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Morphological Computation as Natural Ecosystem Service for Intelligent Technology †

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Abstract: The basic idea of natural computing is learning from nature. Naturalist framework provides info-computational architecture for cognizing agents, modelling living organisms as informational structures with computational dynamics. Intrinsic natural information processes can be used as natural ecosystem services to perform resource-efficient computation, instead of explicitly controlling every step of computational process. In robotics, morphological computing is using inherent material properties to produce behavior like passive walking or grasping. In general, morphology (structure, shape, form, material) is self-organizing into dynamic structures resulting in growth, development, and decision-making that represent processes of embodied cognition and constitute naturalized basis of intelligent behavior.

Keywords: information; knowledge; structures; general theory of information; cognition; turing machine; structural machine; data structures; knowledge structures

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1. Introduction

Morphological computation is a process of creation of new informational structures in nature, living as well as non-living, defining relationships realized in the substrate of matter/energy. Cognition in living system involves life-organizing, life-sustaining goal-directed processes, while in artifactual systems, cognition comprises corresponding engineered process based on sensors, actuators, and computing units. Unlike self-organized natural cognition, engineered computational cognition is essentially dependent on human-made infrastructure with resource supply and control. Physical/morphological cognition in solid-state inanimate matter is governed by language-controlled information processing without intrinsic connection to autonomous agency which all living creatures have. Engineered cognitive systems can still learn a lot from living agents, even from the simple ones like unicellular organisms about resource effective cognitive processes.

Natural info-computational model of reality for an agent includes agent itself and the world as it appears for the agent (Umwelt). Computation is information processing [1]. It is natural information transformation [2–7], on different levels of organization (physics, chemistry, biology, cognition) [2,8–10].

Evolutionary process in living organisms, in the sense of extended evolutionary synthesis [11,12] unfolds as a result of interactions of living agents with the environment, including other living agents. It starts with the first simplest pre-biotic structures and leads to more complex forms such as viruses and bacteria, continuing up in complexity through the evolution of species, from single cells to humans [13,14].

The info-computational framework is treating cognition as an open-ended process of self-organization where computation for the most part proceeds as signal processing in natural systems, and only under special circumstances it takes form of symbol manipulation

and language-based communication [15]. Both living and engineered info-computational artifacts possess various degrees of cognitive capacities [8–10,16].

Mechanisms of cognition, based on natural computation/morphological computation are far more sophisticated than the machine-like classical computationalist models based on abstract symbol manipulation, as argued in detail by Kampis [16]. As Witzany and Baluska [17–19] show, the rule-based machines are not good enough models of natural cognition of highly complex living organisms. According to Varela [19], embodiment is the fundamental characteristics of cognition, which implies that senses, feelings, and emotions must be considered as constitutive of cognition, also elaborated in [8,20–22].

Info-computational approach incorporates scientific knowledge about the processes in nature, translating them into language of natural info-computation. The aim of this approach to cognition is to increase understanding of cognitive processes in diverse types of agents, biological and synthetic, including their ability of learning, and learning to learn (meta-learning) [22], as well as their communications and mutual interactions. The focus is on the understanding of the fundamental mechanisms of cognitive processes based on natural information and morphological computation, which boils down to the study of the structures and their dynamics at different levels of organization. Magnani uses the term "cognitive domestication of ignorant entities" to describe the process of using natural computation as ecosystem service for intelligent technology.

As the development of increasingly sophisticated intelligent cognitive computational systems rapidly progresses, a framework that can seamlessly connect the natural with the artificial is useful for learning in both directions—from the natural system to the model and back.

