WORLD LOGIC DAY 2022 UNESCO

COMPUTING NATURE - NEW TRENDS ROUND TABLE January 14, 17.00-19.30 CET

LOGIC OF COGNITIVE SYSTEMS FROM SINGLE CELL UP

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http://www.gordana.se

Gordama Dodig-Crnkovic Research

Chalmers University of Technology, Interaction Design, Professor of Interaction Design,
https://www.chalmers.se/en/staff/Pages/gordana-dodig-crnkovic.aspx
Mälardalen University, Full Professor of Computer Science http://www.idt.mdh.se/~gdc

Research topics

COMPUTING

Morphological computing and Cognition (Swedish Research Council Project)

Computing Paradigms, Natural/Unconventional Computing, Cognitive computing, Social computing

Foundations of Information, Info-Computational framework

Cognitive aspects of ubiquitous computing and interaction design

ETHICS

Ethics of Computing, Information Ethics, Roboethics and Engineering Ethics. Special current focus on Ethics of autonomous transportation

MORE INFORMATION

https://www.chalmers.se/en/staff/Pages/gordana-dodig-crnkovic.aspx
http://www.es.mdh.se/staff/37-Gordana_Dodig_Crnkovic

http://www.gordana.se

Current Projects

CONFERENCES

Summit of the International Society for the Study of Information IS4SI https://summit-2021.is4si.org
Board member, Past President, Co-organizer

PT-AI 2021 Gothenburg (hybrid) September 27-28, 2021
https://www.pt-ai.org/

4th Conference on "Philosophy and Theory of Artificial Intelligence" https://www.pt-ai.org/2021

ETHICS4EU September 22, CHALMERS (online)

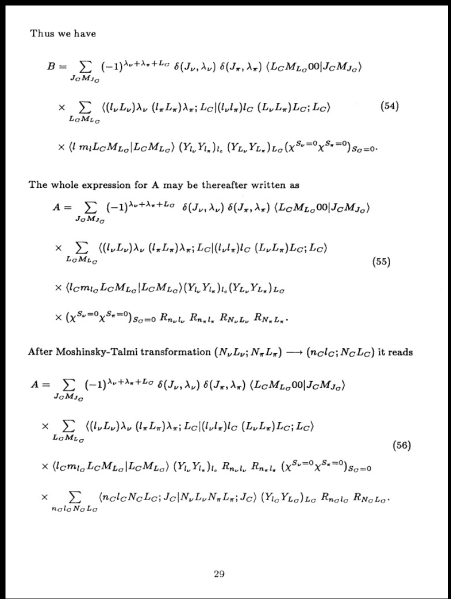
SPECIAL ISSUES

"Contemporary Natural Philosophy and Philosophies", Philosophies journal Part 3

"Information-Processing and Embodied, Embedded, Enactive Cognition, Part 3: Part 3: Morphological Computing and Evolution of Cognition", Entropy

From Formal to Natural Languages

PhD in Physics, 1988
On Alpha-decay, Department of Physics, University of Zagreb



Thus we have

$$B = \sum_{J_C M_{J_C}} (-1)^{\lambda_\nu+\lambda_\pi+L_C}\, \delta(J_\nu,\lambda_\nu)\, \delta(J_\pi,\lambda_\pi)\, \langle L_C M_{L_C} 00 | J_C M_{J_C}\rangle$$
$$\times \sum_{L_C M_{L_C}} \langle (l_\nu L_\nu)\lambda_\nu\, (l_\pi L_\pi)\lambda_\pi; L_C | (l_\nu l_\pi) l_C\, (L_\nu L_\pi) L_C; L_C\rangle \qquad (54)$$
$$\times \langle l\, m_l L_C M_{L_C} | L_C M_{L_C}\rangle\, (Y_{l_\nu} Y_{l_\pi})_{l_c}\, (Y_{L_\nu} Y_{L_\pi})_{L_C} (\chi^{S_\nu=0}\chi^{S_\pi=0})_{S_C=0}.$$

