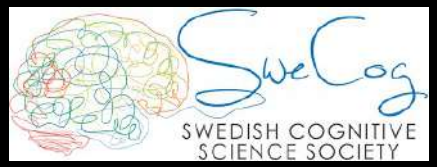
SweCog 2016 Conference, Gothenburg 10-12 Nov. 2021
Skövde, online http://swecog.se/conference

# Cognition as a Result of Information Processing in Living Agent's Morphology. Species-specific Cognition and Intelligence




GORDANA DODIG-CRNKOVIC

Chalmers University of Technology and University of Gothenburg
& Mälardalen University

http://gordana.se

# THE "HIGH-LEVEL" VS. "LOW-LEVEL" VIEW OF COGNITION

Cognitive science, according to *The Stanford Encyclopedia of Philosophy* (Thagard, 2014) is an interdisciplinary study of *human mind* and *intelligence*.

It investigates *knowledge generation* in humans through perception, thinking (reasoning), memory, learning, and problem solving.

Under this framing of cognitive science, variety of unsolved/unsolvable problems appear, as it ignores the role of the physical world and the body of a cognizing agent, neglecting the dynamical systems aspects, and emotions, as well as the phenomenon of distributed cognition.

Moreover, it is ignoring the existing mathematical results which indicate that the human brain cannot be a classical computer (the Turing machine), with cognition modeled as computation over mental representations.

On the other hand, radical biologism argues "Cognition = Life" (Maturana and Varela, 1980) (Stewart, 1996), thus the totality of biological processes.

# COGNITION IN OTHER LIVING ORGANISMS

Importantly, the idea of cognition is currently being generalized from the exclusively human capacity to the capacity of a variety of goal-directed adaptive self-reflective systems, from simplest living organisms (cells) to humans (Baluška and Levin 2016; Lyon 2005; Lyon 2015) (Dodig-Crnkovic, 2018) (Manicka and Levin 2019; Levin et al. 2021).

The aim is to better understand generative mechanisms of cognition in the light of evolution, as according to (Dobzhansky, 1973) "Nothing in biology makes sense except in the light of evolution."

# INFORMATION PROCESSING AS MORPHOLOGICAL COMPUTATION

Implementations of cognition and intelligence in artifacts are contributing to the more detailed view of the relationship between cognition and its substrate.

To achieve a connection between symbolic and sub-symbolic information processing of cognition, the concepts of information processing (computation) and cognition must be generalized.

Computation can be understood as process of morphogenesis (the development/generation of morphological characteristics, such as shape, form, and material composition in material bodies) on different levels of organization: physical, chemical, biological, cognitive, and virtual-machine-level computation built on top of them.

Morphological computation/information processing approach to cognition provides a framework that connects low-level with high-level approaches to cognition and meets challenges and open questions listed by (Thagard, 2014).

# CONNECTING THE TWO

The functional connection is still missing between those two views, the high-level view of cognition with thoughts, mind, and intelligence (symbol processing) and the low-level view where each living organism (and all its building blocks, cells) is processing information that has a function for survival.

The development of both cognitive science and related research fields of psychology, philosophy of mind, linguistics, neuroscience, bioinformatics, anthropology, and artificial intelligence go in the direction of embodied, embedded, extended, and enacted cognition (EEEE).

# "THINKING" INCLUDING EMOTIONS

(Thagard 2013; 2014) makes an extension of the idea of "thinking" to include emotional experience "The term cognition, as used by cognitive scientists, refers to many kinds of thinking, including those involved in perception, problem solving, learning, decision making, language use, and emotional experience." Similarly, (Lerner et al. 2015) argues for the importance of emotion in the decision making.

The extension of "thinking" to emotional decision-making, also found in (Kahneman 2011), bridges some of the distance between cognition as (rational) thinking and its embodiment, but the basic problems remain of generative mechanisms that can dynamically connect body (matter) and mind.

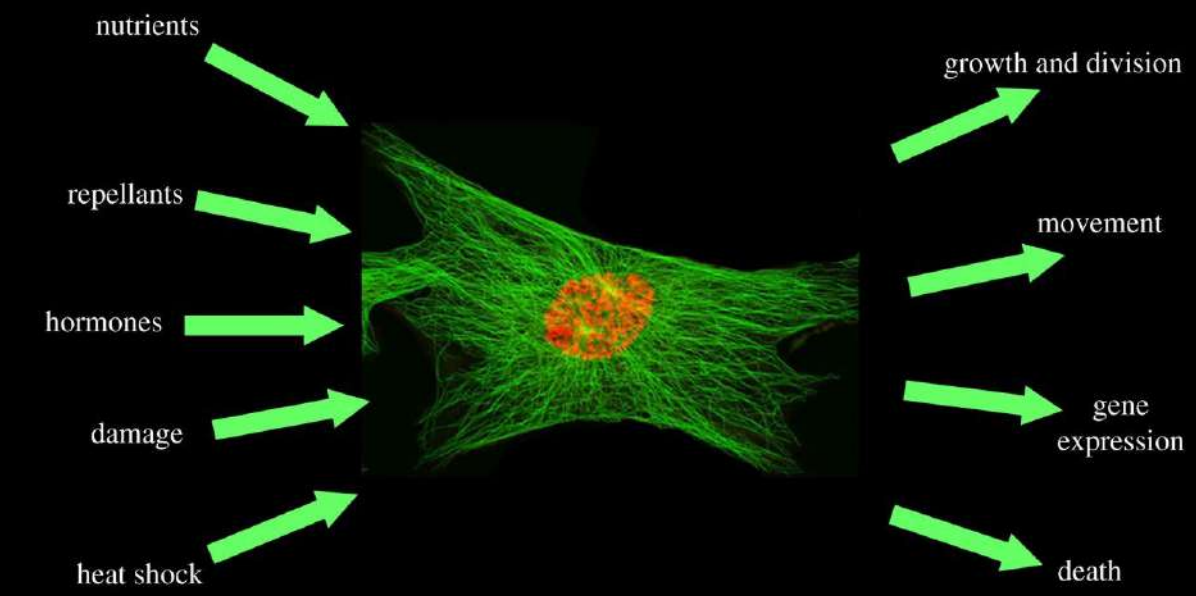
Thagard's description of cognitive science that includes emotions, does not make connections to biology, chemistry, (quantum- nano-, etc.) physics or chaos theory, self-organization, artificial life or data science, extended mind, distributed cognition, network science, sociology, or ecology, thus offering a rather high-level and thus necessarily simplified view.

# NATURALIZED EVOLUTIONARY APPROACH TO COGNITION

In living organisms, profound insights can be made by studying evolution and mechanisms of cognition at a variety of levels of organization, from single cells up to most complex living organisms. Cognition in nature appears throughout biological systems (Baluška and Levin 2016; Lyon 2005; Lyon 2015) and it is important to understand its evolutionary development from the basal/basic/elementary cognition on the cell level, to the human level (Manicka and Levin 2019; Levin et al. 2021).

Naturalized evolutionary approach to cognition is based on the view of hierarchical recursive structure of information processing in nature, in living organisms from cells, to tissues, organs, organisms, and their groups – all of them communicating at different levels of organization by exchanging specific types of information – physical (elementary particles, electro-magnetic), chemical (electric, molecular), biological, and symbolic (signs, languages).

# Cells are processing information and posess basal cognition




http://rsfs.royalsocietypublishing.org/content/4/3/20130070

# Microorganismic cognition

microorganisms have sensors and actuators and use chemical signaling and transfer of genetic information as a basis for adaptation and learning.


http://phys.org/news/2009-11-conquer-social-network-cells.html

Lacrymaria olor, single celled organism, has a “neck” and a “mouth” Chasing food it beats the hair-like cilia around its 'head" and extends its neck up to 8 times its body length.
https://www.youtube.com/watch?v=zSvgHX6C2Jk

Eshel Ben Jacob bacterial colony

Bacteria sense, adapt and communicate by “chemical language”


https://en.wikipedia.org/wiki/Ben-Jacob%27s_bacteria

http://www.cellcognition.org/ The cell cognition project

# Plant cognition

**Plants do not have nervous system, but they have information-processing systems as a basis for adaptation, and learning.** Plants selectively adapt to the resources in the environment which are available for their survival and reproduction.

