Artificial cognitive functions towards AI-enabled collaborative robots

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ABSTRACT

In this paper we discuss work in progress and our approach to next generation robotics. The use of cognitive architectures can overcome some of the challenges encountered when Artificial Intelligence (AI) algorithms are introduced to robotic systems. New cognitive functionality is required to that end. We discuss system requirements that are currently not sufficiently addressed, and present our current work.

CCS CONCEPTS

• **Computing methodologies** → **Cognitive robotics**; **Artificial intelligence**.

KEYWORDS

AI-enabled robotics, artificial cognition, robotics, intelligent systems

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1 INTRODUCTION

Although impressive, current robotic systems are good at performing relatively limited, repetitive, and well-defined tasks under specific conditions, however, anything beyond that requires human supervision. At the moment, it is not quite possible to deploy robots in new environments, broaden the scope of their operation, and allow them perform diverse tasks autonomously, as systems are not versatile, safe, nor reliable enough for that. Pre-programmed and pre-configured robots lack the ability to adapt, learn new tasks, and adjust to new domains, conditions, and missions [21].

Artificial Intelligence (AI) has progressed tremendously especially during the past decade, yet AI has only barely been incorporated in robotics, and the progress in robotics lags significantly. Currently AI is extremely data-hungry, and robots are expensive to run. Also robots have bodies that can do a lot of harm if they should malfunction, hence giving them more freedom to act independently cannot happen unless they are able to perform well, predictably and reliably. Robot applications in our close everyday environment require them to become autonomous systems with situational awareness, able to perform complex tasks in a real environment, in proximity of humans, interact and collaborate with humans effectively and safely, and be trained directly by humans. This is not an incremental change. A lot of AI methods and tools have matured and are available to build upon, yet the technology for this transformation is not yet available. It requires a major paradigm shift from current specialized and pre-configured robots – to AI-enabled human-centic collaborative robots.

Cognitive robotics is a multidisciplinary research field that has gained increased interest recently as it has become apparent that an advanced system architecture is a prerequisite for progressing from specialized "caged" systems to real-life autonomous systems [5]. In this article we present work in progress, and our approach to AI-enabled next-generation robotics. Our approach builds on the hypotheses [22] that a cognitive architecture is required in order to develop robots that are intelligent enough to be deployed in real-life systems in the vicinity of humans, and that to that end we need to encompasses some of the processes of the right hemisphere of the human brain – such as situational awareness and holistic perception, holistic evaluation, intuition, imagination, and moral reasoning. We elaborate on these in this short paper.

2 AI-ENABLED ROBOTICS

Robots are very productive, yet a lot of what is simple for humans to perform is extremely complex and currently impossible for robots. For example, robots are unable to successfully transfer knowledge between similar but distinct tasks (e.g. apply knowledge from playing squash to learn playing tennis). AI-enabled robots currently cannot manage to learn new skills without forgetting old skills, termed "catastrophic forgetting" [12]. The human brain is the most advanced system we know of. It comprises two interconnected hemispheres – the left and the right – that have distinct functions and operate in different ways. The left hemisphere stands for linear thinking, detail-oriented perception, facts processing, computations, language processing, planning, logic. The right hemisphere stands for holistic perception, intuitive learning, ambiguity handling, imagination, creativity, emotional and moral cognition, holistic thinking and decision making. The ability of humans to abstract, conceptualise, adapt, learn new skills, and be as ingenious and efficient problem-solvers as we are in a real environment, relies on engaging both brain hemispheres.

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Cognition encompasses the mental functions by which knowledge is acquired, retained, and used [10], mainly: perception, attention, memory, learning, language, thought, emotion [2]. In humans, it encompasses processes such as comprehension, judgment and evaluation, reasoning and computation, problem solving and decision making, and production of language. In order to realize such functionality in artificial systems, one needs to define an architecture that describes and governs these processes. Such system architectures are inspired by human cognition. They comprise the necessary modules for taking care of individual processes at many levels, and for overall system operation, as well as define the way information flow takes place for knowledge acquisition, reasoning, decision making, and detailed task execution. Current models of human cognition are computational in nature and represent primarily the functions of the left hemisphere. The operation and processes of the right hemisphere are less understood, and they are by and large not included in the models of human cognition.