The whole expression for A may be thereafter written as

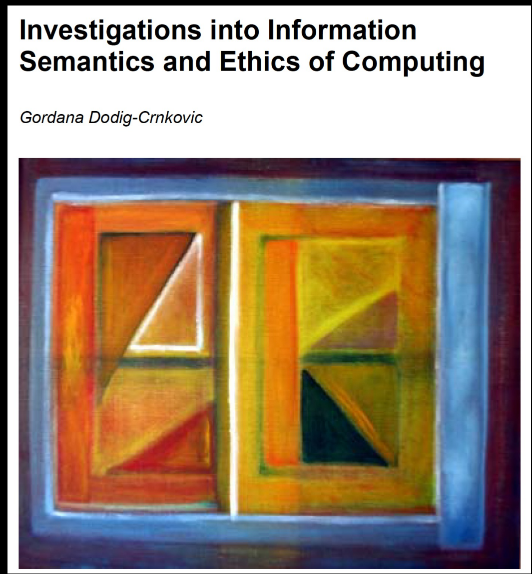
$$A = \sum_{J_C M_{J_C}} (-1)^{\lambda_\nu+\lambda_\pi+L_C}\, \delta(J_\nu,\lambda_\nu)\, \delta(J_\pi,\lambda_\pi)\, \langle L_C M_{L_C} 00 | J_C M_{J_C}\rangle$$
$$\times \sum_{L_C M_{L_C}} \langle (l_\nu L_\nu)\lambda_\nu\, (l_\pi L_\pi)\lambda_\pi; L_C | (l_\nu l_\pi) l_C\, (L_\nu L_\pi) L_C; L_C\rangle \qquad (55)$$
$$\times \langle l_C m_{l_C} L_C M_{L_C} | L_C M_{L_C}\rangle (Y_{l_\nu} Y_{l_\pi})_{l_c} (Y_{L_\nu} Y_{L_\pi})_{L_C}$$
$$\times (\chi^{S_\nu=0}\chi^{S_\pi=0})_{S_C=0}\, R_{n_\nu l_\nu}\, R_{n_\pi l_\pi}\, R_{N_\nu L_\nu}\, R_{N_\pi L_\pi}.$$

After Moshinsky-Talmi transformation $(N_\nu L_\nu; N_\pi L_\pi) \longrightarrow (n_C l_C; N_C L_C)$ it reads

$$A = \sum_{J_C M_{J_C}} (-1)^{\lambda_\nu+\lambda_\pi+L_C}\, \delta(J_\nu,\lambda_\nu)\, \delta(J_\pi,\lambda_\pi)\, \langle L_C M_{L_C} 00 | J_C M_{J_C}\rangle$$
$$\times \sum_{L_C M_{L_C}} \langle (l_\nu L_\nu)\lambda_\nu\, (l_\pi L_\pi)\lambda_\pi; L_C | (l_\nu l_\pi) l_C\, (L_\nu L_\pi) L_C; L_C\rangle \qquad (56)$$
$$\times \langle l_C m_{l_C} L_C M_{L_C} | L_C M_{L_C}\rangle\, (Y_{l_\nu} Y_{l_\pi})_{l_c}\, R_{n_\nu l_\nu}\, R_{n_\pi l_\pi}\, (\chi^{S_\nu=0}\chi^{S_\pi=0})_{S_C=0}$$
$$\times \sum_{n_C l_C N_C L_C} \langle n_C l_C N_C L_C; J_C | N_\nu L_\nu N_\pi L_\pi; J_C\rangle\, (Y_{l_C} Y_{L_C})_{L_C}\, R_{n_C l_C}\, R_{N_C L_C}.$$

29

PhD in Computing, 2006
Computer Science,
Mälardalen University



Current: Morphological Computing and Cognition

Connecting Morphological Computing and Cognition to Logic: Practical Logic & Logic in Action

...A logic that is practical in our sense falls within the ambit of the pragmatic.