| Exogeneous signals | Endogeneous signals |
|---|---|
| Light (quality, quantity, duration, direction) | Growth regulators (cytokinin, ethylene, gibberellin, auxin, abscisic acid, brassinosteroids) |
| Mechanical, constant (substrate, support) | |
| Mechanical, variable (wind, herbivores) | Mechanical, growth related tissue compression and tension |
| Atmospheric humidity | |
| Other plants proximity | Defence signals Jasmonic acid Salicylic acid |
| Temperature | |
| Nutrients | |
| Water | |
| $CO_2$ | Developmental regulators (mobile RNA) |
| Pathogenes | |
| Gravity | |
| | Metabolites (sugars, glutamate) |

http://www.nature.com/nrm/journal/v2/n4/images/nrm0401_307a_f1.gif

S. Gilroy and A. Trewavas (2001)

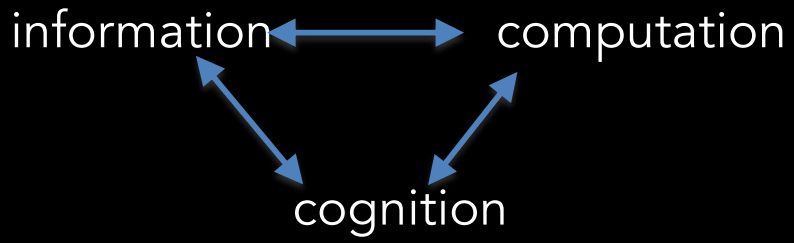
Signal processing and transduction in plant cells: the end of the beginning? Nature Reviews Molecular Cell Biology 2, 307-314

Notaguchi Michitaka, Okamoto Satoru (2015) Dynamics of Long-distance Signaling via Plant Vascular Tissues Frontiers in Plant Science. Vol. 6 No. 00161

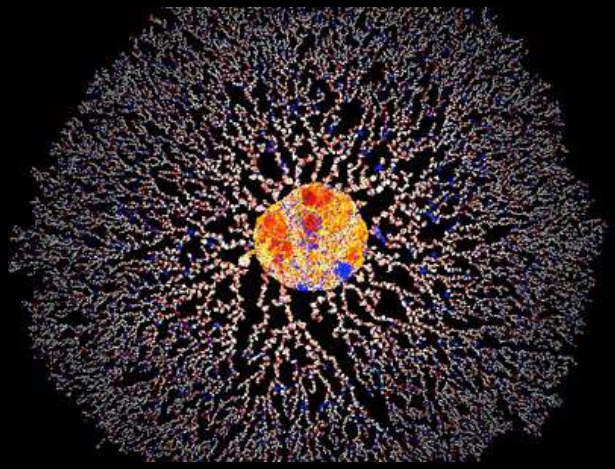
http://journal.frontiersin.org/article/10.3389/fpls.2015.00161/full

# Animal cognition

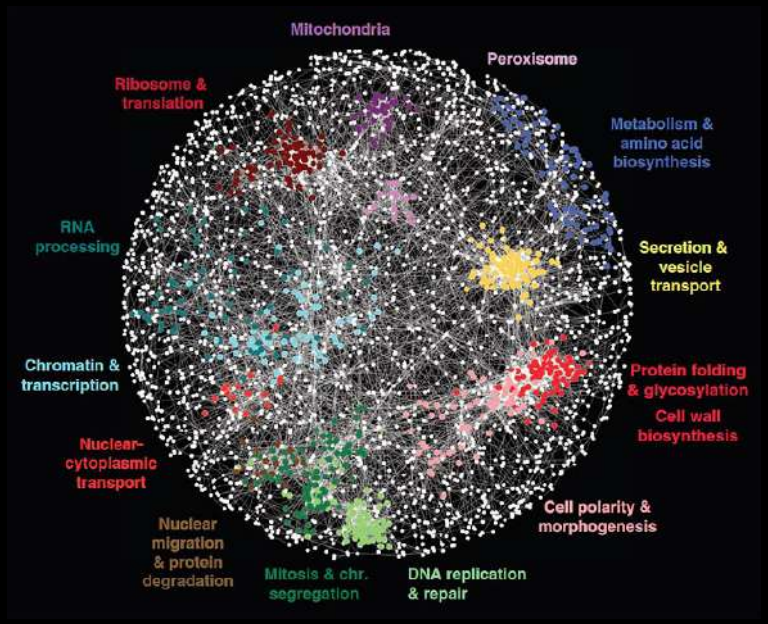
## Basic forms of language in higher animals




http://www.cellcognition.org/
The cell cognition project

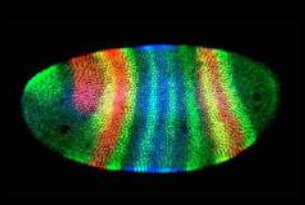


http://www.visualcomplexity.com/vc/images/122_big01.jpg
Protein network

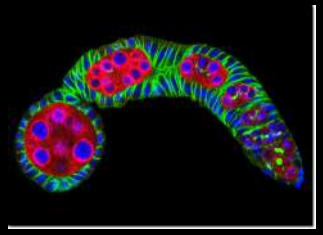



http://phys.org/news/2009-11-conquer-social-network-cells.html

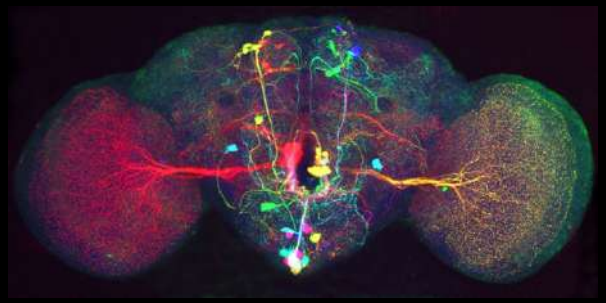
http://www.hhmi.org/research/global-mapping-genetic-networks A functional network for a yeast cell



Fruit fly embrio



Fruit fly larva



Fruit fly brain neurons

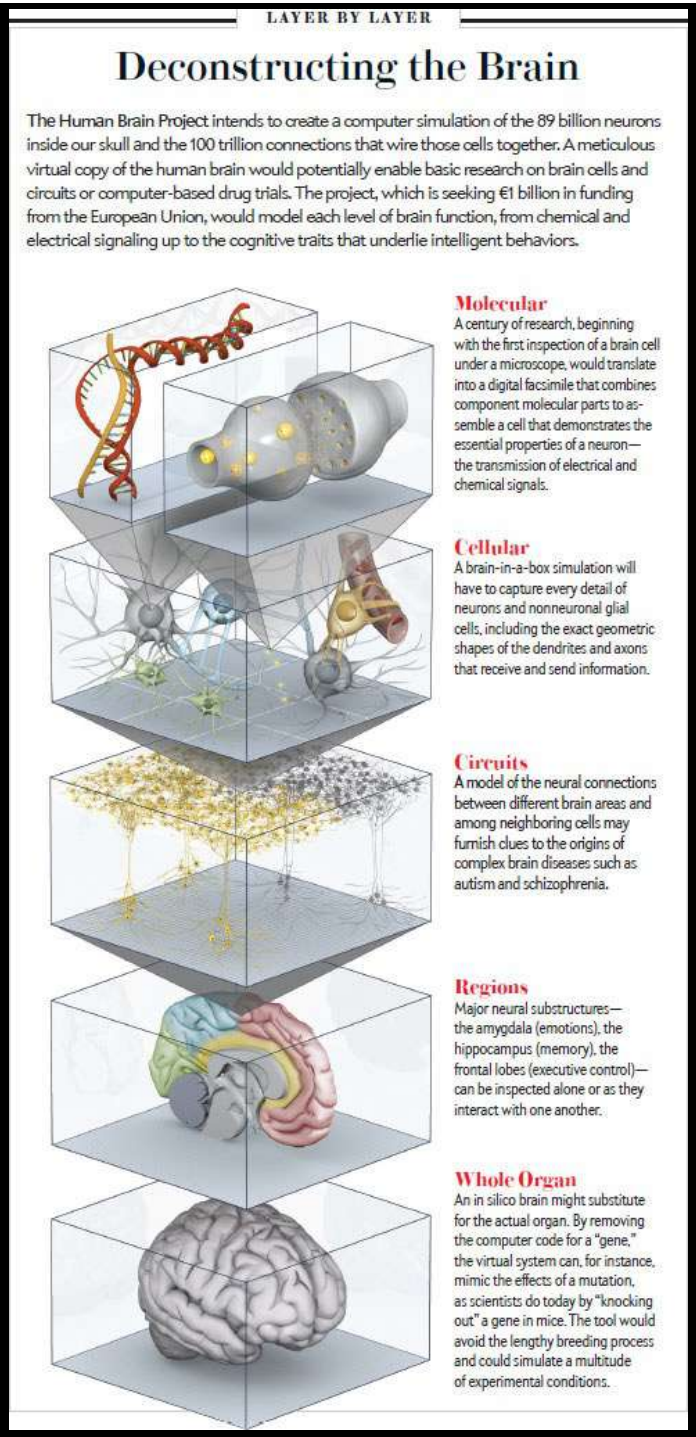
Fruit fly head

## Reality for humans – human cognition

Complex language and material culture

Human connectome

http://outlook.wustl.edu/2013/jun/human-connectome-project



LAYER BY LAYER

# Deconstructing the Brain

The Human Brain Project intends to create a computer simulation of the 89 billion neurons inside our skull and the 100 trillion connections that wire those cells together. A meticulous virtual copy of the human brain would potentially enable basic research on brain cells and circuits or computer-based drug trials. The project, which is seeking €1 billion in funding from the European Union, would model each level of brain function, from chemical and electrical signaling up to the cognitive traits that underlie intelligent behaviors.

