MORPHOLOGICALLY COMPUTING EMBODIED, EMBEDDED, ENACTIVE, EXTENDED COGNITION

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IN THE CLASSICAL VIEW, **COGNITIVE SCIENCE** IS CONSIDERED TO BE **THE STUDY OF (HUMAN) MIND AND INTELLIGENCE** (STANFORD ENCYCLOPEDIA OF PHILOSOPHY).

NATURALISED COGNITION MODELLED AS INFORMATION PROCESSING IN COGNIZING AGENTS **AT VARIETY OF LEVELS OF ORGANISATION**, **FROM THE FUNCTIONS OF SINGLE CELLS TO ORGANISMS, SOCIETIES AND CULTURES,** GIVES A BROADER FRAMEWORK FOR UNDERSTANDING OF COGNITION AND REMOVES PARADOXES OF THE CLASSICAL VIEW.

NATURALISED COGNITION IS EMERGING THROUGH THE EVOLUTION OF ORGANISMS IN INTERACTION WITH THE ENVIRONMENT THAT IS INCLUDING OTHER ORGANISMS THROUGH PROCESSES OF **MORPHOLOGICAL COMPUTATION** ON SUCCSESSION OF LEVELS OF ORGANISATION .

On the current view, cognition is about *high-level processes* remote from physical-chemical-biological substrate. It is modeled by classical sequential computation, understood as symbol manipulation. Historically, behaviorism offered an alternative view of cognition with the focus on the *observable behavior* of a subject. This divide is mirrored in the schism between cognitivism/computationalism and EEEE (embodied, embedded, enactive, extended) cognition. There have been numerous attempts to bridge this gap made by (Clark 1997, 1989, 2013), (Scheutz, 2002), (Pfeifer et al. 2005, 2006, 2007) and others, offering connection between sub-symbolic (signal processing) and symbolic (higher level) notions of cognition.

Recently, the idea of **morphological computing** has been proposed, (Paul, 2004) (Pfeifer et al. 2005, 2006, 2007), (Hauser, Füchslin and Pfeifer, 2014) (Müller & Hoffmann, 2017a, 2017b) defining computing in a more general way than the traditional symbol manipulation, taking into account physical embodiment of computational mechanisms, in that way presenting suitable tool for modeling of broader range of cognitive phenomena.

The process of cognition in a cognitive agent can be modeled through **morphological computation, within the framework of info-computational constructivism as generative modeling scheme** (Dodig-Crnkovic 2012, 2014).

Cognition in this framework is capacity possessed by every living organism in diferent degrees of complexity, as (Maturana and Varela, 1980) and (Stewart, 1996) argued.

It is entirety of processes going on in an organism that keeps it alive and thriving. Physico-chemical-biological and other information-exchange processes depend on the morphology of the organism, where morphology is characterized by the material, form and structure. **Morphological is defined on a structure of nodes (agents) that exchange (communicate) information.** Unicellular organisms such as bacteria communicate and build swarms or films with far more advanced capabilities than individual organisms, through social/distributed cognition. In general, in nature groups of smaller agents (cells, organisms, groups) cluster into bigger ones (multicellular assemblies, societies, cultures) with specific control mechanisms from the cell level to the tissue, organ, organism and groups of organisms, societies and cultures and this layered organization provides information processing benefits (information processing speed-up).

With the development of specific nervous system, multicellular organisms acquire ability of self-representation, which enables distinction between "me" and the "other". Through all levels of organisation, the same principle can be found: simpler agents (information processors) aggregate in more complex structures that enable new types of cognition – from cellular to cultural (extended). This enables addressing challenges that classical view of cognition as mind and inteligence does not address:

The emotion challenge: *Morphological computing of embodied cognition is layered architecture with sub-symbolic electro-chemical information processing. (von Haugwitz and Dodig-Crnkovic, 2015)*

The consciousness challenge: *Consciousness is proposed as information integration on the organismic level and has central role in the control of behavior. (Tononi, 2004, 2008, 2015) (Freeman, 2009)*

The world challenge: *Distributed morphological computation processes representing hierarchies of computation from non-symbolic to symbolic, connects an agent and the world expressed in terms of info-computation. (Abramsky Coecke, 2007) (Rozenberg and Kari, 2008) (Sloman, 2011) (Piccinini and Shagrir, 2014) (Dodig-Crnkovic 2016a, 2016b, 2017)*

The body challenge: *Explicit modeling of a body through the inclusion of computational processes in the physical substrate as an integral part of cognition. (Matsushita, Lungarella, Paul, Yokoi, 2005) (Pfeifer and Bongard, 2006) (Stepney, 2008) (MacLennan, 2010, 2011)*

The dynamical systems challenge: *Here there is a common misunderstanding that dynamical systems are not computational. Dynamical systems are an important class of computational systems. (van Leeuwen and Wiedermann, 2017)(Burgin and Dodig-Crnkovic, 2015).*

The social challenge: *Done through social computing, agent-based models and networks. (Newman, Barabasi, Watts, 2006) (Epstein, 2007) (Barabasi, 2010)*

The mathematics challenge: *Morphological computing in living beings starts at quantum level and propagates to higher levels of organisation by different kinds of physical, chemical, biological, cognitive and social computing (Cooper, 2012) (Zenil, 2012)*

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