Historically, pragmatics is that branch of the theory of signs in which there is irreducible and non-trivial reference to agents, to entities that receive and interpret messages.

By an easy extension, a pragmatic theory of reasoning is a theory in which there is express irreducible and non-trivial reference to cognitive agents.

If in turn a cognitive agent is conceived of as a certain kind of information-processor, then a pragmatic theory of cognitive agency will provide descriptions of processors of information.

Given that a logic is a principled account of certain aspects of practical reasoning, logic too is a pragmatic affair. If we ask, 'which aspects of practical reasoning are the proper province of logic?', we say again that the answer lies in operational arrangements.

Gabbay, Dov M. & Woods, John (2003) A PRACTICAL LOGIC OF COGNITIVE SYSTEMS, Volume 1. Agenda Relevance. A Study in Formal Pragmatics. NH. Elsevier

Connecting Morphological Computing and Cognition to Logic: Practical Logic & Logic in Action

…practical logic is that part of a pragmatic theory that deals with the requisite aspects of practical cognitive agency at both linguistic and sublinguistic levels, and for which a suitably flexible notion of information will prove necessary.

It is well to emphasize that, in taking logic into 'a practical turn', we are not alone. Our approach, although developed independently, also shows a certain affinity to work done under the rubric of 'the dynamic turn', an approach to logic that emphasizes the 'interfaces with cognitive science, and the experimental study of how information and cognition works in humans once we set ourselves to study the psychological and neurological realities underneath ... ' [van Benthem, 2001, p. 5].

Dov M. Gabbay & John Woods (2003) A PRACTICAL LOGIC OF COGNITIVE SYSTEMS, Volume 1. Agenda Relevance. A Study in Formal Pragmatics. NH. Elsevier

J. van Benthem, P. Dekker, J. van Eijck, M. de Rijke, and Y. Venema, editors. (2001) LOGIC IN ACTION. Amsterdam: Institute for Logic, Language and Computation, Amsterdam, 2001.

Johan van Benthem (2010) LOGICAL DYNAMICS OF INFORMATION AND INTERACTION. Cambridge University Press

Practical Logic

“A practical logic is a description of certain aspects of the behaviour of practical agents under conditions that qualify it broadly as cognitive.

A cognitive agent is a being capable of perception, memory, belief, desire, reflection, deliberation, decision and inference.

A practical cognitive system is a cognitive system whose cognitive agent is a practical agent in our sense, that is, an individual.

A practical logic of the sort we are describing gives 'a certain kind of description' of a practical cognitive system.”

Dov M. Gabbay & John Woods (2003) A PRACTICAL LOGIC OF COGNITIVE SYSTEMS, Volume 1. Agenda Relevance. A Study in Formal Pragmatics. NH. Elsevier

Logic, Rationality and Interaction*

2007: "studying information, first and foremost, means studying information exchange**.
This acknowledgement of the inherently social character of information shows up at many places in modern logical theories.

2020: [this will generalize to inherently **relational** character of information]

More generally, information exchange is a form of interaction where agents act together in strategic ways.
This new perspective has led to contacts between logic and game theory, bringing a new set of disciplines into the scope of logic: viz., economics, and the social sciences.

*Workshop series started in 2007
https://link.springer.com/conference/lori, International Workshop on Logic, Rationality and Interaction

**Johan van Benthem (2011) Logical Dynamics of Information and Interaction, Cambridge University Press
Alexandru Baltag & Sonja SmetsJohan (2014) van Benthem on Logic and Information Dynamics, Springer, Cham

Logic, Rationality and Interaction*

2007 (human-centric perspective):

"New interfaces are arising, such as epistemic studies of rational behavior in games.

Another interesting development in this area is the rise of the notion of 'social software', the idea of using computational techniques for analyzing patterns of social behavior.