**Molecular**
A century of research, beginning with the first inspection of a brain cell under a microscope, would translate into a digital facsimile that combines component molecular parts to assemble a cell that demonstrates the essential properties of a neuron—the transmission of electrical and chemical signals.

**Cellular**
A brain-in-a-box simulation will have to capture every detail of neurons and nonneuronal glial cells, including the exact geometric shapes of the dendrites and axons that receive and send information.

**Circuits**
A model of the neural connections between different brain areas and among neighboring cells may furnish clues to the origins of complex brain diseases such as autism and schizophrenia.

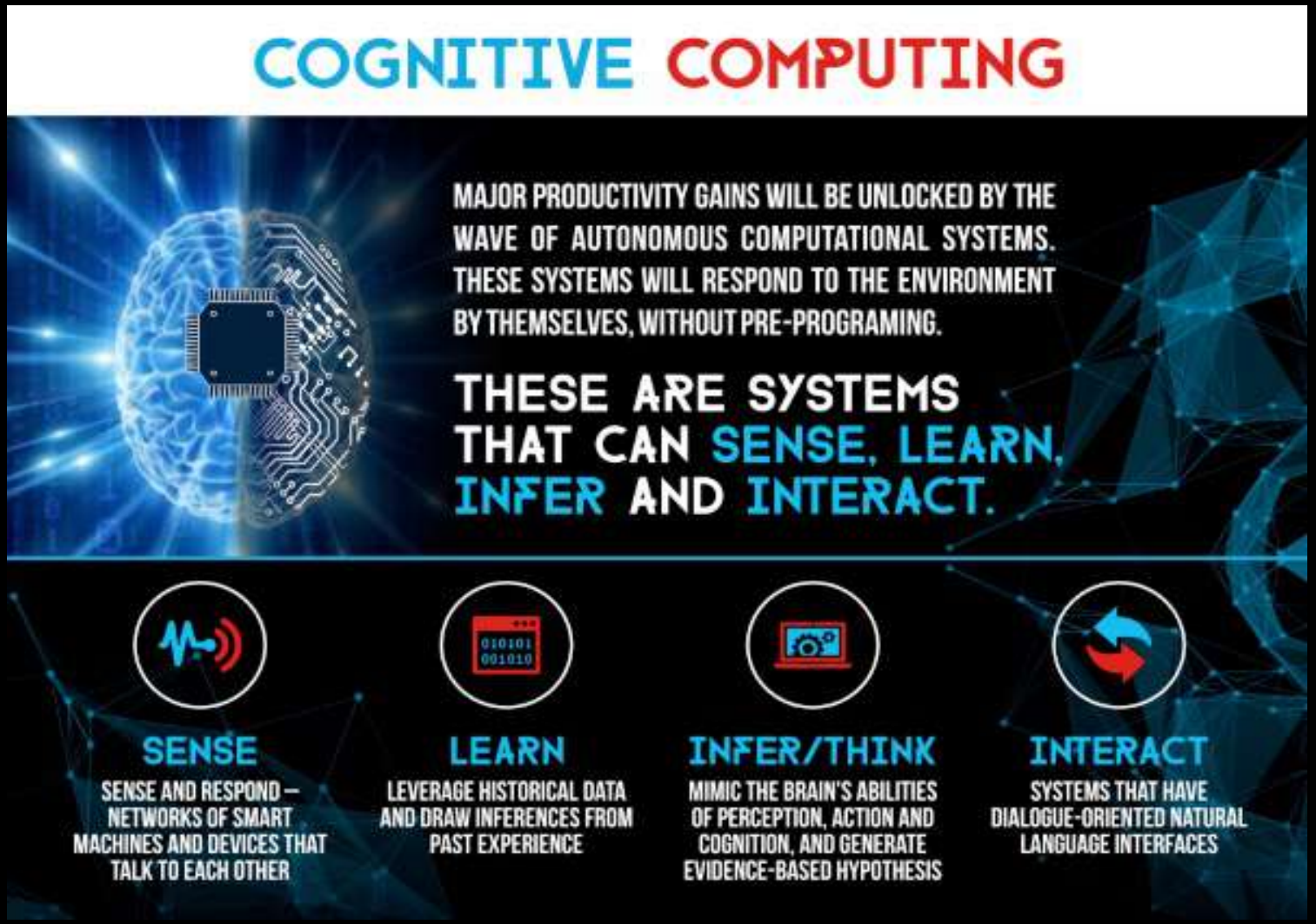
**Regions**
Major neural substructures—the amygdala (emotions), the hippocampus (memory), the frontal lobes (executive control)—can be inspected alone or as they interact with one another.

**Whole Organ**
An in silico brain might substitute for the actual organ. By removing the computer code for a "gene," the virtual system can, for instance, mimic the effects of a mutation, as scientists do today by "knocking out" a gene in mice. The tool would avoid the lengthy breeding process and could simulate a multitude of experimental conditions.

http://www.nature.com/scientificamerican/journal/v306/n6/pdf/scientificamerican0612-50.pdf The Human Brain Project

# Cognition in machines

research is made to develop machines that sense, learn, reason/think and interact with us in natural language.




http://www.enterrasolutions.com/media/Wipro-Cognitive-Computing-2.png

# Morphological computation in robotics connecting body, brain, and environment (Rolf Pfeifer)

soft robotics / self-assembly systems and molecular robotics/

self-assembly systems at all scales / embodied robotics /

reservoir computing / physical reservoir computing/ real neural systems

systems medicine / functional architecture / organization /

process management / computation based on spatio-temporal dynamics/

information theoretical approach to embodiment mechatronics /

amorphous computing / molecular computing

http://morphcomp.org/2nd International Conference on Morphological Computation ICMC2011.

*http://www.eucognition.org/index.php?page=theoretical-scheme* Tutorial on Embodiment: R Pfeifer

# Life = cognition

Cognition is capacity possessed in different forms and degrees of complexity by every living organism. It is entirety of processes going on in an organism that keeps it alive as a distinct agent in the world.

Single cell while alive constantly cognizes, that is registers inputs from the world and its own body, ensures its own continuous existence through food hunting and metabolism while avoiding dangers that could cause its damage or disintegration, at the same time adapting its own morphology to the environmental constraints. The entirety of physico-chemical processes depends on the morphology of the organism, where morphology is meant as the form and structure.

Maturana H.R. & Varela F.J. (1980). Autopoiesis and cognition: the realization of the living. Reidel, Dordrecht
Maturana H. & Varela F.J. (1987). The tree of knowledge. Shambhala, Boston.
John Stewart (1996). Cognition = Life : Implications for higher-level cognition. Behavioural Processes 35: 311-326.
P. C. Marijuán∗, J. Navarro, R. del Moral (2010) On prokaryotic intelligence: Strategies for sensing the environment. BioSystems 99. pp. 94–103

# Morphogenesis as computation (information processing) - Turing's reaction-diffusion model of morphogenesis

"Patterns resulting from the sole interplay between reaction and diffusion are probably involved in certain stages of morphogenesis in biological systems, as initially proposed by Alan Turing. Self-organization phenomena of this type can only develop in nonlinear systems (i.e. involving positive and negative feedback loops) maintained far from equilibrium." Dulos, E., Boissonade, J., Perraud, J. J.Rudovics, B., Kepper, P. (1996) Chemical morphogenesis: Turing patterns in an experimental chemical system, Acta Biotheoretica, Volume: 44, Issue: 3, pp. 249 -261

http://cgjennings.ca/toybox/turingmorph

# Morphological computing

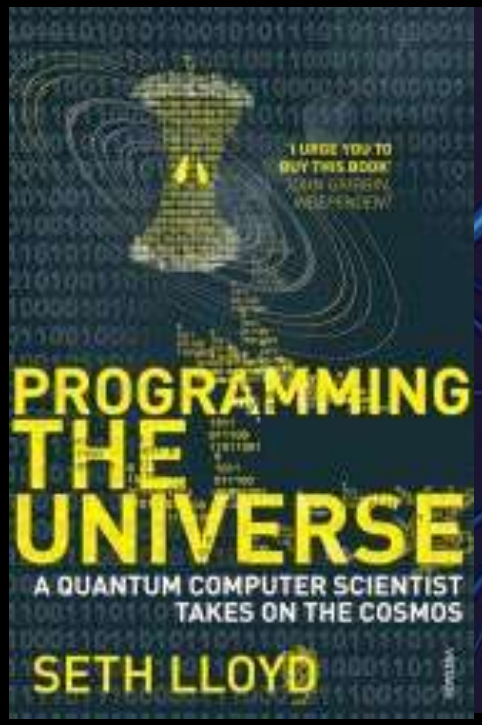
The essential property of morphological computing is that it is defined on a structure of nodes (agents) that exchange (communication) of information.

