,
   Reservoir Computing Lab, Ghent University, Belgium
2. Manfred Hild,
   Neurorobotics Research Laboratory, Beuth Hochschule für Technik Berlin,Germany
3. Auke Ijspeert,
   Biorobotics Laboratory, École Polytechnique Fédérale de Lausanne, Switzerland
4. Herbert Jaeger,
   MINDS, Jacobs University Bremen, Germany
5. Jason Yosinski
   Cornell Creative Machines Lab, Cornell University, USA

Program

8:30	–	8:35	Welcome
8:35	–	9:05	Auke Ijspeert: Learning about animal locomotion control using robots
9:05	–	9:35	Manfred Hild: Self-Exploration of Autonomous Robots Using Attractor-Based Behavior Control
9:35	–	10:00	Poster Session
10:00	–	10:30	Coffee Break
10:30	–	11:00	Joni Dambre: Practical approaches to exploiting body dynamics in robot motor control
11:00	–	11:30	Herbert Jaeger: Generating and Modulating Complex Motion Patterns with Recurrent Neural Networks and Conceptors
11:30	–	12:00	Jason Yosinski: Training and Understanding Deep Neural Networks for Robotics, Design, and Perception
12:00	–	12:30	Stefan Ulbrich: The Neurorobotics Platform of the Human Brain Project
		12:30	End

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Talks

Learning about animal locomotion control using robots

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The ability to efficiently move in complex environments is a fundamental property both for animals and for robots, and the problem of locomotion and movement control is an area in which neuroscience and robotics can fruitfully interact. Animal locomotion control is in a large part based on spinal cord circuits that combine reflex loops and central pattern generators (CPGs), i.e. neural networks capable of producing complex rhythmic or discrete patterns while being activated and modulated by relatively simple control signals. These networks are located in the spinal cord for vertebrate animals and interact with the musculoskeletal system to provide "motor primitives" for higher parts of the brain, i.e. building blocks of motor control that can be activated and combined to generate rich movements. In this talk, I will present how we model the spinal cord circuits of lower vertebrates (lamprey and salamander) using systems of coupled oscillators, and how we test these models on board of amphibious robots. The models and robots were instrumental in testing some novel hypotheses concerning the mechanisms of gait transition, sensory feedback integration, and generation of rich motor skills in vertebrate animals. I will also discuss how the models can be extended to control biped locomotion, and how they can help deciphering the respective roles of pattern generation, reflex loops, and descending modulation in human locomotion.

Self-Exploration of Autonomous Robots Using Attractor-Based Behavior Control

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An autonomous robot which is equipped with sensorimotor loops and situated within a specific environment can be regarded as a dynamical system. In the language of dynamical systems theory, behavioral body postures and repetitive body motions then correspond with fixed points and quasiperiodic orbits. Both of which can either be naturally stable, i.e., attractors of the situated physical body, or be stabilized by the whole system including the sensorimotor loops.

As is well-known, even most simple two-neuron networks may already exhibit many co-existing attractors, which, if properly chosen, may nicely go along with the overt behavior of an autonomous robot. Standing and walking is one example, obstacle avoidance another one. The question arises, how larger neural networks can be found (preferable by the robot itself), that explore behavioral options, starting from scratch and getting increasingly rich over time.

Attractor-Based Behavior Control (ABC) follows the afore-mentioned path and confidently finds attractors which correspond to energy-efficient behavioral body postures, either fully alone or in gently guiding physical human-machine interaction. The latter helps protecting the robot from harming itself as it would easily happen if using, e.g., motor-babbling or homeokinetic learning rules. In addition, ABC learning does not only find behavioral attractors, but also the corresponding attractor-connecting heteroclinic orbits which can be utilized to generate stable motion trajectories.

After briefly revisiting the necessary concepts, I will introduce ABC-Learning and demonstrate how it enables an autonomous robot to self-explore its behavioral capabilities from scratch and without any given body model.

Practical approaches to exploiting body dynamics in robot motor control

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Motor control systems in the brain of humans and mammals are hierarchically organised, with each level controlling increasingly complex motor actions. Each level is controlled by the higher levels and also receives sensory and/or proprioceptive feedback. Through learning, this hierarchical structure adapts to its body, its sensors and the way these interact with the environment. An even more integrated view is taken in morphological or embodied computation. On the one hand, there is both biological and mechanical (robotics) evidence that a properly chosen body morphology can drastically facilitate control when the body dynamics naturally generate low level motion primitives. On the other hand, several papers have used robot bodies as reservoirs in a reservoir computing setup. In some cases, reservoir computing was used as an easy way to obtain robust linear feedback controllers for locomotion. In other cases, the body dynamics of soft robots were shown to perform general computations in response to some input stimulation. In general, very specific highly compliant bodies were used. At Ghent University's Reservoir Lab, we have previously used reservoir computing to generate locomotion on quite different robot platforms: the highly compliant tensegrity robot Recter and the far less compliant quadruped robot Oncilla and a new low cost modular quadruped puppy robot. In all cases, we succeeded in generating stable gaits. However, not surprisingly, not all robot bodies are equally suitable to help generating their own motor actuations. As a result, the reservoir computing principle alone was not always sufficient. We present an overview of our experience with these different robot platforms and give practical guidelines for applying physical reservoir computing to new robots. We finally discuss some perspectives on a more systematic evaluation between body morphology, compliance and the complexity of generating stable gaits for locomotion.

