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Anticipation: Beyond synthetic biology and cognitive robotics

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ABSTRACT

The aim of this paper is to propose that current robotic technologies cannot have intentional states any more than is feasible within the sensorimotor variant of embodied cognition. It argues that anticipation is an emerging concept that can provide a bridge between both the deepest philosophical theories about the nature of life and cognition and the empirical biological and cognitive sciences steeped in reductionist and Newtonian conceptions of causality.

The paper advocates that in order to move forward, cognitive robotics needs to embrace new platforms and a conceptual framework that will enable it to pursue, in a meaningful way, questions about autonomy and purposeful behaviour. We suggest that hybrid systems, part robotic and part cultures of neurones, offer experimental platforms where different dimensions of enactivism (sensorimotor, constitutive foundations of biological autonomy, including anticipation), and their relative contributions to cognition, can be investigated in an integrated way.

A careful progression, mindful to the deep philosophical concerns but also respecting empirical evidence, will ultimately lead towards unifying theoretical and empirical biological sciences and may offer advancement where reductionist sciences have been so far faltering.

1. Introduction

The debate on the nature of cognition and the mechanisms that support it has been at the heart of one of the most profound areas of human inquiry. Some researchers and philosophers believe that there is a fundamental link between cognition and living (Thompson, 2007). As opposed to inanimate objects, which are passive recipients of external forces and disturbances, living systems seem to be characterised by their ability to act in the environment in a way that suggests goal-oriented behaviour. One of the characteristics that seem to be underpinning intentional and purposeful behaviour is an ability to act, taking into consideration future events.

Accounting for such intentional states, however, has been very problematic in traditional science, which is mostly dominated by the reductionist and Newtonian conception of causality, implying that physical laws admit state changes of physical objects only on the basis of past and current state. Causality understood in this way has been a sacro-sanct postulate in physics and, following its undeniable successes, has become a broadly accepted axiom across sciences.

Thus, teleology has been largely eliminated, at least from biological sciences, and some thinkers would even go as far as to deny goal-directedness of cognitive agents like ourselves. Others adhere to a computational view of cognition which, consistently with scientific position (currently accepted conception of computing is a classically causal mechanistic paradigm), deems the 'hard problem' as simply non-existent, (Dennett, 1996), or as a mere consequence of sufficient 'complexity' and computational power.

Enactive and embodied cognition propose that the computational account misses an important constituent, the embodiment in lived and living body, in order to provide a full account of mind states.

In response to the dissatisfaction with the purely computational accounts, the next generation of AI efforts broadly subscribing to embodied cognition consider augmentation of the traditional computing paradigm (discrete, symbolic) with robotic hardware body (amounting to analogue, continuous computing), as possessing sufficient explanatory power, at least in principle (O'Reagan, 2007; Haikonen, 2012).

Cognitive robotics has invigorated the enthusiasm in studying and perhaps even recreating at least certain aspects of cognition in purely man-made systems. This growing interest may be partly explained by the seeming balance struck by cognitive robotics. On the one hand it sits well in the embodied cognition framework, whereby sensorimotor accounts offer a natural conceptual framework and justification for this approach. On the other hand, it is still

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firmly tied to hard sciences, thus offering an opportunity to study and understand cognitive processes within an analytic framework.

However, the only truly cognitive system we know of are biological living organisms; an observation which would seem to suggest that the only approaches that can elucidate the most fundamental questions about the nature of life and cognition must involve biological, neuroscience and cognitive sciences. On that view robotic systems can never, in principle, offer satisfactory explanations. Hence, on this account, a cognitive robotics programme must fail where neurobiology and cognitive science prevail.

Nevertheless, the position put forward in this paper is more subtle. Both cognitive robotics and much of natural science share a common philosophical framework tantamount to a very mechanistic view of the world. We propose that this commonly inherited framework underlies common difficulties any of these approaches would have, when trying to provide an account of autonomous behaviour or intentionality. This is because there seems to be a deep chasm between our system of knowledge based on traditional science and our subjective experience, in light of which the ability to anticipate the future, and act on it, appears to be a rather basic property of agency in general and specifically of human agency.

We propose, largely following theoretical biologist Robert Rosen, that anticipation is one of the most fundamental characteristics of living, cognitive systems and that its proper account necessitates reframing the usual notions of causality and mechanism. In fact, although on the surface it may seem that anticipation requires the presence of a sophisticated cognitive system, forms of anticipatory behaviour have been observed even in unicellular organisms. It is altogether not too surprising, because the ability to modify behaviour in anticipation of the future may offer an adaptive advantage to organisms possessing it, thus may putatively playing a role in evolution.