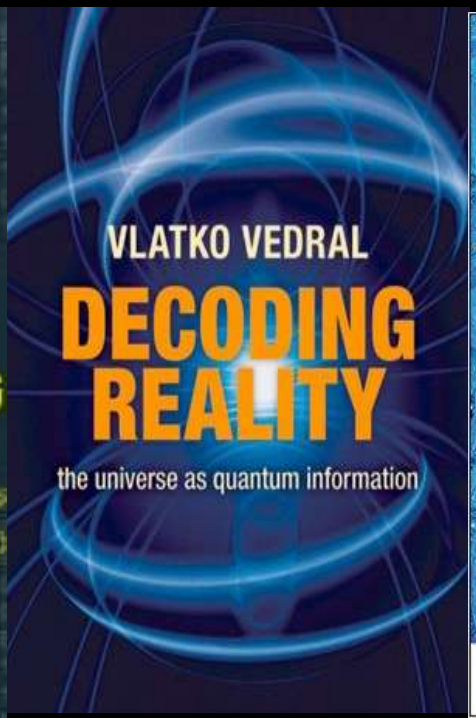
Unicellular organisms such as bacteria communicate and build swarms or films with far more advanced capabilities compared to individual organisms, through social (distributed) cognition.

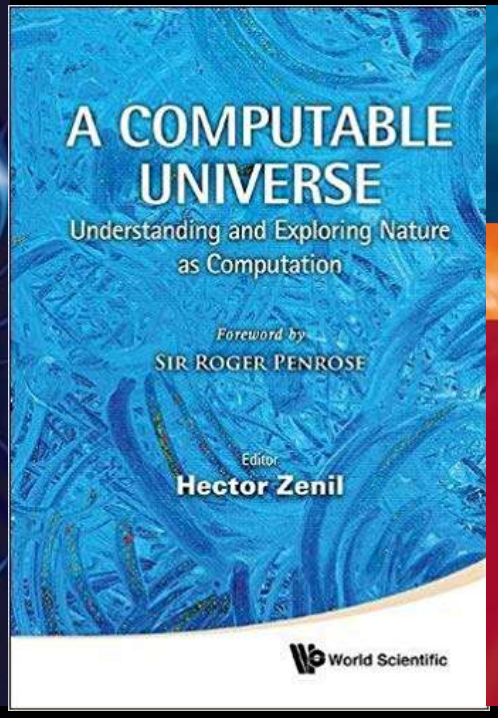
In general, groups of smaller organisms in nature cluster into bigger ones with differentiated control mechanisms from the cell level to the tissue, organ, organism and groups of organisms, and this layered organization provides information processing benefits.

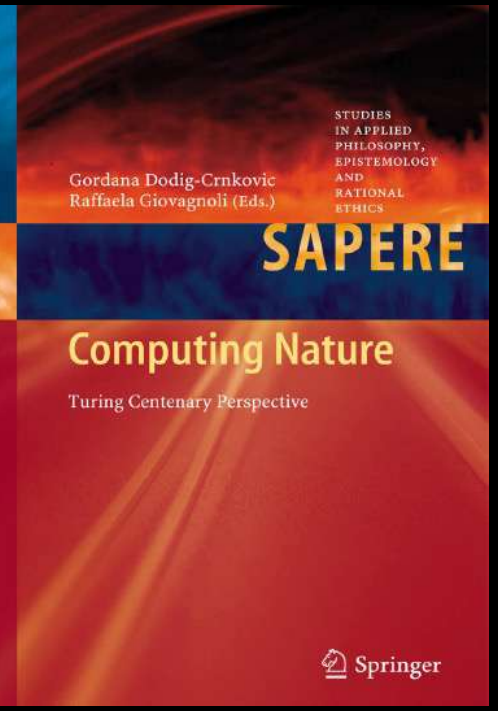
# Literature, Further Reading – Mapping Territory Through Various Disciplines