Several cognitive architectures can be considered for artificial cognition, some of these model human cognition, others are built specifically for artificial agents [1]. Among the most commonly used are: ACT-R [3], SOAR [13], LIDA (Learning Intelligent Distribution Agent) [8], KnowRob 2.0 [4], Icarus [14], Clarion [18]. Artificial cognition builds on models of human cognition, and hence lacks most of the functionality of the right hemisphere that arguably makes it possible for us to perform and learn as flexibly and effectively as they do. Ideally, a cognitive robot shall be able to abstract goals and tasks, combine and manipulate concepts, synthesize, make new plans, learn new behaviour, and execute complex tasks - abilities that at the moment only humans acquire, and lie in the core of human intelligence. Cognitive robots shall be able to interact safely and meaningfully and collaborate effectively with humans.

Our approach to AI-enabled robotics is to incorporate some of the cognitive functions of the human brain that current artificial cognition models have neglected - such as curiosity, creativity, moral evaluation and reasoning, and intuitive learning.

3 COGNITION-ENABLED ROBOTICS

Narrow-scope cognitive functionality has been implemented in robotic systems to enable their operation. Current systems incorporate relatively simple processes, mostly related with behavioral elements closest to the sensory input at the base of the cognition pyramid [19], whereas more advanced and complex cognitive processes are to a limited degree realised. *Perception* provides agents with relevant information from their environment. Beyond simple object recognition, advanced perception attempts to analyze the whole scene and reason on the content of the scene [15]. Scene understanding has been used for knowledge acquisition in ambiguous situations [9]. Semantic scene understanding, holistic perception, and situational awareness are only to a very basic extent realised thus far, merely at a proof-of-concept level. Despite the huge advances in speech analysis, translation, and synthesis, *Language* is currently merely incorporated as an input/ output interface in robotic systems, and is hardly included in any of the artificial cognitive processes [6]. *Learning* is a core cognitive function [16]. In current systems, it is closely woven with sensory-motor inputs and outputs, data processing, and perception, hence limited to the lower layers of the cognition. The pinnacle of cognition is *Thought*, reasoning, planning, decision making. A holistic approach to thinking with human-like cognitive reasoning and decision making processes, is far from realised, and thought processes are relatively basic at the moment.

Table 1: Functions of the Left and the Right hemisphere of the human brain

Left hemisphere	Right hemisphere
linear thinking	analog holistic thinking
computations	holistic perception
order	intuition
sequencing	imagination
logic	creativity
mathematics	arts
reading	rhythm
writing	feelings visualization
verbal	emotional evaluation
thinking in words	non-verbal cues

Emotion has only recently been recognized as a part of cognition in humans [20] as it has previously been considered as innately hardwired into our brains. Emotions are not incorporated in the thought process in any of the architectures or implementations, whereas in humans they often play a central role in decision making. A fair amount of work has been done on moral reasoning and logic [7] however, moral reasoning and evaluation is not yet incorporated in artificial cognition, neither is it an integral part of a holistic decision process. Although ethics and moral values may not be considered as part of cognition directly, in fact they play an important role in human decision making, govern human behavior, and in our opinion will be instrumental for developing responsible robots. Another relatively neglected area is artificial curiosity and imagination. This ability is critical for robots operating autonomously in unknown environments, and will allow them to effectively solve tasks even when their knowledge is not complete, and there is no human to provide the necessary information [17]. Finally, Intuition is the ability to understand or know something without needing to use reasoning. The mechanisms behind human intuition are not quite understood, however, it is evident that it is employed in knowledge transfer for learning new skills, as well as in decision making under ambiguous situations or when knowledge is highly incomplete [11]. A degree of intuition could guide new-task learning in artificial systems and lead to efficient knowledge transfer mechanisms.

4 SUMMARY

In this short paper we present our approach to next generation AI-enabled robotics and intelligent systems. The validity of our approach remains to be demonstrated. Artificial cognitive systems are emerging, and currently at a rather early stage of development. In our opinion, they are a cornerstone for unlocking the potential of robots and artificial intelligence, and enabling their use in real-life human-centric applications.

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