INSTITUTE PRESENTATION

Biologically Inspired Robotics Group
Swiss Federal Institute of Technology Lausanne
Lausanne, Switzerland

Presented by
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OVERVIEW

The Biologically Inspired Robotics Group (BIRG, http://birg.epfl.ch) at the Swiss Federal Institute of Technology in Lausanne (EPFL) carries out research in robotics, computational neuroscience, nonlinear dynamical systems, and learning/optimization algorithms. We are interested in understanding the fascinating control and learning abilities observed in animals, and to develop systems –programs, simulations, and robots– that exhibit and replicate those abilities. In particular, we are interested in developing systems that evolve, adapt, self-organize, and self-repair.

The group was founded in November 2002. It is headed by Auke Ijspeert (assistant professor), and is composed of one part-time postdoc –Dr Olivier Michel–, three PhD students –Jonas Buchli, Alessandro Crespi, and Ludovic Righetti–, one programmer –Yvan Bourquin–, and two part-time electromechanical technicians –André Badertscher and André Guignard. The group has funding from the Swiss National Science Foundation, the Swiss CTI (Swiss Federal Office for Professional Education and Technology), the EPFL, the European Space Agency, and the European Union, through the Integrated Project ROBOT-CUB (IST-FET6).

RESEARCH

Understanding animal motor control

Part of our work is to study how learning and control are implemented in animals either at an abstract level using a dynamical systems approach (see below) or at a more realistic level by developing neuromechanical simulations of animals. Some of our research is focused on the adaptive control of movement and locomotion, an area in which animals still largely outperform current robots. In particular, using our numerical simulations we contribute to a better understanding of the neural mechanisms underlying movement control, and how these neural circuits have changed during vertebrate evolution. In addition to help neurobiologists, these models give new ideas for the development of better algorithms to control robots with multiple degrees of freedom (i.e. with many joints), see below.

For instance, we carry out projects that investigate the anguiliform swimming of the lamprey, one of the earliest vertebrates, as well as the swimming and walking of the salamander. Following the work of Orjan Ekeberg, we develop neuromechanical simulations of the lamprey and the salamander (i.e. simulations composed of both a neural network and a biomechanical model) to investigate the functioning of central pattern generators for locomotion (Figure 1). These projects use genetic algorithms to automatically design part of the neural networks given a description of the desired behavior of the complete system. This approach has many interesting properties both for computational neuroscience –by fitting a model to biological data, and automatically setting parameters instead of hand-tuning them– and for robotics –by optimizing a controller in terms of speed of swimming, or ability to induce turning, for instance. In addition these projects give insights into how the locomotor system of vertebrate animals might have evolved from simple lamprey-like structures to more complex mammals (including humans).