## Computing Nature/Universe

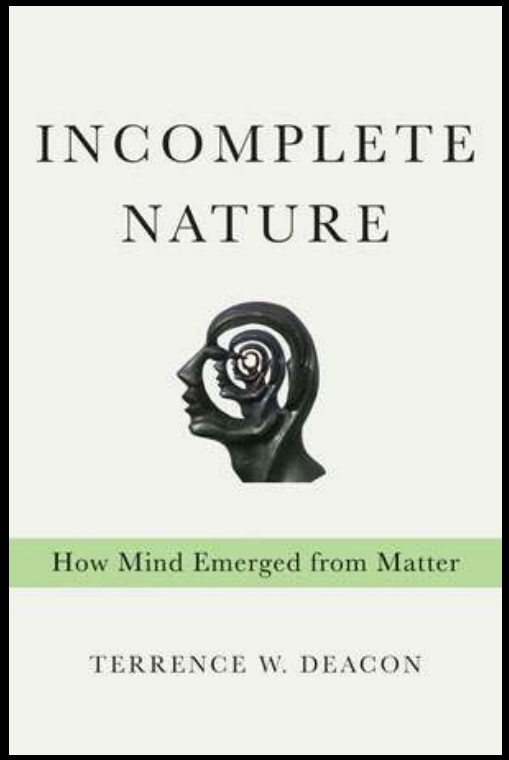


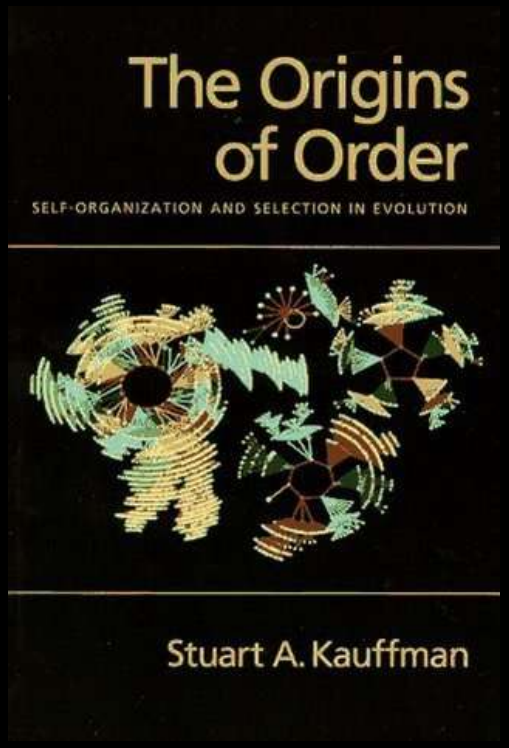



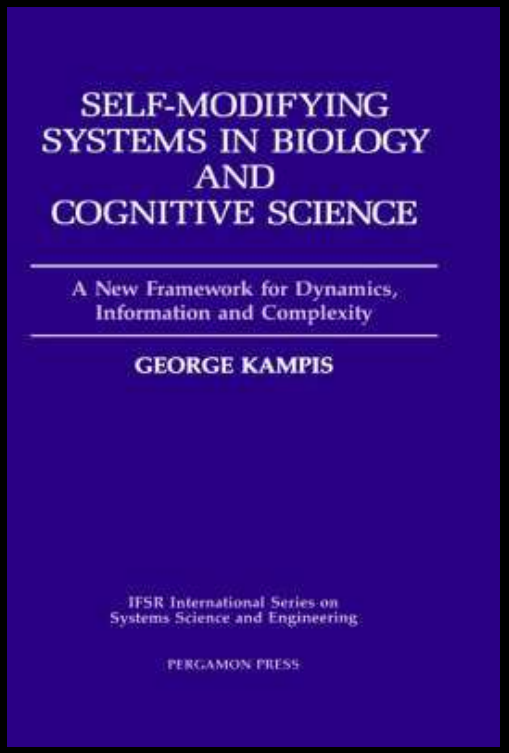



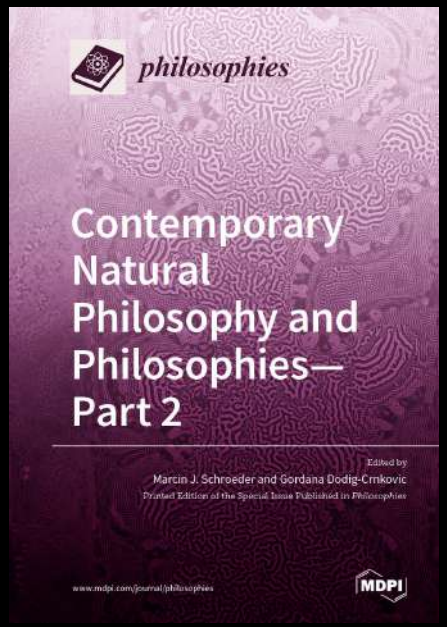
# Self-organizing Nature

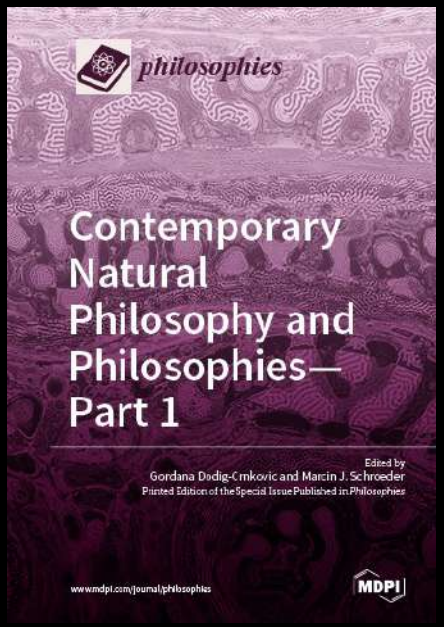


# Contemporary Natural Philosophy – Special Issues and Book Series




Open call for submissions for Part 3:

Deadline August 31 2021
Journal Philosophies

https://www.mdpi.com/journal/philosophies/special_issues/Philosophy_and_Philosophies3

Schroeder M. and Dodig Crnkovic, G. (2020)
CONTEMPORARY NATURAL PHILOSOPHY AND PHILOSOPHIES - PART 2

ISBN 978-3-03943-535-7 (Hbk);
ISBN 978-3-03943-536-4 (PDF)
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Dodig Crnkovic, G. and Marcin Schroeder (2019)
CONTEMPORARY NATURAL PHILOSOPHY AND PHILOSOPHIES - PART 1

ISBN 978-3-03897-822-0 (Pbk);
ISBN 978-3-03897-823-7 (PDF)
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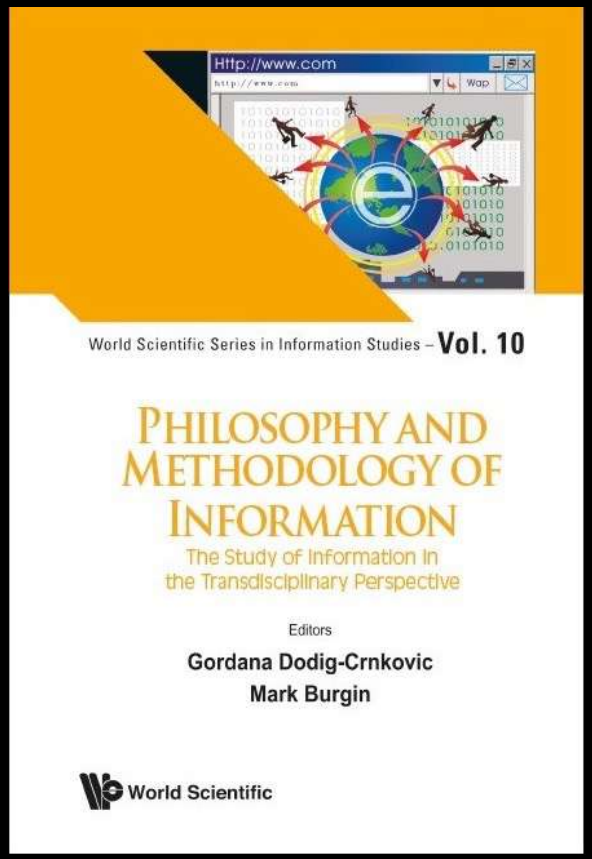
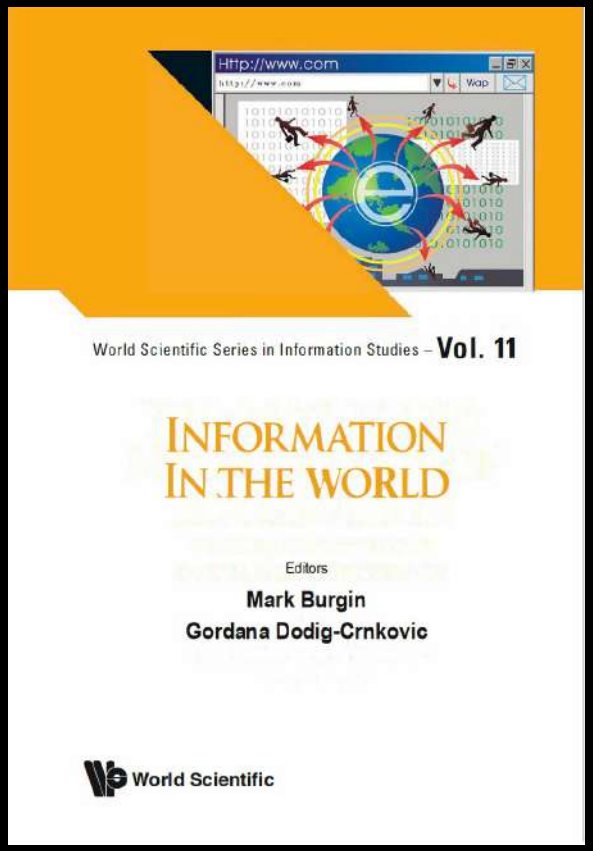
# Nature, Information & Computation




PHILOSOPHY AND METHODOLOGY OF INFORMATION

*Dodig-Crnkovic G. and Burgin M.*

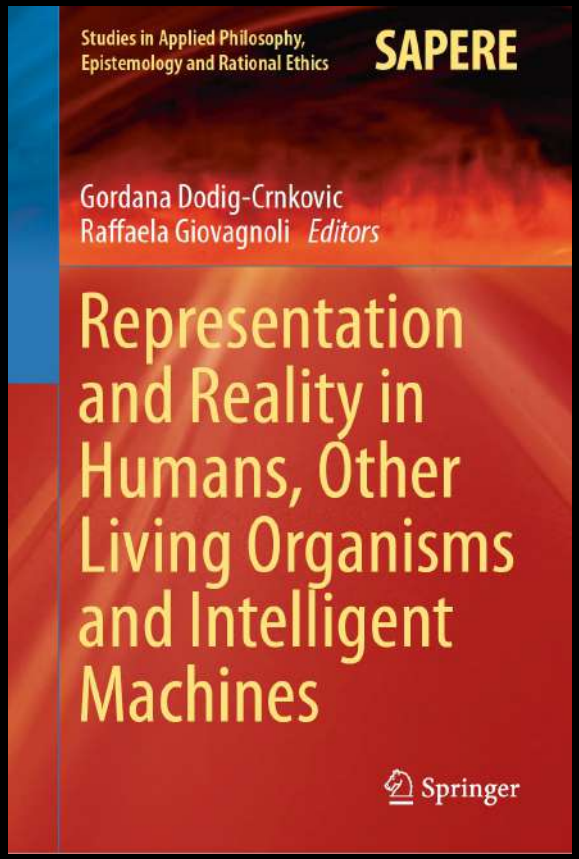
*World Scientific, 2019*




INFORMATION IN THE WORLD

Burgin M. and Dodig-Crnkovic M.

