The Wetware Route to Explore Embodied Cognition: A Proposal

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Abstract

Embodied AI, the main direction of AI engaged in the synthetic modeling of natural cognition, is generally based on hardware-software approaches. Here we present the general lines of a proposal referred as the "wetware route" to *Embodied AI*, construed as the ideation and implementation of chemical models of cognitive processes inspired by the theory of autopoiesis. Our approach proposes to focus on the organizational traits that characterize autopoietic systems as cognitive systems, and accordingly attempts to define a viable organizational Embodied AI research program in the nascent wetware sci-tech arena of Synthetic Biology.

A Wetware Route to Embodied AI?

Embodied AI (EAI) emerged in the early 90s to overcome the "crisis" of computationalist or classic AI by focusing on the role of the body in cognition [1, 2]. In line with the programmatic ambition of releasing the cognitive mind from the "ghostly" status it had assumed in computationalism [3, 4], pioneering EAI programs worked on synthetically modeling natural cognition not through computer programs, but through "embodied agents" [5, 6, 7]. The idea was that of "biological-like robots", which, as living systems, learn about their environment and accomplish cognitive tasks through their bodies. The goal was modeling in these robots the whole range of natural cognitive processes – all the phenomenology of "the embodied mind" [8] – through "emergent design". In other words: combining basic sensory-motor processes, based on scientific insights, to generate increasingly complex cognitive processes [7].

In the late 90s, while EAI was already producing effective "adaptive robots", it became evident that this goal was out of reach. Pioneers such as Brooks announced that a "fundamental change" was needed, as EAI's robots lacked "organizing principles of biological systems" and could not aspire to their cognitive performances [9]. Related analyses in philosophy of AI (P-AI), asking "whether" EAI's "robots are embodied", prospected the needed turn as the transition from "organismoid" to "organismic" robots [10]. As Ziemke construed it: The shift from artifacts sharing superficial features of natural organisms, such as anatomical structures, to artifacts sharing the living form of organization, viewed as the network of functional relations generating living systems' self-production – their capability of producing their material identity by themselves, based on metabolism [10, 11]. Dedicated philosophical debate can be divided into two camps: a pessimistic camp, affirming the impossibility of recreating the biological organization [e.g., 12], and a proactive camp, engaged in filling EAI's gap. The latter generated some of the most interesting EAI's programs, such as Organismically-inspired robotics [13] and Enactive AI [14]. Both are inspired by well-defined theoretical models of the biological organization, namely, the autopoietic model and its filiations [15, 16]. And both propose approaches to implement these theoretical models, at an acceptable level of abstraction, in hardware and software models. Despite their theoretical value, more than ten years after their definition, these programs have not produced concrete organizational approaches in EAI, that is, approaches grounding their ambition of modeling natural cognition in systematic attempts of implementing artificially the biological organization. Indeed, the most significant recent results in EAI are extensive advances in building organismoid robots.

The theoretical-experimental research program we are currently developing, and presenting here, intends to join the proactive camp of P-(E)AI, and draw on its previous work, to lay the grounds of a new EAI's organizational approach. The novel programmatic idea is that of a *wetware autopoietic EAI*: a synthetic study of natural cognitive processes based on the construction and experimental exploration of wetware – i.e., chemical – implementations of the autopoietic model of the biological organization [15]. The goal is grounding an autopoietic organizational approach to EAI in new modeling techniques, developed in the chemical/ biochemical domains of Synthetic Biology. Making a pun with the ALIFE 2023 theme, such an approach would – so to say – exorcize the "ghost in the machine".

Let us shortly summarize the general lines and a possible implementation of a wetware EAI based on autopoietic organization. The aim of this report is to promote the interest in this approach among the Artificial Life practitioners, to develop theoretical discussions and the first (possibly achievable) experimental attempts.