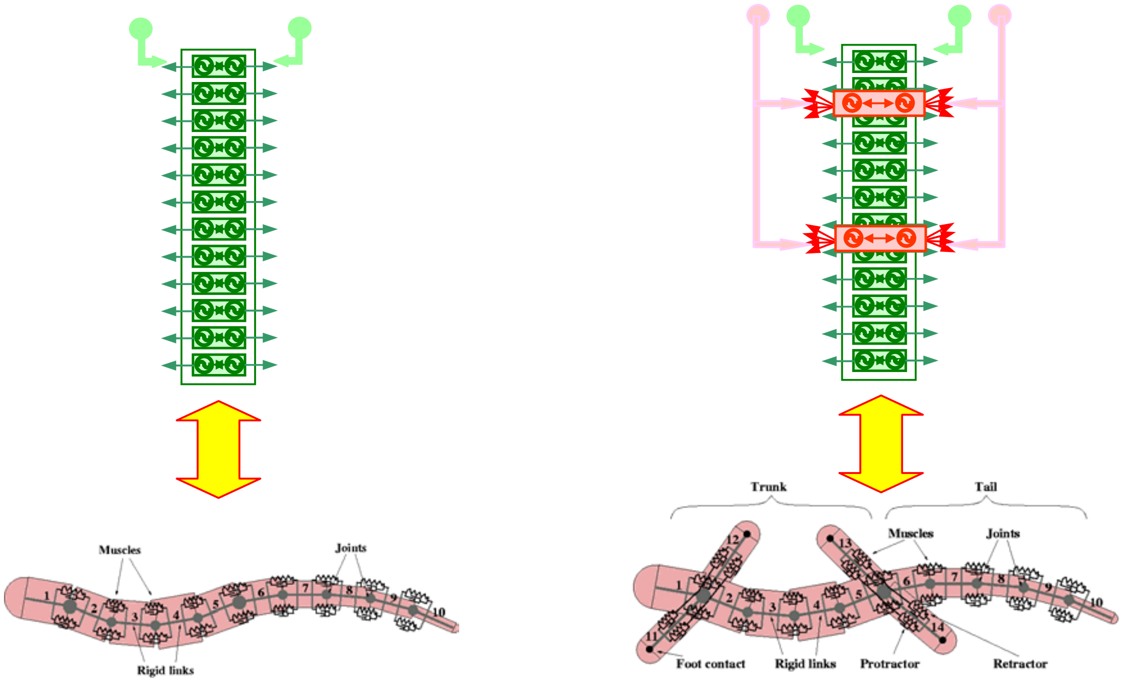

Figure 1: Neuromechanical models of the lamprey and the salamander developed at BIRG.

Adaptive dynamical systems

We develop numerical models of adaptive nonlinear dynamical systems with multiple time scales. Nonlinear dynamical systems are an interesting approach for the generation of trajectories for robots with many degrees of freedom (e.g. legged locomotion). There are many interesting properties of nonlinear dynamical systems which can be exploited, e.g. attractor properties (fixed point, limit cycles) and robustness against perturbations, synchronization effects with signals from the body and the environment, filtering and fusing of noisy sensory signals, production of robust, high-dimensional oscillatory signals for gaits, etc. Designing a nonlinear dynamical system to satisfy a given specification and goal is however not an easy task, and, hitherto no methodology exists to approach this problem in a unified way.

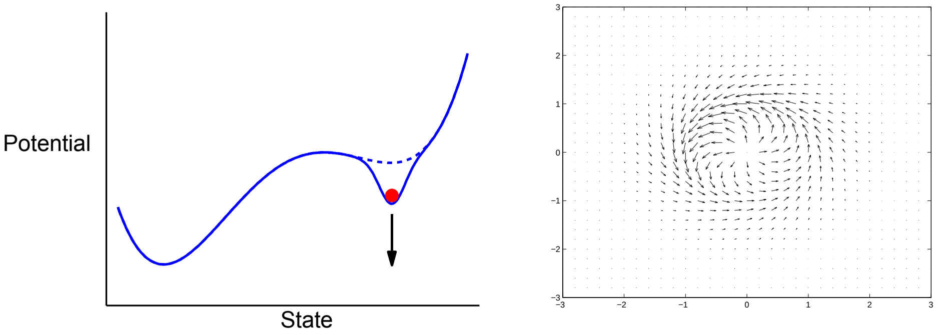

Figure 2: Left: Illustration of a plastic dynamical system (adaptive potential). Right: An attractor formed after one-shot learning.

We are therefore interested in exploring how adaptation can be added to dynamical systems to obtain interesting dynamics such as frequency adaptation and synchronization in systems of coupled oscillators, for instance. We do this with plastic dynamical systems, in which parameters are transformed into (slow varying) state variables, whose dynamics is determined by differential equations derived from insights related to synchronization properties (Figure 2). We have different implementations of the approach, including (1) a system composed of a nonlinear oscillator coupled to a simple spring-mass system which can optimize the speed of locomotion by tuning the frequency of the oscillator to the natural frequency of the spring-mass system, (2) an adaptive controller that tunes itself to the mechanical properties of a simulated hopping robot, and (3) an adaptive nonlinear oscillator which can extract the main frequencies of arbitrary rhythmic signals without any phase information.

