Guest Editorial
Emerging Topics on Development and Learning

I. Scope of this Special Issue

This special issue includes state-of-the-art research on emerging topics on development and learning in natural and artificial systems. In addition to new submissions, the special issue includes extensions of the paper awarded the *Best Paper Award* at ICDL-EpiRob 2020 – the 10th Joint IEEE Conference on Development and Learning and Epigenetic Robotics 2020 (https://cdstc.gitlab.io/icdl-2020/).

This special issue has a focus on development and learning from a multidisciplinary perspective gathering researchers from computer science, robotics, psychology, and developmental studies. Researchers share their knowledge and research on how humans and animals develop sensing, reasoning and actions, and how to exploit robots as research tools to test models of development and learning.

The submitted contributions emphasize the interaction with social and physical environments and how cognitive and developmental capabilities can be transferred to computing systems and robotics. This approach goes hand in hand with the goals of both understanding human and animal development and applying this knowledge to improve future intelligent technology, including for robots that will be in close interaction with humans.

II. Themes

This special issue reports state-of-the-art approaches and recent advances on Development and Learning with a cross-disciplinary perspective. Topics included in this special issue are:

- Principles and theories of development and learning
- Development of skills in biological systems and robots
- Models on the contributions of interaction to learning
- Models on active learning
- Cognitive Robotics
- Prospective behavior and memory
- Architectures for lifelong learning
- Models for prediction, planning and problem solving
- Epistemological foundations and philosophical issues
- Robot prototyping of human and animal skills
- Ethics and trust in computational intelligence and robotics

III. Contributions to the Special Issue

This special issue includes four papers that describe work inspired by developmental processes. They cast light on this topic from multiple angles. We briefly highlight each paper's main contributions and their field of application as follows.

Understanding time perception mechanisms provide an incredible opportunity for cognitive robotics and artificial intelligence. To include temporal information in the decision-making process represents a milestone in artificial agents providing new strategies for planning, recalling experiences, and communication with other agents. On the other hand, time perception modelling is challenging, especially because internal neural mechanisms and environmental stimuli are combined in the decision-making process. Lourenço et al. address this subject in the article entitled *A Biologically-Inspired Computational Model of Time Perception* where they suggest a neural mechanism model based on reinforcement learning to be implemented in an artificial agent performing time-aware actions. Using a robotic platform, the authors evaluate the ability of a robot to distinguish time intervals classifying them into different categories. These results were compared with mice data obtaining similar results, evidencing the capacity of the model to mimic biological principles exploiting temporal information in time-aware actions. On the other hand, matching behavioural data with the model predictions, the authors estimate some reinforcement learning framework parameters related to the agent's internal timing mechanisms. Using a maximum-likelihood estimator, the authors infer biological characteristics of time perception neural mechanisms and conditions where the estimation improves. Merging time perception mechanisms with various sensory information in the decision-making process is a natural extension of this approach that can be easily implemented in artificial agents acting in complex and varying scenarios. Adding different time scales of fitting the model for other animal data (e.g., humans) are also interesting paths to explore as further work.

The following article studies the Contrastive Multiview Visual Representation Learning (CMVRL) framework from a cognitive and developmental point of view. The CMVRL framework has recently gained attention in the unsupervised representation learning community. CMVRL builds a representational space where pairwise similarities between inputs produced via data augmentation are enforced as metric constraints by a Contrastive Learning loss. In particular, Laflaquière in the article titled *A Sensorimotor Perspective on Contrastive Multiview Visual Representation Learning* analyse the CMVRL framework from a perception perspective by drawing a parallel between the training procedure of contrastive multiview representation learning and the sensorimotor experience that a robot would collect by actively exploring its environment. Thus, the authors propose that the data augmentation strategies used in the literature can be interpreted as a first-order approximation of the transformations that an active agent experiences when physically exploring its environment. Laflaquière hypothesise that the pairwise similarity relations generated in CMVRL can be interpreted as approximations of sensorimotor reachability, which characterises if an agent can transform one sensory input into another. Moreover, they propose that the use of a contrastive loss drives representations to be invariant to these spatio-temporal transformations while still being discriminative between different local explorations and their semantic content. Finally, Laflaquière also discuss the relevance of CMVRL in light of contemporary active, dynamical, and hierarchical theories of perception and extrapolates this sensorimotor perspective to outline promising future research directions.

