Cognitive Development and the *iCub* Humanoid Robot

Keynote Talk

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In this talk we consider the role of humanoid robotics in cognition research and we discuss in particular the *iCub* humanoid robot, the motivation for its creation, the specific paradigm of cognition that has been adopted in its design, and we address the attendant phylogenetic and ontogenetic implications from both neuro-physiological and psychological perspectives. We consider what development means in this context and we provide an overview of the progress that has been made so far.

The *iCub* is a humanoid robot R&D platform for modelling the development of cognitive capabilities. It was created by the recently-completed RobotCub project[1] as a freely-available open system to be used by research groups across Europe and elsewhere. To date, fifteen robots have been shipped and a further five are in production. This has created an extensive community of users and developers who all share their work, and specifically their software, on the *iCub* website. By developing on a common platform, results can be directly replicated, evaluated, and improved by other R&D teams.

One of the chief tenets underlying the design of the *iCub* that action is the organizing principle in cognitive behaviour and, in particular, that manipulation plays a key role in this development. As such, the complexity and sophistication of cognitive behaviour is dependent on the richness and diversity of the perceptual and motoric repertoire. Consequently, the design of the *iCub* was aimed at maximizing the number of degrees of freedom of the upper part of the body (head, torso, arms, and hands). The lower body (legs) supports crawling on arms and legs and sitting on the ground in a stable position. This allows the robot to explore the environment and to grasp and manipulate objects on the floor. The total number of degrees of freedom is 53 (7 for each arm, 9 for each hand, 6 for the head and 3 for the torso and spine). Each leg has a further 6 degrees of freedom. The sensory system includes binocular vision and haptic, cutaneous, aural, and vestibular sensors.

Whilst the *iCub* can support any cognition paradigm, it was designed with the specific objective of furthering the enactive systems paradigm. Enaction is based on five central principles: embodiment, experience, emergence, autonomy, and sense-making. Cognition is the process by which the issues that are important for the continued operation of a cognitive entity are brought out or enacted: co-determined and co-developed by the entity as it interacts with the environment in which it is embedded. An enactive cognitive agent is embodied and embedded in the environment and is specified by it. At the same time, the process of cognition determines what is real or meaningful for the agent. Ultimately, this means that the system's perceptions reflect those actions which are consistent with the maintenance of the system's autonomy. Thus, an enactive cognitive agent constructs its reality as a result of its operation in that world and therefore cognitive understanding is intrinsically specific to the embodiment of the system and dependent on the system's history of interactions, i.e., its experiences. Thus, nothing is 'pre-given'. Instead there is an enactive interpretation: a real-

[1] RobotCub, Project IST-004370, was funded by the European Commission under Strategic Objective 2.3.2.4: Cognitive Systems.

time context-based choosing of relevance. This is often referred to as 'sense-making'. For enactive systems, the purpose of cognition is to uncover unspecified regularity and order that can then be construed as meaningful because they facilitate the continuing operation, development, and autonomy of the cognitive system.

The *iCub*'s software – encapsulating its perception-action skills – was and continues to be developed on the basis of an extensive roadmap for the development of cognitive capabilities. This roadmap is founded on the phylogeny and ontogeny of natural cognitive systems, embracing the perspectives of both neuro-physiology and developmental psychology. The roadmap asserts the dual purpose of development to improve the prospective capability of the cognitive system and the consequent expansion of its space of effective actions. It also identifies the key features that a system capable of cognitive development should exhibit and, in particular, it identifies the requisite constituents of the *iCub* phylogeny and sets out several scenarios for the *iCub*'s ontogeny.

In this talk, we illustrate the foregoing issues by considering the progress that has been made to date in using the *iCub* to develop cognitive capabilities, addressing, for example, selective visual and aural attention, sensorimotor coordination, learning to reaching & grasp, learning affordances, locomotion, imitation and social interaction, as well as their relationship to the *iCub* cognitive architecture.

For more information on the *iCub*, please refer to the *iCub* and RobotCub websites: www.icub.org and www.robotcub.org.