Swimming and walking machines

We are interested in the design and the control of autonomous articulated robots with many degrees of freedom, from snake robots to humanoid robots. Some of our projects use commercial robots such as Aibo, Hoap II, or DB (a humanoid robot at ATR, Kyoto). Other projects involve the design of new robots, such as the amphibious snake robot Amphibot I and the modular robots Yamor.

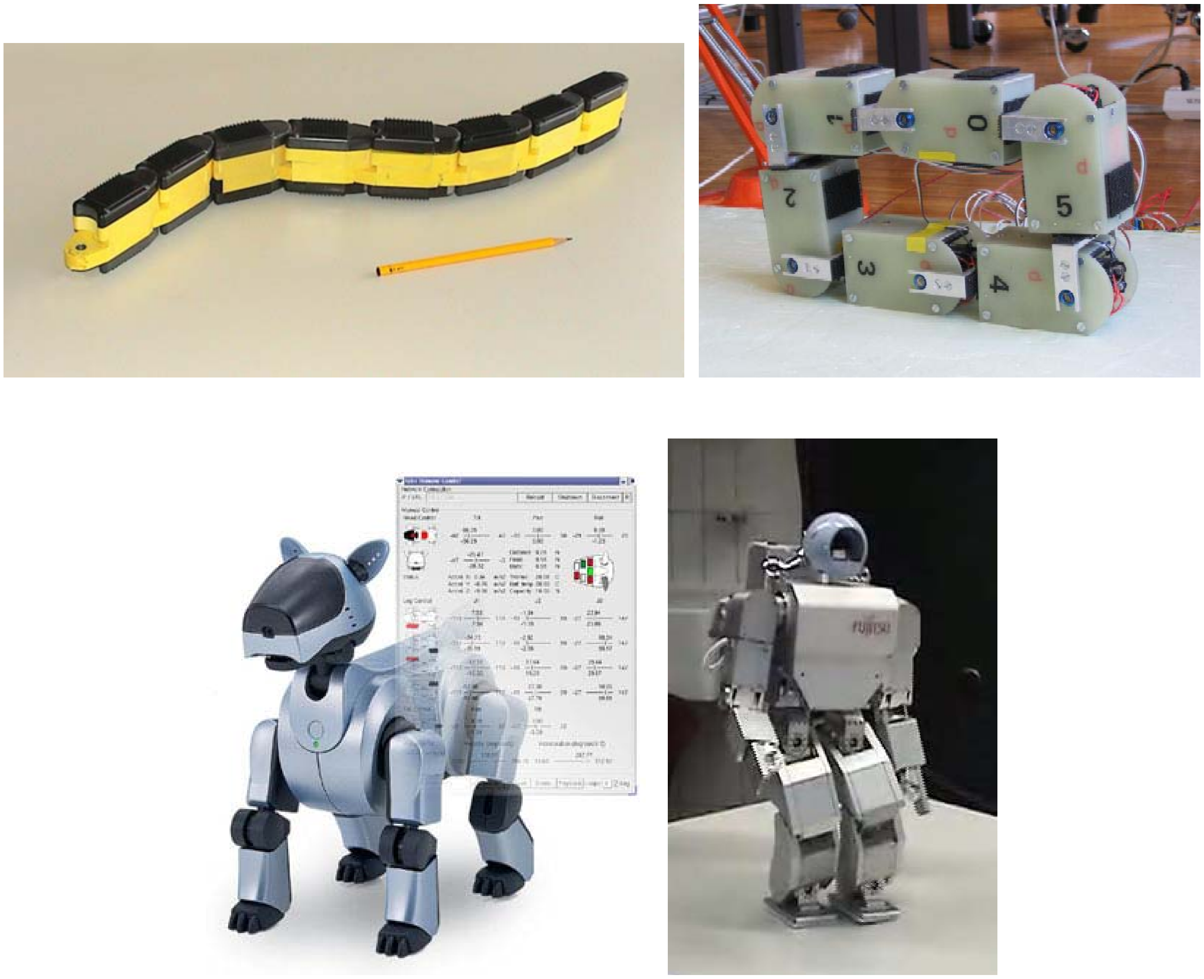

Figure 3: Robots used at BIRG. From left to right and up to down: Amphibot I, Yamor, Aibo, Hoap II.