Generating and Modulating Complex Motion Patterns with Recurrent Neural Networks and Conceptors

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In biological brains "higher" cognitive control modules regulate "lower" brain layers in many ways. Examples for such top-down processing pathways include triggering motion commands ("reach for that cup"), modulating ongoing lower-level motor pattern generation ("wider steps, slooow down!"), setting attentional focus ("look closer... there!"), or predicting the next sensory impressions ("oops - that will hit me"). Not much is known about computational mechanisms which would implement such top-down governance functions on the neural level. As a consequence, in machine learning systems which are based on artificial neural networks, top-down regulation is rarely implemented. Specifically, today's top-performing pattern recognition systems ("deep learning" architectures) do not exploit top-down regulation pathways.

This talk gives an introduction to a novel neural control mechanism which addresses such top-down governance mechanisms in modular, neural learning architectures. This computational principle, called conceptors, allows higher neural modules to control lower ones in a dynamical, online-adaptive fashion. The conceptor mechanism lends itself to numerous purposes:

- A single neural network can learn a large number of different dynamical patterns (e.g. words, or motions).
- After some patterns have been learnt by a neural network, it can re-generate not only the learnt "prototypes" but a large collection of morphed, combined, or abstracted patterns.

- Patterns learnt by a neural network can become logically combined with operations AND, OR, NOT subject to rules of Boolean logic. This reveals a fundamental link between the worlds of “subsymbolic” neural dynamics and of “symbolic” cognitive operations.
- This intimate connection between the worlds of neural dynamics and logical-symbolic operations yields novel algorithms and architectures for lifelong learning, signal filtering, attending to particular signal sources (“party talk” effect), and more.

Expressed in a nutshell, conceptors enable “top-down logico-conceptual control” of the nonlinear, pattern-generating dynamics of recurrent neural networks.

Training and Understanding Deep Neural Networks for Robotics, Design, and Perception

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Artificial Neural Networks (ANNs) form a powerful class of models with both theoretical and practical advantages. Networks with more than one hidden layer (deep neural networks) compute multiple functions on later layers that share the use of intermediate results computed on earlier layers. This compositional, hierarchical structure provides a strong bias, or regularization, toward solutions that seem to work well on a large variety of real-world problems.

In this talk we will examine this bias in action via several vignettes. First we will look at a method for using ANNs to learn fast gaits for walking robots. Second, we will see how the same method can be applied to design three dimensional solid objects. Finally we will discuss a few simple experiments that shed light on the inner workings of neural nets trained to classify images. The studies shed light on the computation performed by each layer of a network and by the network as a whole. The experiments taken together reveal some surprising behaviors of large networks and lead to a greater understanding and intuition for the computation performed by deep neural nets.

The Neurorobotics Platform of the Human Brain Project

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The Neurorobotics Platform (NRP) is a web-based simulation environment for neuroscientists for performing neurorobotic experiments. It is developed in the sub-project 10 “Neurorobotics” of the Future and Emerging Technologies (FET) Flagship project “The Human Brain Project” funded by the European Commission. The software grants neuroscientists painless access to sophisticated brain, robot and physical simulators and provides the necessary tools for designing brain-body interfaces, virtual world and robot modeling as well as the definition of complex experiments. The NRP is still under development and this talk presents its current state and capabilities as well as an outlook on future development.

Posters

Neurocognitive Architecture for Autonomous Task Recognition, Learning, and Execution (NARLE)

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Humans and higher animals are able to solve new problems and reuse the acquired solutions later in their behaviour. This capacity of the biological neuronal systems for constant adaptation enables biological agents to refine their skills and expand their behavioural repertoire. Understanding how neuronal dynamics may be organised to enable learning new skills will enable us to build cognitive robots that are adaptive and can autonomously acquire new behaviors. Recently, we have introduced a neurocognitive architecture that addresses the problem of learning and execution of hierarchical behaviors and complex skills. The proposed architecture uses Dynamic Neural Fields (DNFs) to implement low-level motor and perceptual behaviours and a Functional System Network (FSN) to tie these behaviors in goal-directed sequences. The DNFs enable a continuous, dynamical representation of perceptual features and motor parameters, which may be coupled to the robot's sensors and effectors. Attractor states and instabilities of the DNFs account for segregation of discrete cognitive states and mark behaviorally relevant events in the continuous flow of the sensorimotor dynamics. The FSN, in its turn, comprises dynamical elements that can be arranged in a multilayered network by a learning process, in which new layers and elementary behaviors are added on demand. Combination of the DNF and FSN frameworks in a neurocognitive architecture NARLE enables pervasive learning and adaptation both on the level of individual behaviors and goal-directed sequence, leading to more adaptive intelligent robotic systems, capable to learn new tasks and extend their behavioral repertoire in stochastic real-world environments. In our robotic scenario, the systems for object and scene representation, action parsing, and sequence learning are detailed and their interplay in a table-top assembly task is described. We discuss the potential of this new biologically-inspired cognitive architecture in the fields of modelling human cognition and autonomous robotics.