World Scientific, 2020

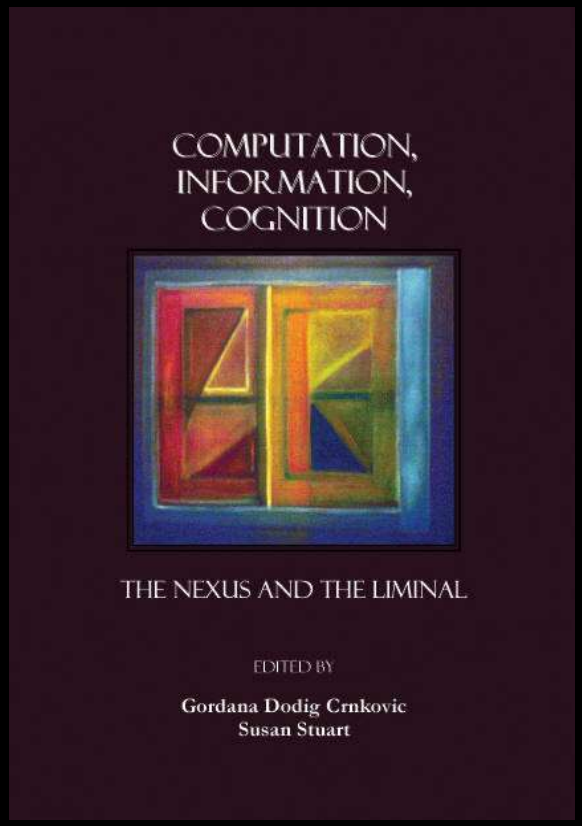



REPRESENTATION AND REALITY

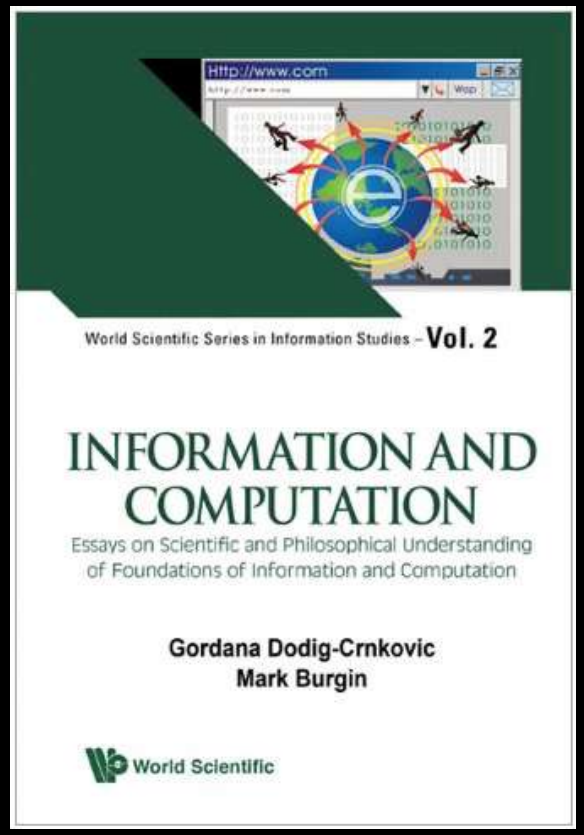
*Dodig Crnkovic G. and Giovagnoli, R.*

*Springer, 2017*

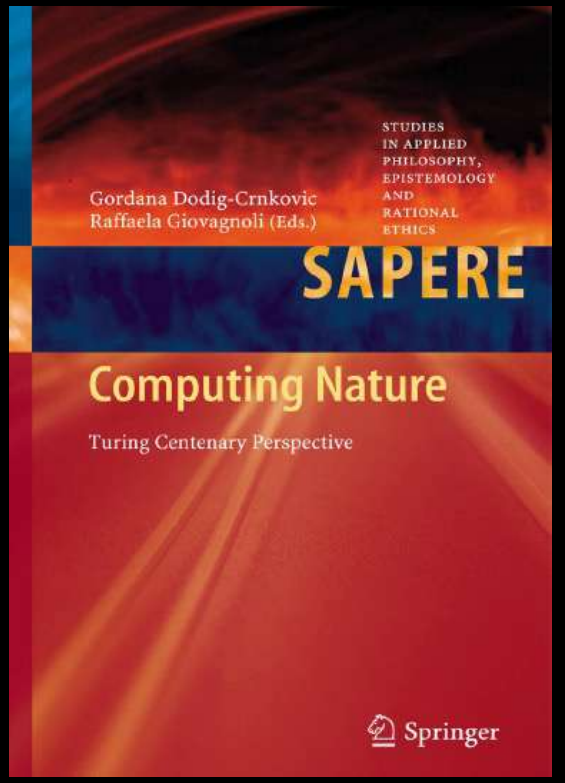
# Computation, Information, Cognition




*Computation, Information, Cognition*
Gordana Dodig Crnkovic and
Susan Stuart, Edts.
Cambridge Scholars Publishing, 2007

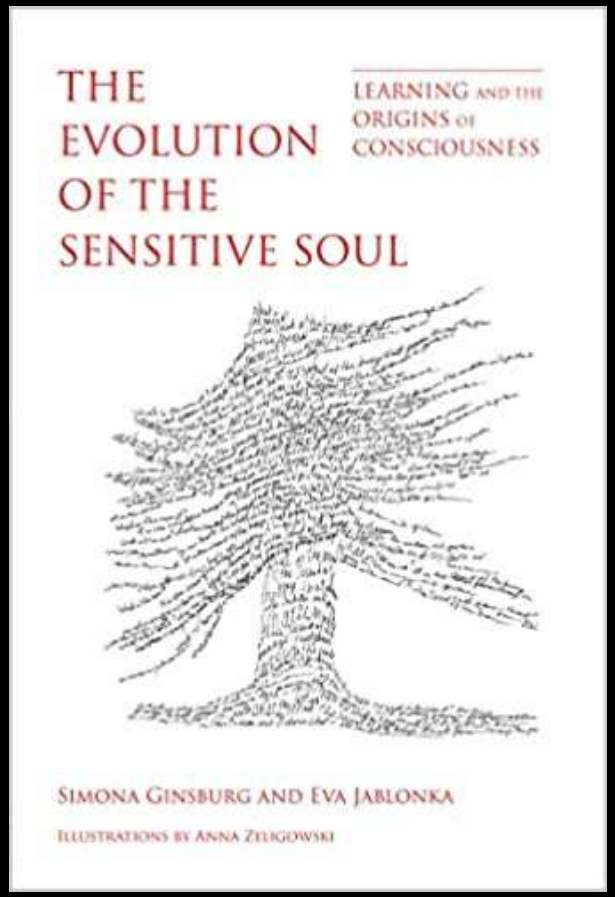


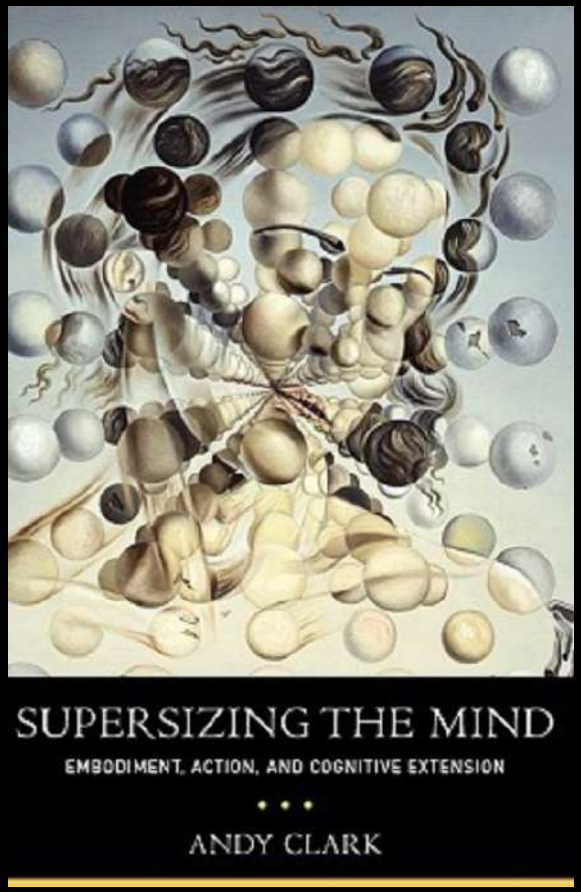

*Information and Computation*
Gordana Dodig Crnkovic and
Mark Burgin, Edts.
World Scientific, 2011