One of our projects is to build a biologically inspired amphibious snake-like (or eel/lamprey-like) robot, called AmphiBot I (Figure 3). The goals of the project are three-fold: (1) to build an amphibious robot for outdoor robotics tasks, taking inspiration from snakes and elongate fishes such as lampreys, (2) to use the robot as a test-bed for novel types of adaptive controllers based on the concept of central pattern generators, and (3) to use the robot to investigate hypotheses of how locomotion-controlling neural networks are implemented in real animals. The first prototype has been built and its swimming and crawling abilities have been extensively tested. We are currently developing controllers for the snake robot based on central pattern generators (implemented as coupled nonlinear oscillators) inspired from our animal modeling studies. These control systems allow the robot to efficiently coordinate its multiple joints, and to smoothly adapt its speed, direction, and type of gait depending on the environment.

Humanoid robotics

Our work in humanoid robotics is concerned with the development of algorithms for movement control based on Dynamical Movement Primitives. These control systems are based on nonlinear dynamical systems with well-defined attractor properties (single point attractors for discrete movements and limit cycle attractors for rhythmic movements). They have the interesting properties that they can be trained based on human demonstrations using a statistical learning algorithm (locally weighted regression), and that, once they have learned a particular movement (e.g. a tennis swing), they can (1) replay the movement while being robust against perturbations, and (2) be reused in new conditions (e.g. towards a new point in space) by the modulation of simple command signals.

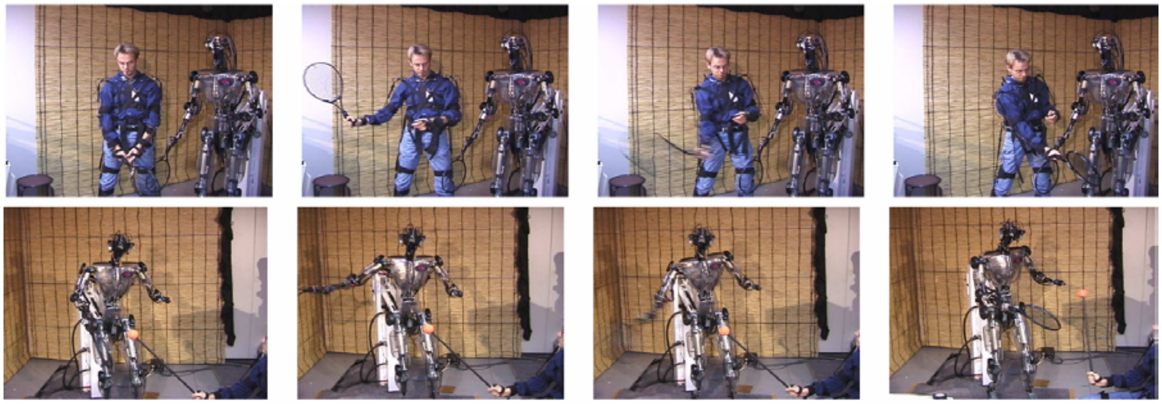

Figure 4: Humanoid robot DB (ATR, Japan) learning tennis swings using dynamical movement primitives.

This work is done in collaboration with Stefan Schaal at the University of Southern California (Los Angeles, USA) and Jun Nakanishi at ATR (Kyoto, Japan). It has been implemented on DB, a humanoid robot with 35 degrees of freedom located at ATR (Japan) where Auke Ijspeert is an external collaborator. We have used the approach to learn different types of movements such as reaching movements, tennis swings, and drumming.