Learning Techniques for Neurorobotics – A Survey on the Role of the Factor Time

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Neurorobotics enables the interaction of simulated biological neural networks with both virtual and real environments in closed perception-action loops. Controlling robotic actuators, processing sensor readings and implementing goal-directed behavior requires the adjustment of synaptic weights by means of learning. The temporal dynamics of the detailed neural models employed in neurorobotics enable the use of learning techniques which incorporate a notion of time. This poster provides an overview of concepts and methods from this field with a special focus on prospective applications in neurorobotics.

Cognitive Walking: Recruitment of an Internal Body Model

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The overall goal of our approach is to understand general cognitive mechanism and to implement those in a functional minimal cognitive system. We are starting from a biological inspired hexapod walking control system and we extended this system towards a minimal cognitive system. In our understanding Cognition is understood following the notion of McFarland and Bösser (1993) as the ability to plan ahead by means of an internal simulation (Hesslow, 2002) relying on internal representation (Steels, 2003; Glenberg, 1997) which are grounded in embodied experiences (Gallese & Lakoff 2005). The extension of our system leads towards a control system for the six-legged walking robot Hector which allows the robot to deal with novel situation and to plan its behavior in advance. Crucial to this approach is, on the one hand, the grounding of internal representation in behavior and, on the other hand, the flexible reuse of such embodied internal models in new contexts which is realized as a form of internal simulation. On the poster, we will present, first, the underlying behavior-based control system from which adaptive and well-cordinated walking behavior emerges. Second, how functional internal models are grounded in lower level behavior. As a first internal representation an internal model of the body will be introduced realized as a simple recurrent neural network. Third, we will show how this functional internal model of the body can be exploited in internal simulation for planning ahead exploiting the predictive forward function of the model.

Real-time Cerebellar Control of a Compliant Robotic Arm

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Flexible and compliant real-time control of artificial limbs is a challenging endeavor for conventional control algorithms. Conversely, the neuro-control of biological limbs is usually highly stable despite the apparent complex nonlinearities and flexibilities. Part of this is caused by cerebellar fast learning of motor actions embedded in a complex sensory feedback system.

In an attempt to exploit this flexibility in a real-time robotic setting, we apply cerebellar control mechanisms to operate a compliant, anthropomimetic robotic arm built using the Myorobotics framework. The spiking neural network we use is simulated in real-time on a SpiNNaker computer. A custom interface translates between SpiNNaker's digital synaptic spikes and the robot's sensors and actuators on a CAN bus. We demonstrate initial results of the implementation with a one-degree-of-freedom robotic joint as proof of principle. Here, we benefit from the modular and extensible design of both the Myorobotics framework and the SpiNNaker platform.

Understanding Neural Networks through Deep Visualization

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Our understanding of how large, deep neural nets work, especially what computations they perform at intermediate layers, is lacking. Progress toward building better models will be accelerated by better tools for visualizing and interpreting neural nets. We introduce two such tools here. The first is an interactive toolbox that visualizes the activations produced on each layer of a trained convnet as it processes an image or video (e.g. a live webcam stream). We've found it fun and informative. The second tool enables visualizing features at each layer of a DNN via regularized optimization in image space. Specifically we introduce several new regularization methods that combine to produce qualitatively clearer, more interpretable visualizations than previous methods. Both tools are open source and work on a pre-trained convnet with minimal setup.

In Silico Neuroscientific Experiments on the HBP Neurorobotics Platform

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This poster presents two experiments centered on visuo-motor capabilities that intend to show the capabilities of the Neurorobotics Platform of the Human Brain Project and its value for performing in silico neuroscientific experiments. The first experiment features a virtual mouse with a deformable surface whose head movements follow visual stimuli. In the second experiment, the humanoid robot iCub tracks a moving target with his eyes. Unlike the mouse experiment, this experiment incorporates a sophisticated neural network controlling the movement of the robot.

Learnable, neural representation of kinematics

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This poster presents our ongoing research effort of constructing a learnable, neural representation of kinematics and, in the future, dynamic models of bio-inspired robots. Currently, we encode a complex mathematical formula in spiking neurons that describes the Kinematic Bezier Model, an optimal Machine Learning method for adaptive kinematic models. With this algorithm the complex non-linear descriptions of the robot's kinematics and dynamics are transformed into purely linear models enabling straight-forward life-long learning methods. In its current state, the basic building blocks have been transformed onto the neural substrate such that priorly learned models can be used. Exploring suitable and biologically plausible learning strategies that render that network adaptive are currently explored.