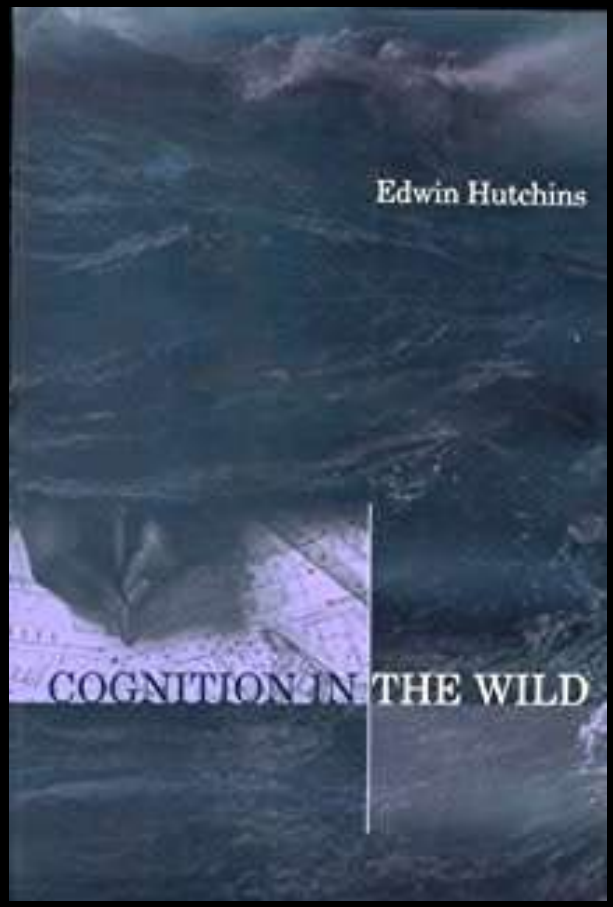



*Computing Nature*
Gordana Dodig Crnkovic and
Raffaela Giovagnoli, Edts.
Springer, 2013