Modular robotics

We are also exploring self-organization in distributed systems of modular robots (i.e. robots made of multiple simple units). The aim of the project is to create robot units that can rapidly be attached to each other in order to create arbitrary multi-unit robot structures (Figure 5). We have designed modular robot units called Yamor which have the following characteristics: (1) each unit is autonomous in terms of power, sensing, actuation, and computing, (2) they are driven by heavy-duty servos such that one unit can lift up to 3 others, (3) they communicate via BlueTooth (i.e. no need for electrical connections between units), and (4) they are equipped with an FPGA for providing flexible computational power.

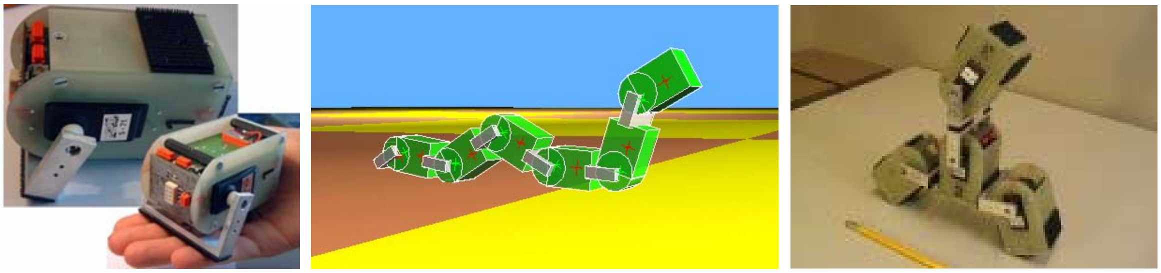

Figure 5: Modular robots made out of real and simulated Yamor units.

Our goal is to develop distributed systems composed of multiple local controllers (one per robot unit) and to explore how local interactions and learning algorithms can be used to optimize the global behavior of the group of units. The main challenge is to develop robust controllers for multi-unit robots whose global structure is not known apriori and might change through reconfiguration. We are exploring different approaches including the co-evolution of controllers and body structures, and the online optimization of central pattern generators.

Development of articulated robot simulations

In collaboration with Cyberbotics, a Swiss software company, we develop Webots Dynamics, a powerful and general-purpose simulation tool, especially for legged robots, including bipeds, quadrupeds, hexapods, but also, more generally, to any robotics architecture involving physics-based simulation, like wheeled robots or flying robots (Figure 6). The software provides a complete simulation framework, including libraries of existing robots, tools to create one's own robots, a sensor and actuator library, modeling and programming facilities, and the possibility to transfer controllers to real robots. Webots is now used by over 250 universities and research centers worldwide.

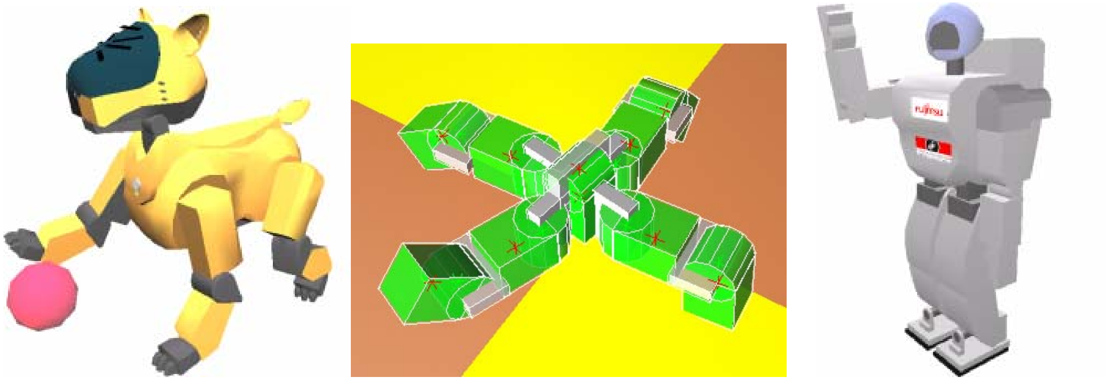

Figure 6: Different types of robots simulated in Webots.

More information

For more information, please visit the web site http://birg.epfl.ch which presents these different research projects in more detail, including movies and online publications.