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Computational modeling in cognitive neuroscience: from neurons to robots

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Developmental Robotics: From Babies to Robots

Prof. Angelo Cangelosi
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Growing theoretical and experimental research on action and language processing and on number learning and space representation clearly demonstrates the role of embodiment in cognition and language processing. In psychology and neuroscience this evidence constitutes the basis of embodied cognition, also known as grounded cognition. In robotics, these studies have important implications for the design of linguistic capabilities in cognitive agents and robots for human-robot communication, and have led to the new interdisciplinary approach of Developmental Robotics. During the talk we will present examples of developmental robotics models and experimental results from iCub experiments on the embodiment biases in early word acquisition studies, on word order cues for lexical development and number and space interaction effects. The presentation will also discuss the implications for the "symbol grounding problem" and how embodied robots can help addressing the issue of embodied cognition and the grounding of symbol manipulation use on sensorimotor intelligence.

Angelo Cangelosi is Professor of Artificial Intelligence and Cognition and the Director of the Centre for Robotics and Neural Systems at Plymouth University (UK). Cangelosi studied psychology and cognitive science at the Universities of Rome La Sapienza and at the University of Genoa, and has been visiting scholar at the University of California San Diego and the University of Southampton. Cangelosi's main research expertise is on language grounding and embodiment in humanoid robots, developmental robotics, human-robot interaction, and on the application of neuromorphic systems for robot learning. He currently is the coordinator of the UK EPSRC project "BABEL: Bio-inspired Architecture for Brain Embodied Language" (2012-2016), and previously coordinated the Marie Curie ITN "RobotDoC: Robotics for Development of Cognition" (2009-2014) and the FP7 Integrating Project "ITALK" (2008-12). He also is Principal investigator for the ongoing projects "THRIVE" (US Air Force Office of Science and Research, 2014-1018), the FP7 projects POETICON++ and ROBOT-ERA, and the Marie Curie projects SECURE, ORATOR and DECORO. Overall, he has secured over £10m of research grants as coordinator/PI. Cangelosi has produced more than 200 scientific publications, and has chaired numerous workshops and conferences including the IEEE ICDL-EpiRob 2011 and 2013 Conferences (Frankfurt 2011, Osaka 2013). In 2012-13 he was Chair of the IEEE Technical Committee on Autonomous Mental Development. In January 2015 he became Editor-in-Chief of the *IEEE Transactions on Autonomous Development*, and also is Editor (with K. Dautenhahn) of the journal *Interaction Studies*. His latest book "Developmental Robotics: From Babies to Robots" (MIT Press; co-authored with Matt Schlesinger) has just been released, as of January 2015.

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Probabilistic model of goal-directed choice and their neurophysiological substrate

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Probabilistic models of brain and cognition start from the assumption that the brain represents probability distributions and uses (forms of) probabilistic inference to perform cognitive operations. Several probabilistic models have been recently developed that cover a variety of domains, from perception to sensorimotor action, categorization, and language processing. Given that probabilistic models have been applied to a variety of domains and levels of analysis, some researchers believe that they can offer a unified view of brain and cognition (a so-called "Bayesian brain" hypothesis). In this talk I will present some examples of probabilistic models, focusing on the domain of goal-directed decision-making. I firstly discuss the probabilistic (and generative) approach to goal-directed decision-making, introducing several families of (related) probabilistic models: active inference, planning-as-inference, and (probabilistic) model-based reinforcement learning. A recurrent theme across these models is that their model-based and generative nature: they use (innate or learned) task models - which encode hypotheses on task structure and contingencies - to make inference and ultimately to select goal-directed actions. Therefore, I will describe some probabilistic models of goal-directed choice that my collaborators and I have recently developed. I will focus mainly on two tasks - a perceptual choice between response alternatives, and a foraging task - discussing both the functioning of the models and the ways they link to neuronal representations in monkeys prefrontal cortex and rodent hippocampus-ventral striatum circuits, respectively.

Giovanni Pezzulo is a researcher at the Institute of Cognitive Sciences and Technologies, National Research Council of Italy, Rome. He uses an interdisciplinary research methodology, which combines computational modeling, robotics, theoretical and empirical research. One of his most recent research topic is goal-directed decision-making. He was recently awarded with a Young Investigators' Grant by the Human Frontier Science Program (HFSP), for the project "Beyond simple choices: computational and neuronal mechanisms for complex spatial behaviors" that studies goal-directed navigation and planning mechanisms in the rodent hippocampus. He was Project Coordinator of the EU-funded project Goal-Leaders, (Goal-directed, Adaptive Builder Robots), which combined neurophysiology, computational modeling and robotics to study the neuronal mechanisms underlying goal-directed action control and choice. He recently guest-edited a special issue on "The principles of goal-directed decision-making: from neural mechanisms to computation and robotics" in the Philosophical Transactions of the Royal Society B Journal (Elsevier), 2014.

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Deep learning models of perception and cognition

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Deep learning in stochastic recurrent neural networks with many layers of neurons ("deep networks"), is a recent breakthrough in neural computation research. These networks build a hierarchy of progressively more complex representations of the sensory data by fitting a hierarchical generative model. Generative learning is unsupervised –it does not require any goal or reward – and it provides a strong hypothesis about the role of feedback connections in the cortex. In this talk I will discuss the theoretical foundations of this approach and show how deep networks can be successfully exploited for developing state-of-the-art computational models of perception and cognition. I will present examples from our modeling studies of numerosity perception, written language processing, and space coding to illustrate how structured and abstract representations may emerge from deep generative learning. I will argue that the focus on deep architectures and generative (rather than discriminative) learning represents a crucial step forward for the connectionist modeling enterprise, because it offers a more plausible model of cortical learning as well as way to bridge the gap between emergentist connectionist models and structured Bayesian models of cognition.

Marco Zorzi is Full Professor of Artificial Intelligence and Cognitive Psychology at the University of Padova, and Senior Researcher at IRCCS San Camillo Neurorehabilitation Hospital in Venice-Lido. He is the director of the Computational Cognitive Neuroscience Lab, an interdisciplinary research laboratory at the frontiers between cognitive science, computer science and neuroscience. He is currently the coordinator of the University of Padova Strategic Grant "The cognitive neuroscience of attention in perception and cognition" (2014-2017) and co-PI on CARIPARO Foundation Excellence Grant "A novel approach to wireless networking inspired by cognitive science and distributed computing". His work was previously supported by a prestigious award from the European Research Council ("Generative models of human cognition"; ERC-StG 2008-2013) and by grants from many other funding agencies (European Commission, FP7 Marie Curie ITN and FP6 Marie Curie RTN; CARIPARO Foundation Excellence Grant 2008; Compagnia di San Paolo Neuroscience Program; MIUR-PRIN; McDonnell-Pew Cognitive Neuroscience Program, USA). Research in his laboratory is focused on the computational bases of cognition, from development to skilled performance and to breakdowns of processing in atypical development or after brain damage. Computational modeling is complemented by empirical research based on a combination of behavioral methods (reaction times and psychophysics), neuropsychology, and functional neuroimaging (fMRI, fNIRS, EEG). The main research line are numeracy and number processing, attention and spatial cognition, reading and dyslexia. He has authored more than 100 articles in international journals.

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