In consequence, two questions arise. Firstly, what processes allow for anticipation to occur? And secondly, are there any common principles underpinning anticipation across different levels of organisms' complexity? Understanding such processes is interesting from a fundamental perspective as it may shed further light on the relationship between life and cognition and also for pragmatic reasons, as it may help us in constructing artifacts with an increased level of autonomy and robustness.

This paper will review some evidence pointing to processes and principles that may offer promising first steps towards our understanding of how anticipation could be realised in biological organisms. Moreover, they could help to reconcile much of traditional science with the notion of anticipation, following in the footsteps of researchers such as Rosen (2012), Louie (2010, 2012), and others, who laid the foundations for our understanding of anticipation. Hence, the answer to the original question of whether cognitive robotics or biological and cognitive sciences are more suited to characterise the most fundamental properties of living systems is neither of them, as long as they remain confined to the mechanistic explanations. Although it seems that cognitive robotics is thus bound to fail, more recent developments in the form of hybrid systems, animats, constituted by cultures of biological neurones embedded in a closed loop in robotic bodies, offer a possible way forward whereby robotics may still be relevant to elucidate such most fundamental issues.

The rest of the paper is organised as follows. Section 2 will discuss how cognitive robotics, building partly on Artificial Intelligence and partly on cybernetics, continuing the development within sciences of tries to provide a mechanistic account of cognition.

Section 3 will review some theories linking life, cognition and anticipation. The next section, Section 4, will discuss the evidence of anticipatory behaviour in organisms.

An approach that may help cognitive robotics to make steps beyond its mechanistic confines, is to use animats, part-machine part-biological hybrid entities. The animat platform is the focus of the penultimate Section 5. The conclusions end the paper with some caveats.

2. From scientific to cognitive robotics accounts of cognition

The attempts to clarify the nature of processes underpinning life and mind have often been pursued independently. This is especially true within the traditional reductionist science paradigm, which tries to isolate the properties in question and to understand them by reducing the above to their primary components. However, in spite of undeniable successes of modern science and medicine, these two problems have so far defied such an approach. It seems that as soon as we start concentrating on individual components and characterise their function mechanistically, we loose sight of the bigger picture and fail to notice that a mechanistic explanation may not be able to account for the highest level of organisation. Thus, within reductionist, mechanistic science paradigm we are then left with a dilemma – either accept that there is nothing more to living or sentience than mere mechanisms (albeit complicated ones) or abandon these questions altogether. The amalgamation of the two stances has characterised the mainstream science position at least since biology and psychology started to aspire to achieve the level of mathematical rigour enjoyed in XIX century physics.

The mechanistic tradition was somewhat continued in approaches rooted in Alan Turing's formalisation of computing operations. Turing wanted to provide a mechanistic minimal definition capturing the essence of operations performed by, then human, computors engaged in highly repetitive tasks used at the time for performing nontrivial calculations. A modern computer was born of these efforts and the Turing Machine (TM) now provides one of the most fundamental definitions of classical computing. The TM was a reflection of the mere fact that the cognitive system's (human computor) ability to follow formal rules can be successfully encapsulated in such a minimal formal mechanism. When combined with an enthusiastic belief that computers can compute anything worth computing (aka Church-Turing hypothesis), this led to a conclusion that the TM can account not only for cognitive system's ability of following formal rules but in fact for the entirety of cognition. Basing cognition on the TM paradigm seemed to have offered a step in the right direction, reuniting the science of human psyche with hard sciences, as the TM presented a quintessentially mechanistic and reductive explanation. Thus, cognitive science and its close cousin, artificial intelligence, incorporated the TM, or formal manipulations of symbol systems within their modus operandi. The outcome of this was that the description (computation) of a very specific phenomenon (formal rule following by humans) was conflated with the phenomenon itself. Although, a distinction between an object and its description is clear and unquestionable in almost every other scientific domain, large part of cognitive science have accepted this conflation without much reserve.

Such approaches were soon opposed by various thinkers who were not satisfied with the perceived shortcomings of the formal symbolic approach to explain fundamental properties of cognition. Many of such criticisms grew out of methods, which at the height of its popularity were the domain of cybernetics, or which later could trace their heritage to cybernetic movement. The critics emphasised the importance of continuous time and state space evolution, and decentralised nature of biological processing; features which were at odds with the computational paradigm. Yet, important caveats as they were, they did not address the fundamental shortcomings of the computational symbolic account as discussed