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References

1. Burgin, M. *Super-Recursive Algorithms*; Springer: New York, NY, USA, 2005; ISBN 0387955690.
2. Burgin, M.; Dodig-Crnkovic, G. Computation as Information Transformation. In Proceedings of the IS4IS Summit Vienna 2015, Vienna, Austria, 3–7 June 2015.
3. Rozenberg, G.; Bäck, T.; Kok, J.N. (Eds.) *Handbook of Natural Computing*; Springer: Berlin/Heidelberg, Germany, 2012.
4. Stepney, S.; Braunstein, S.L.; Clark, J.A.; Tyrrell, A.M.; Adamatzky, A.; Smith, R.E.; Addis, T.R.; Johnson, C.G.; Timmis, J.; Welch, P.H.; et al. Journeys in Non-Classical Computation I: A Grand Challenge for Computing Research. *Int. J. Parallel Emerg. Distr. Syst.* **2005**, *20*, 5–19. [CrossRef]
5. Stepney, S.; Braunstein, S.L.; Clark, J.A.; Tyrrell, A.M.; Adamatzky, A.; Smith, R.E.; Addis, T.R.; Johnson, C.G.; Timmis, J.; Welch, P.H.; et al. Journeys in Non-Classical Computation II: Initial Journeys and Waypoints. *Int. J. Parallel Emerg. Distr. Syst.* **2006**, *21*, 97–125. [CrossRef]
6. Stepney, S. The neglected pillar of material computation. *Phys. D Nonlinear Phenom.* **2008**, *237*, 1157–1164. [CrossRef]
7. MacLennan, B.J. Natural computation and non-Turing models of computation. *Theor. Comput. Sci.* **2004**, *317*, 115–145. [CrossRef]
8. Dodig-Crnkovic, G.; von Haugwitz, R. Reality Construction in Cognitive Agents through Processes of Info-Computation. In *Representation of Reality: Humans, Other Living Organism and Intelligent Machines*; Dodig-Crnkovic, G., Giovagnoli, R., Eds.; Springer: Cham, Switzerland, 2017.
9. Dodig-Crnkovic, G. Morphologically Computing Embodied Cognition. In *Philosophy and Theory of Artificial Intelligence*; Müller, V., Ed.; Springer: Cham, Switzerland, 2017.
10. Dodig-Crnkovic, G. Nature as a Network of Morphological Infocomputational Processes for Cognitive Agents. *Eur. Phys. J.* **2017**, *226*, 181–195. [CrossRef]
11. Jablonka, E.; Lamb, M.J.; Zeligowski, A. *Evolution in Four Dimensions: Genetic, Epigenetic, Behavioral, and Symbolic Variation in the History of Life*; MITCogNet: Cambridge, MA, USA, 2014.
12. Laland, K.N.; Uller, T.; Feldman, M.W.; Sterelny, K.; Müller, G.B.; Moczek, A.; Jablonka, E.; Odling-Smee, J. The extended evolutionary synthesis: Its structure, assumptions and predictions. *Proc. R. Soc. B Biol. Sci.* **2015**, *282*, 20151019. [CrossRef] [PubMed]
13. Dennett, D. *From Bacteria to Bach and Back: The Evolution of Minds*; Norton & Company: New York, NY, USA, 2017.

14. Dodig-Crnkovic, G. The Architecture of Mind as a Network of Networks of Natural Computational Processes. *Philosophies* **2015**, *1*, 111–125. [CrossRef]
15. Ehresmann, A.C. MENS, an Info-Computational Model for (Neuro-)cognitive Systems Capable of Creativity. *Entropy* **2012**, *14*, 1703–1716. [CrossRef]
16. Kampis, G. *Self-Modifying Systems in Biology and Cognitive Science: A New Framework for Dynamics, Information, and Complexity*; Pergamon Press: Amsterdam, The Netherlands, 1991; ISBN 9780080369792.
17. Witzany, G. *Life: The Communicative Structure. A New Philosophy of Biology*; Libri Books on Demand: Norderstedt, Germany, 2000.
18. Witzany, G.; Baluška, F. Turing: A formal clash of codes. *Nature* **2012**, *483*, 541. [CrossRef] [PubMed]
19. Varela, F. *Principles of Biological Autonomy*; North Holland: Amsterdam, The Netherlands, 1979; ISBN 978-0444003218.
20. Damasio, A.R. *The Feeling of What Happens: Body and Emotion in the Making of Consciousness*; Harcourt Brace and Co.: San Diego, CA, USA, 1999.
21. Thagard, P. *Hot Thought: Mechanisms and Applications of Emotional Cognition*; MIT Press: Cambridge, MA, USA, 2006.
22. Dodig-Crnkovic, G. Natural Morphological Computation as Foundation of Learning to Learn in Humans, Other Living Organisms, and Intelligent Machines. *Philosophies* **2020**, *5*, 17. [CrossRef]