# Evo-Devo-Robo Workshop Program

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## ABSTRACT

Developmental robotics (also known as epigenetic robotics) is mainly concerned with modeling the postnatal development of cognitive behaviors in living systems, such as language, emotion, curiosity, anticipation, and social skills. While current work in this field has shown significant successes, we believe integrating research on developmental (including epigenetic and morphogenetic) robotics and evolutionary robotics is the natural next step.

This workshop aims at bringing together evolutionary robotics and developmental robotics to form a new research area "evolutionary developmental robotics" (evo-devo-robo). The present paper contains the abstracts of the talks given by each of the seven invited speakers. These abstracts cover research in both fields and give an overview of the potential interactions between developmental and evolutionary robotics.

**Categories and Subject Descriptors:** I.2.6 [Artificial intelligence]: Learning, Robotics

**General Terms:** Algorithms.

**Keywords:** Evolutionary Algorithm, Evolutionary Robotics, Neuro-Evolution, Behavior, Exploration, Diversity, Novelty.

## 1. TOPIC

Developmental robotics (also known as epigenetic robotics) is mainly concerned with modeling the postnatal development of cognitive behaviors in living systems, such as language, emotion, curiosity, anticipation, and social skills. While current work in this field has shown significant successes, several aspects can be added to go even further. First, ontogenetically, mental development is based on and closely coupled with physical development of an organism, including development of both the body plan and the nervous systems. Autonomous mental development in living system was gradually shaped by a brain-body co-evolution embedded in a changing environment. The introduction of morphogenetic robotics addresses this first challenge in developmental robotics to a certain extent by integrating mental and physical development. Second, biological evidence suggests that autonomous mental development is driven by intrinsic motivational systems among others. Current robotics systems have a predefined intrinsic motivation system. However, the evolutionary origin that accounts for both physical and mental development is still missing. Evolutionary robotics applies evolutionary algorithms to the automatic design of neural controllers for autonomous robots without considering the role of development. Thus, integrating research on developmental (including epigenetic and morphogenetic) robotics and evolutionary robotics is the natural next step. Developmental plasticity can not only bias evolution, but also enhance evolvability by maintaining genetic diversity in changing environments and resolving robustness-variability trade-off. Therefore, we believe that it is high time to bring together evolutionary robotics and developmental robotics to form a new research area: evolutionary developmental robotics (evo-devo-robo).


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## 2. INVITED TALKS

### 2.1 The iCub and Developmental Robotics

*G. Metta (Italian Institute of Technology, Italy).*

My talk consists of two parts. I will first introduce the iCub, a fully opensource humanoid robot specifically designed for researchers interested in embodied cognition. I will talk about the design, sensors, and basic behaviors, e.g. attention, reaching, grasping, as developed by a large community of researchers. I will then enter more into the details of some of my research where the concept of affordances and the connection between motor control and perception is analyzed. I will show how this more blue sky research will one day merge into the iCub available skills.

### 2.2 Evo-Devo-Robo De Novo: What does Devo Buy Us?

*J. Bongard (University of Vermont, USA).*

Embodied cognition research demonstrates that the body plays an important role in the generation of adaptive behavior. The 'development' of Evo-Devo-Robo indicates that some aspect's of the robot's phenotype should change over its lifetime. However, this change is usually confined to the neural control of the robot. In our work we investigate how morphological change over the lifetime of the robot can positively impact the acquisition of adaptive behavior. In this talk I will survey some of these results and discuss implications for future work.

## 2.3 Morphogenetic Engineering: Reconciling Architecture with Self-Organization

*R. Doursat (Universidad de Málaga (UMA), Spain).*

Multicellular organisms and social insect constructions are rather unique examples of naturally evolved systems that exhibit both self-organization *and* a strong architecture. Can we export their precise self-formation capabilities to technological systems? I have proposed a new research field called "Morphogenetic Engineering", which explores the artificial design and implementation of complex, heterogeneous morphologies capable of developing without central planning or external lead. Particular emphasis is set on the *programmability* and controllability of self-organization, properties that are often underappreciated in complex systems science–while, conversely, the benefits of multi-agent self-organization are often underappreciated in engineering methodologies, including evolutionary computation. In this talk I will present various examples of morphogenetic engineering, in particular multi-agent systems inspired by biological development based on gene regulation networks, and self-construction of graph topologies based on "programmed attachment" rules. Potential applications range from robotic swarms to autonomic networks and socio-technical systems. In all cases, the challenge is to "meta-design", especially through an evolutionary search, the proper set of rules followed by each agent of a complex system on how to interact with the other agents and the environment. Whether "offline" (slow time scale), where agents always share the same genotype, or "online" (fast time scale), where agent types may diverge and specialize dynamically, it constitutes an inherently massively parallel "artificial evo-devo" (evolutionary developmental) problem.

## 2.4 Soft Robotics Approach to Artificial Morphogenesis

*F. Iida (ETH Zurich, Switzerland).*

Artificial ontogenetic development is a highly interesting research area, which have been nicely demonstrated by many computer simulation studies in the past. There are, however, still a number of technical challenges if we attempt to bring it to the real world. In this presentation, I will introduce some potential solutions to this challenging problem stemmed from soft robotics research. More specifically, we demonstrate how autonomous construction, autonomous body extension, and autonomous robot climbing locomotion can be achieved by exploiting unconventional soft material, the so-called Hot Melt Adhesives.

## 2.5 Environment-driven Evolutionary Adaptation for Swarm Robotics

*N. Bredèche (Université Paris Sud, France).*

We will present our recent work in the scope of the european Symbrion Integrated Project on Embodied Evolution for swarm of robotic units in order to achieve self-sustainability, rather than optimizing a pre-defined objective. This work is concerned with a fixed-size population of autonomous agents facing unknown, possibly changing, environments. The motivation is to design an embodied evolutionary algorithm that can cope with the implicit fitness function hidden in the environment so as to provide adaptation in the long run at the level of the population. We will describe several recent contributions, including achieving robustness to environmental changes, learning altruistic behaviors and considerations with respect to behavior specialization. Experiments in both simulated environment and real robots will be shown and discussed.

## 2.6 Evolving Robot Teams through Multiagent HyperNEAT

*K. Stanley (University of Central Florida, USA).*

In the past most machine learning approaches for training multiagent behavior were based either on multiagent reinforcement learning (MARL) or coevolution, which both focus on separately training individuals that learn to cooperate. However, indirect encoding and generative and development systems have recently opened up a new possibility for multiagent learning: A set of heterogeneous policies for every agent on a team can potentially be compactly encoded by a single genome. That way, the policies can all share common regularities (which would need to be learned separately by traditional methods) because they are all encoded by the same genetic source. Another interesting implication is that it may be possible to encode very large teams that can change in size. This talk will describe the multiagent HyperNEAT approach that realizes this vision and then review the results of the last several years of research into indirectly-encoded robot teams with multiagent HyperNEAT.

## 2.7 Autonomous Exploration Through Curiosity and Social Guidance

*M. Lopes (INRIA Bordeaux, France).*

An evolving and developing agent has to acquire many different perceptual, motor and cognitive skills during its lifetime. Learning such skills requires suficient experience for achieving a behavioral robustness in different situations and to generalize to future unexpected events. In this talk I will address the problem of autonomous exploration where the agent is active and choosing what, when and where to learn. Instead of waiting for relevant information, it is the agent that searches the information that reduces its uncertainty or that provides a maximum progress of learning. The agent will also use as source of information its peers. I will consider methods from active learning, intrinsic motivation systems and social learning.