The following article by Pitti et al. in the article entitled *In Search of a Neural Model for Serial Order: A Brain Theory for Memory Development and Higher-Level Cognition* advocate that the prefrontal cortex (PFC) is instrumental in the development of abstract thinking and to the hierarchical organisation of the brain. Further, the authors suggest that infants prefrontal cortex primary function is to detect hierarchical patterns in temporal signals in the form of ordinal patterns and use them to index information. As suggested by the authors, the second function of the immature PFC is to organise the spatial ordering of the cortical networks from which information can be retrieved from different parts of the brain. Pitti et al. support this proposal with references from different neuroscientific research and also build on top of similar proposals. However, beyond the neuroscientific interpretation, Pitti et al. also discuss the pros and cons of several existing neural models as potential candidates to implement different aspects of this proposal, they include Task-setting Networks, Hierarchical Tree Networks, Reservoir Computing, and Gain-Modulatory Networks. In particular, the authors derive possible implementations and the merits of these neural models from the learning mechanism of spike-timing-dependent plasticity (STDP) to code ordinal patterns into rank-order codes. Pitti et al. advocate for the concept that the neocortex organises information into hierarchies and small-world dynamics, which in turn is a fast and robust mechanism of information retrieval avoiding catastrophic forgetting.

Finally, Bennett et al. in the article entitled *Philosophical Specification of Empathetic Ethical Artificial Intelligence* address a very timely topic for research on embodied cognition, namely how to build an Ethical Artificial Intelligence. The paper targets explicitly the need of avoiding methods based on predefined rules or simply mimicking behaviour because a mimicking AI would simply react, and it cannot infer the goals or beliefs of others. In both cases, i.e., obeying predefined rules or mimicking behaviour, the agent cannot predict whether its actions will be considered ethical. Thus, Bennett et al. argue that an ethical framework must be learned instead of hardcoded, and consequently, an ethical agent must infer what is ethical. This implies that the agent must learn an explicit concept of ethics by observing and communicating with humans to infer what most humans would consider ethical. In the search for an ethical agent, the authors follow an enactivist approach where cognition arises through a situated agent interacting with its environment through its sensors and actuators. Embodiment is central in providing a perceptual symbol system (where symbols represent the states of sensors and actuators) which, in turn, constitutes the basis for the emergence of an abstract symbol system supporting the ability of an agent to learn not just arbitrary relations between signs but their meaning in terms of the states of its sensorimotor system. The model proposed in this article targets ethics not based on correlated information but on the observable causal relationship. The agent does not learn a function but the rules by which a human judges the ethical value of an action.

IV. Conclusion

The articles presented in this special issue represent some of the current challenges and implications of development and learning in biological and artificial systems. These articles show state-of-the-art results for various applications and settings: sensorimotor internal representation and transformation, robots internalizing the concept of time, the emergence of abstract reasoning, and ethical behaviour learning.

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Nicolás Navarro-Guerrero is a Senior Researcher at the German Research Center for Artificial Intelligence GmbH. He received a degree in Electronic Engineering from the Universidad Técnica Federico Santa María, Valparaíso, Chile, in 2010. Where he specialised in embedded systems and artificial intelligence. In 2016 he completed a Ph.D. in Computer Science at the University of Hamburg (Germany) under the supervision of Prof. Stefan Wermter. His dissertation concerned computational models for adaptive robot behaviour based on neural self-preservation mechanisms. Between 2017 and 2021, Nicolás was an Assistant Professor at Aarhus University, where he co-founded and coordinated the multidisciplinary AU Social Robotics Lab, co-founded the AU ENG Makerspace and established the Latin American Summer School on Cognitive Robotics (LACORO). He is a member of the editorial board of the journals IEEE TCDS, Frontiers in Neurorobotics, two speciality sections of the journal Frontiers in Robotics and AI, and reestablished and chaired between 2018 and 2021 the Task force on "Action and Perception" of the IEEE Technical Committee on Cognitive and Developmental Systems. Nicolás' research activities focus on cognitive-inspired and embodied intelligent systems. For more information visit his webpage: https://nicolas-navarro-guerrero.github.io

Javier Ruiz-del-Solar received his degree in Electrical Engineering from the Universidad Tecnica Federico Santa Maria (Chile) in 1991, and the Doctor-Engineer degree from the Technical University of Berlin in 1997. Since 2009 he has been Executive Director of the Advanced Mining Technology Center (AMTC) at the Universidad de Chile. His main research interests include fundamental research in perception and learning and applications of robotics technology in the real world. In recent years his research has focused on the application of deep reinforcement learning to mobile robotics applications.

Giulio Sandini is a Founding Director of the Italian Institute of Technology, where in 2006 he established the department of Robotics, Brain and Cognitive Sciences. As a research fellow and Assistant Professor at the Scuola Normale in Pisa and Visiting Researcher at the Neurology Department of the Harvard Medical School, he investigated visual perception and sensorimotor coordination in humans and technologies for Brain Activity Mapping in children with learning disabilities. As a professor of bioengineering at the University of Genova in 1990, he founded the LIRA-Lab (Laboratory for Integrated Advanced Robotics, www.liralab.it), which became the birthplace of the iCub humanoid robot. In 1996 he was Visiting Scientist at the Artificial Intelligence Lab of MIT. Giulio Sandini research activity is characterized by an engineering approach to the study of natural intelligent systems, focusing on the design and implementation of artificial systems to investigate the development of human perceptual, motor and cognitive abilities (and vice versa).