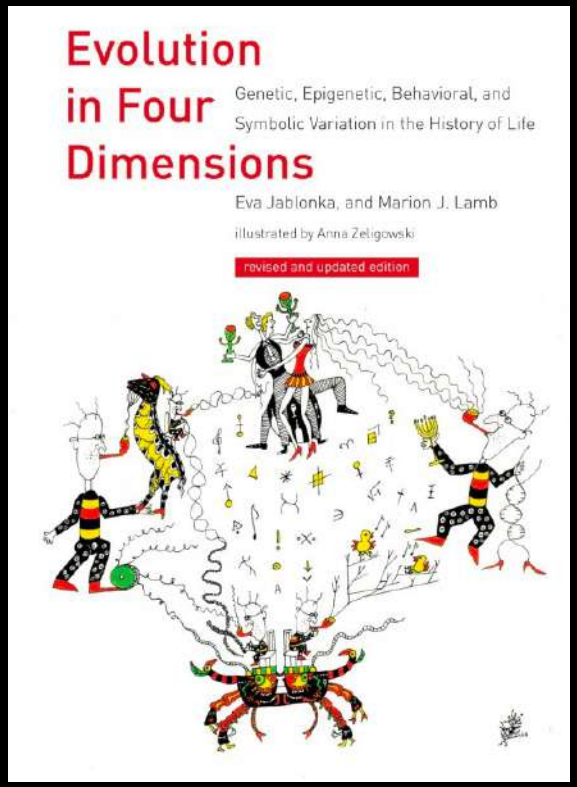
# The Extended Mind in Nature

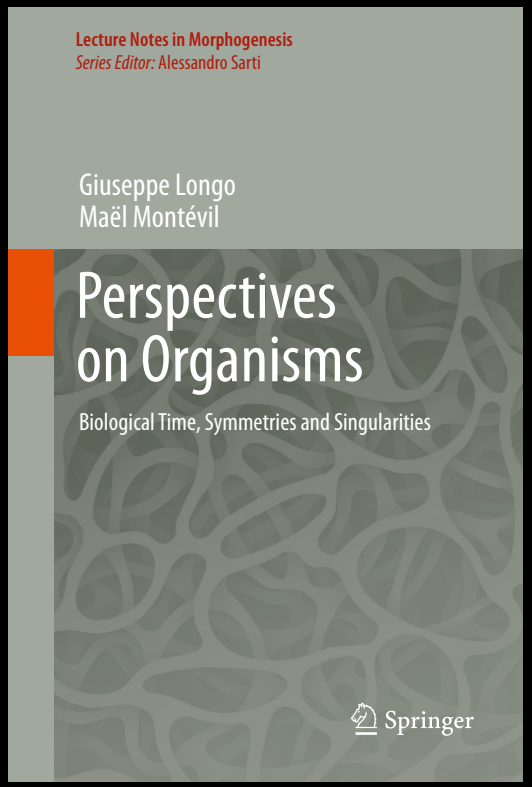


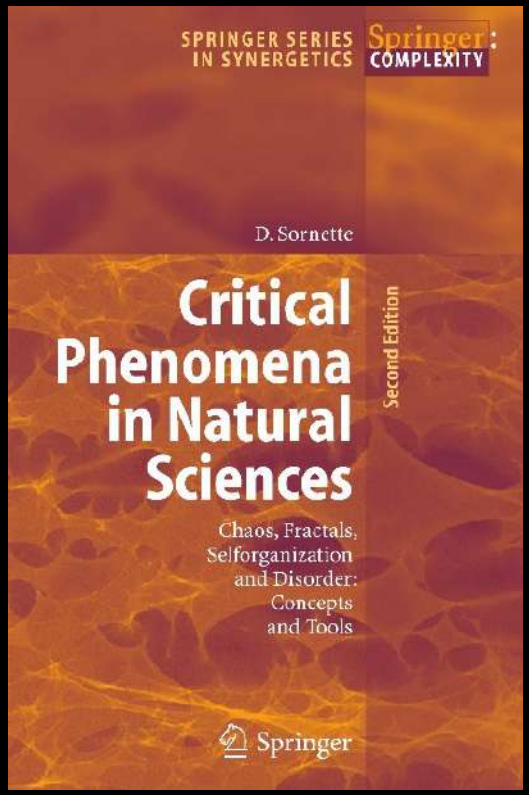



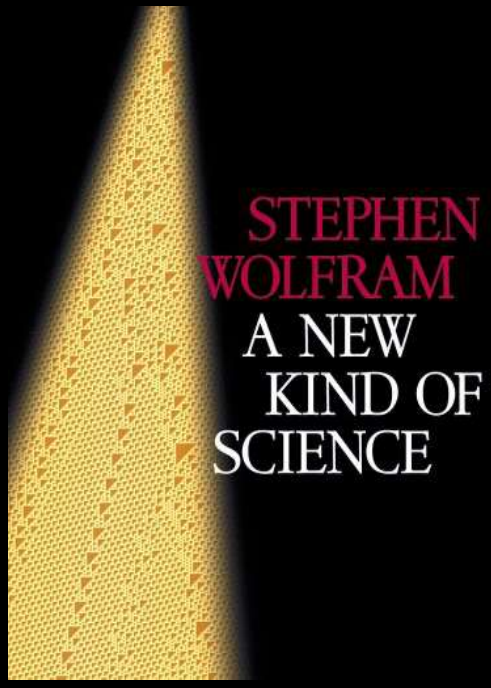
# Evolution and The Extended Mind

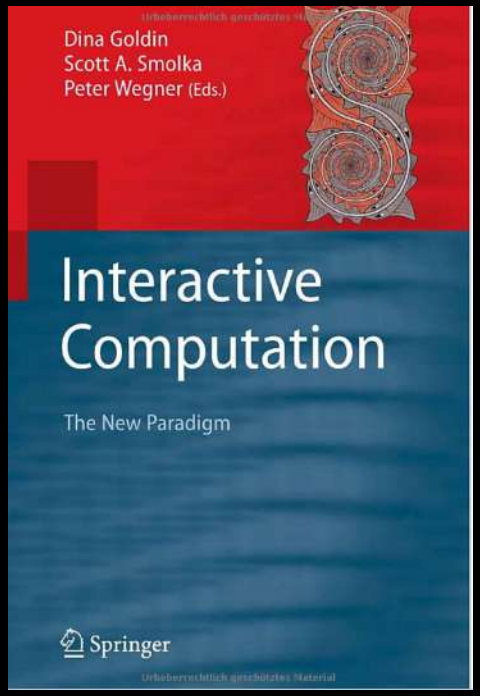


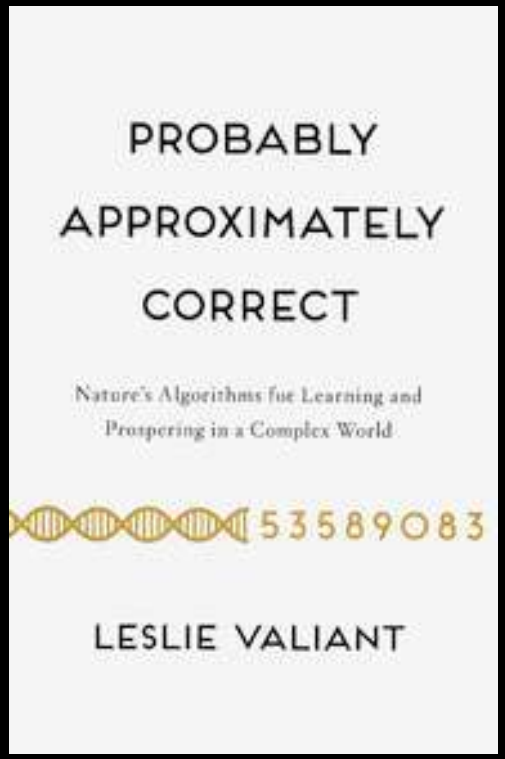



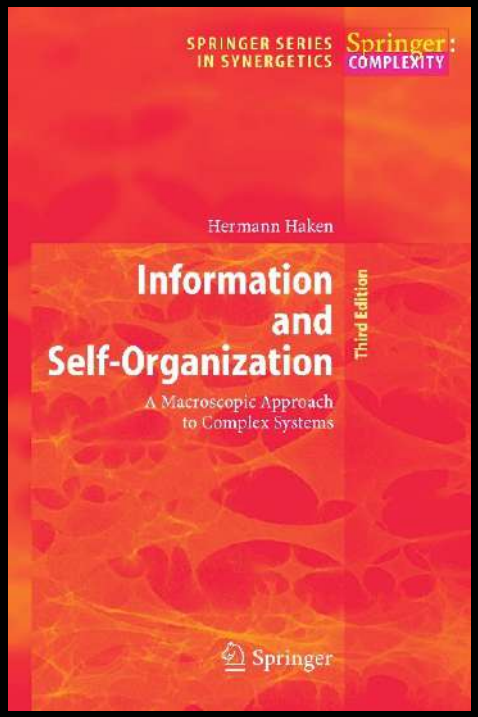
# New Computation Frameworks

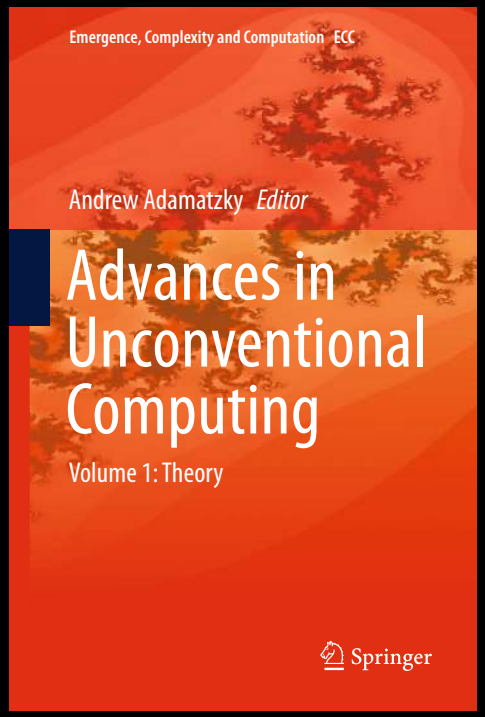


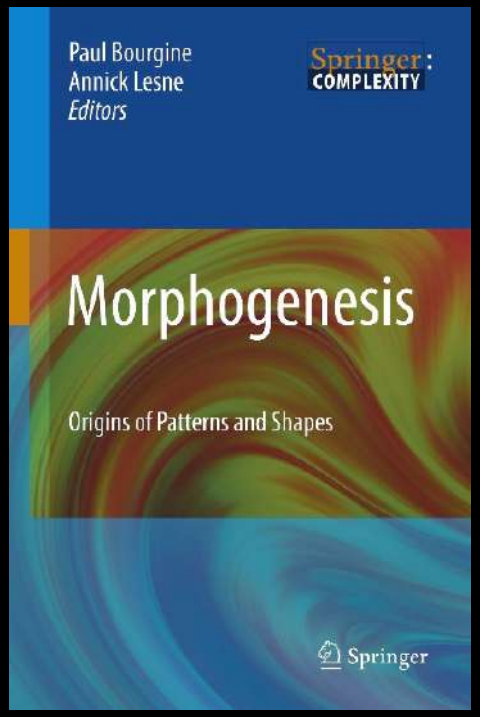



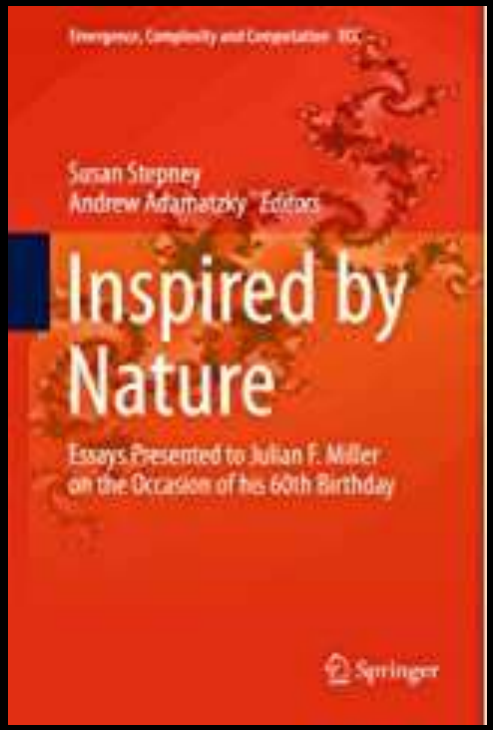
# Natural/Unconventional/Morphological Computing

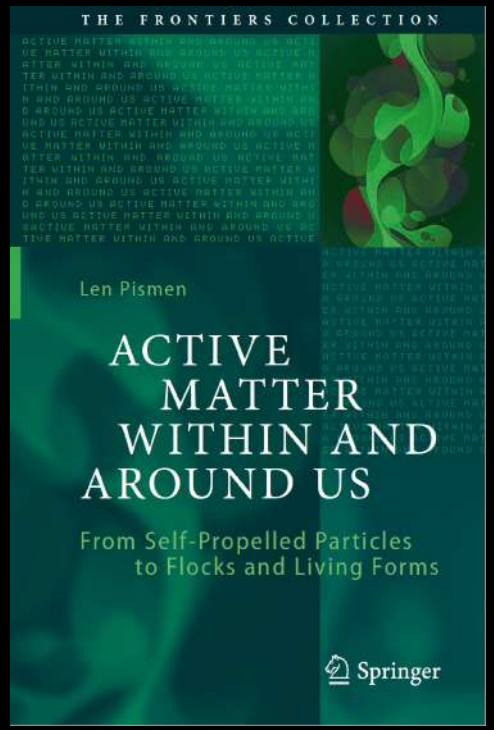


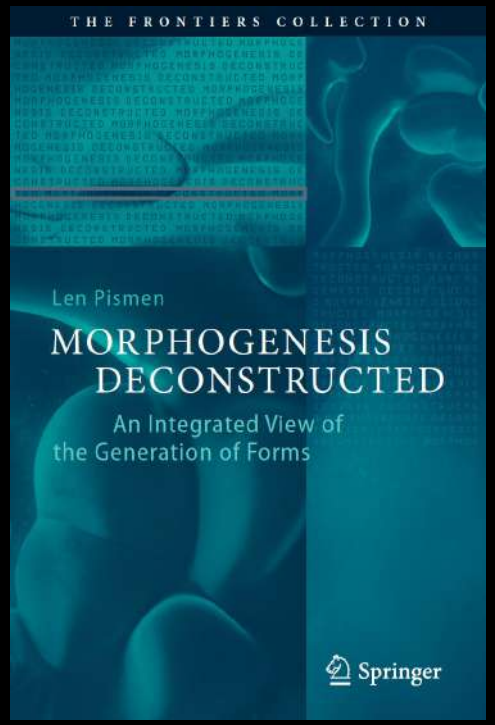



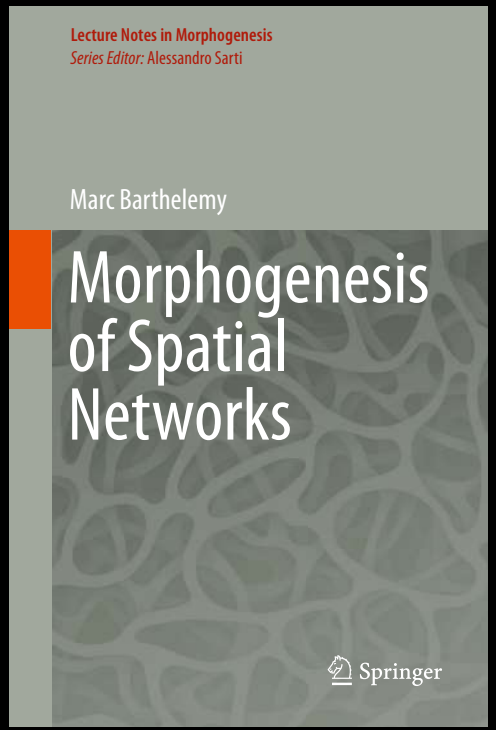




# Natural/Unconventional/Morphological Computing



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