The IM-CLeVeR Project: Intrinsically Motivated Cumulative Learning Versatile Robots

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Abstract

This short paper presents the core ideas of the IM-CLeVeR Project. IM-CLeVeR aims at developing a new methodology for designing robot controllers that can: (a) cumulatively learn new skills through autonomous development based on intrinsic motivations, and (b) reuse such skills for accomplishing multiple, complex, and externally-assigned tasks. This goal will be pursued by investigating three fundamental issues: (a) the mechanisms of abstraction of sensorimotor information; (b) the mechanisms underlying intrinsic motivations; (c) hierarchical architectures that permit cumulative learning. The study of these issues will be conducted on the basis of empirical experiments run with monkeys, children, and human adults, with bio-mimetic models aimed at reproducing and interpreting the results of such experiments, and through the design of innovative machine learning systems. The models, architectures, and algorithms so developed will be validated with experiments and demonstrators run with the simulated and real iCub humanoid robot.

1. Introduction

How can we create truly intelligent and autonomous machines and robots? This goal has both a huge technological and scientific importance. As a technology, autonomous intelligent machines can be exploited, for example, to perform repetitive tasks that humans do not like to carry out and conduct missions in hostile environments. On the scientific side, the ability to construct truly intelligent machines can shed new light on the mechanisms underlying learning and intelligence of humans and other primates, thus also enabling better treatments of psychiatric and neurological disorders.

The IM-CLeVeR project aims at developing a new design methodology for building autonomous intelligent robots based on intrinsically-motivated cumulative learning of skills. The central idea behind this new design methodology is that, instead of directly programming, training or evolving a set of specific skills in robots, we should endow them with developmental programs that allow an autonomous development of the needed skills on the basis of prolonged periods of interactions with the environment under the guidance of intrinsic motivations. Robots could then use the general abilities so acquired as building blocks for the solution of tasks that are relevant for the robot's users. Notice how these types of processes mark some of the most intelligent aspects of complex

organisms' behaviour, in particular human and non-human primates. For example, children at play carry out several activities driven only by intrinsic motivations such as curiosity. These activities allow them to acquire knowledge and skills exploited in later adult stages to pursue useful goals. The main objectives of the project will be pursued with these phenomena in mind.

2.   Research issues

The central working hypothesis of the project is that cumulative, open-ended learning in artificial systems must be based on three fundamental principles:

1. Hierarchical architectures. Cumulative learning architectures for controlling robots should have the capability of developing sensorimotor and cognitive skills in an incremental hierarchical fashion. This requires: (a) acquiring skills and systematically increasing their complexity; (b) learning new skills using previously acquired skills as building blocks; (c) storing new skills without forgetting (and possibly improving) previously acquired ones.

2. Novelty detection and intrinsic motivations. A cumulative learning robot needs internal drives that focus learning on skills that: (a) are novel for the robot; (b) are within the robot's 'zone of proximal development' – that is the robot has the drive to learn new skills that can be acquired on the basis of those already in its repertoire. To achieve this, the robot should be endowed with 'intrinsic motivations' that lead it to autonomously engage in activities that produce the maximum learning rate and/or information gain. Internal motivations differ from external motivations and rewards as the latter are associated with the practical outcomes that actions produce on the external world (e.g., food or sex in organisms or accomplishment of users' goals in robots). Intrinsically motivated learning must rely on 'novelty detectors', devices capable of monitoring and measuring the level of subjective novelty of action outcomes and learning rates so as to focus robot's activity on suitable experiences and boost learning speed.

3. Sensory abstraction and attention. Although sensory abstraction is a widely-investigated topic in cognitive sciences (e.g. in computer vision), the project will aim at isolating and studying the particular problems of abstraction related to the specific topics of the project, namely novelty detection and hierarchical architectures for cumulative learning.

3.   Objectives

IM-CLeVeR has four main scientific and technological objectives:

1. To advance our knowledge about how cumulative learning is achieved in natural organisms. To this purpose, the project involves the implementation of empirical non-invasive experiments on intrinsically motivated learning in monkeys, children, human adults, and Parkinson patients, on the basis of novel experimental paradigms suitable for studying exploration, novelty detection, and the (cumulative) acquisition of novel actions".

2. To advance our knowledge about the mechanisms underlying intrinsically motivated cumulative learning in natural organisms. To this purpose, the project will develop bio-mimetic models (including both computer simulations and robotic experiments) aiming at reproducing and explaining the empirical findings provided by the aforementioned empirical experiments. In addition to its scientific value, this effort will also allow isolating new computational principles exploitable in robots.

3. To develop new machine learning techniques, architectures, and learning algorithms for the optimal design of cumulative learning robots. In particular, the project will aim at making substantial progress in the three distinct but related principles of the project working hypothesis: (a) hierarchical architectures, (b) intrinsic motivations, and (c) perceptual abstraction and attention.

4. To integrate the knowledge gained by the empirical experiments, the bio-mimetic computational models developed to interpret them, and the machine learning architectures and algorithms for building real robots demonstrating cumulative learning abilities. This challenge will involve the use of three iCub humanoid robotic platforms for the development of two demonstrators: CLEVER-K, a technologically-oriented demonstrator that will be tested in a kitchen scenario, and CLEVER-B, a demonstrator with which will be used to reproduce and interpret the results of the experiments carried out with monkeys and children.

Acknowledgements