Wetware Organizational Embodied AI: The General Lines

There is currently no effective organizational approach in EAI. Work done to structure this kind of approach in P-AI is limited to attempts of grounding an effective modeling of the biological organization in hardware and software systems, while adopting a theoretical framework describing it in terms of a chemical network. A wetware approach to organizational EAI, based on chemical models of the biological organization, is still missing. Our plan for theoretical and experimental investigations aims at filling this gap by producing comprehensive groundings for a Wetware Organizational EAI, which include: (1) a theoretical framework of reference, (2) technical and experimental specifications for its implementation, (3) epistemological criteria for assessment, (4) a detailed description of potential applications, and (5) ethical indications. Indeed, to achieve our programmatic goal, current theories of biological organization have to be used to generate theoretical models implementable in wetware models. In view of such an implementation, theoretical models have to be used as references to determine the technical general lines of their appropriate translations into chemical models. Moreover, epistemological criteria need to be developed in order to evaluate the relevance, for the scientific understanding of life and cognition, of the wetware models to be implemented. On these bases, wetware models can be conceived, analyzed, implemented, and empirically explored for scientific purposes. At the same time, a library of potential applications can be developed, which should include the elaboration of related ethical guidelines to warrant the sustainability of the applicative endeavor.

In particular, we focus on the theoretical, technical and experimental groundings (1, 2) of *Wetware Organizational Embodied AI*,[1] which derives its specific features based on two main choices: (a) the selection of theory of autopoiesis as the main starting conceptual framework of reference, susceptible to be significantly redefined by the development of the inquiry; (b) the option of adopting Synthetic Biology (SB), Systems Chemistry, Molecular Communications, and Neuromorphic Chemical Networks as a set of frontier chemical approaches of reference, with a specific attention for those dedicated to the construction of "artificial cells" (ACs).

On these grounds, the *Wetware Autopoietic Organizational Embodied AI* adopts (E)AI's "understanding-by-building" method [2, 11], through which it engages in the (bio)chemical fabrication of non-trivial chemical systems that display at least some of the living or living-like properties of biological organisms.

Wetware Modeling of Life and Cognition – The first moves might aim at autonomy rather than autopoiesis

Surely a chemical approach can substantially match the requirements of autopoietic dynamics, and it must be kept as long-range goal, but it is evident that establishing artificial systems that self-produce *all* components is quite challenging. By keeping in mind the central idea of circularity, we believe that, in first steps, a not less interesting target is the concept of autonomy, as expressed and defined by Varela [16] (thus resonating well with the general goal of autopoietic organization). While in autopoiesis the processes that generate an autopoietic system are intended as "processes of production (transformation and destruction)" of the components participating into the autopoietic dynamics, in the definition of autonomy the specification of "processes of production" is dropped off, in favor of processes which "recursively depend on each other in the generation and realization of the processes themselves" (p. 55), i.e., just organized in a causally closed manner. However, the processes still need to "constitute the system as a unity recognizable in the space (domain) in which the processes exist" (p. 55). Similar considerations have been recently presented in the field of artificial agency in robotics [13,18].

This perspective can suggest new and original directions to generate autonomous ACs, the latter being somehow less demanding (easier to approach, experimentally) than autopoietic ACs, yet being relevant to experimental model minimal cognition. For example, it would be possible to refer to processes entailing each other, in closed loops or in similar topological equivalent networks. We can imagine developing a range of autonomous moduli to be engrafted in non-autopoietic ACs, and focus on how to make autonomous moduli adaptable, plastic, self-regulative – discarding for the moment the much more challenging goal of full-system autopoiesis.

Examples of systems that work in multiple, consequentially entailing steps can be identified in the literature of bottom-up ACs [19-23], even if chain processes do not always come to full-circle. The common trait of these studies is that they derive from a series of entailing processes, whose effects invest multiple organizational levels, and – we believe – should be further explored, modified, engineered, aiming at achieving a closed loop of entailment. To start with, auxiliary modules (even not in the wetware domain) could be included in the organization – just for proof of principle demonstrations.

An additional direction – which has the potential to integrate SB with neuromorphic engineering – is the inclusion of neural network-like circuitry in ACs. An intriguing option, related to the concept of autonomy, is when the results of a neural network computation feed back in the network, by changing its organization – e.g., modifying concentrations and in turn rates, affinities, and ultimately its dynamics [24]. The goal is to generate minimal forms of chemical autonomy, and explore their possibilities of "upgrading" it in the direction of minimal autopoietic, and thus biological, autonomy.

[1] More exhaustive descriptions of the theoretical, technical and applicative aspects of *Wetware Organizational Embodied AI* program can be found in [e.g., 11]. The epistemological aspects are thoroughly discussed in [17].

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