And finally, interaction is also crucial to intelligent behavior in the field of natural language. Here pragmatics, the study of the actual use of language between different agents, has become the primary focus of research. Notions from game theory, in particular evolutionary games, are being used to-day to answer all kinds of pragmatic issues, for instance, how linguistic conventions can arise.

This workshop aims to bring together researchers working on these and related topics in logic, philosophy, computer science, and related areas in order to arrive at an integrated perspective on knowledge acquisition, information exchange, and rational action.

2022 (cognitive/intelligent agent-centric perspective), living-agents and artificial agents

Cognition in Nature and Artifacts as Computation of Information

Our goal: Connecting human-centric, human language-based logic (grounded in cognition) with natural logic and natural cognition of living agents.

An info-computational framework for analysis of cognition and intelligence, natural and artificial, is a foundation for the study of information processing/ computational phenomena.

Two-way learning: from theoretical and experimentalstudy of natural systems to constructive study of artifacts (such as deep neural networks, machine learning and robots) and from increasingly sophisticated artifacts back to models and theories of structures and behaviors of natural systems (such as brains, swarms, or unicellular organisms).

At the time when the first models of cognitive architectures have been proposed, some forty years ago, understanding of cognition, embodiment and evolution was substantially different from todays.

Learning from Nature
Requires Updates of Definitions

Information = structure - means not only news and artifacts in our human civilization that are used to transmit data and knowledge, but similar structures utilized by other living organisms, even the simplest ones like bacteria.

Computation = dynamics of information - is taken to be any process of information transformation, that leads to behavior, and not only those processes that we currently use to calculate, manually or with machinery.

Cognition is ability to learn from environment and adapt so to survive as individual and species, for which organisms use information and its processing/computation. Intelligence as capacity for problem-solving can be found in all organisms as they all possess cognition. Finally, understanding cognition and intelligence because of biological mechanisms is only possible if we see it in the context of evolution.

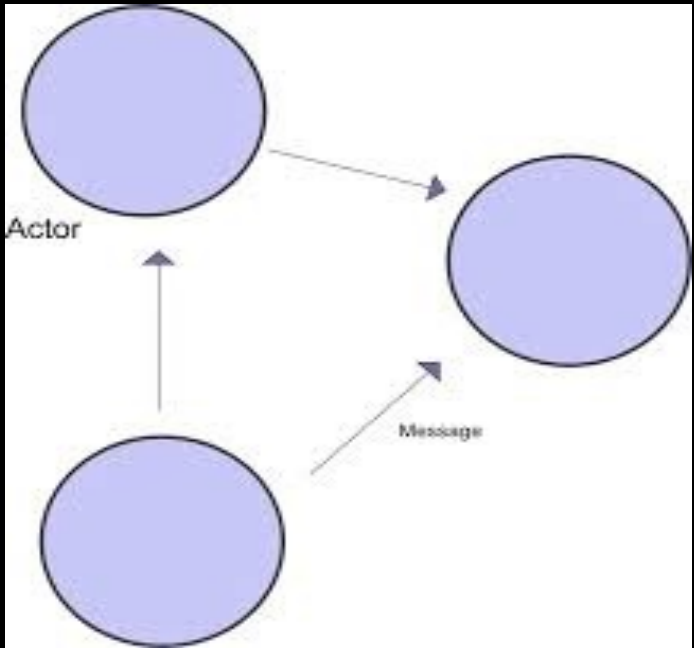
Evolution understood as *extended evolutionary synthesis* formulation of evolutionary theory, which is the interpretation of the theory of evolution based on the newest scientific knowledge about life and its changes, emphasizing fundamental mechanisms of constructive development and reciprocal causation with environment.

Computing Nature

Computing Nature (Naturalist computationalism) framework makes it possible to describe all cognizing agents (living organisms and artificial cognitive systems) as informational structures with computational dynamics [Dodig-Crnkovic, 2006-2020].

Morphological computation in this framework is a process of creation of new informational structures, as it appears in nature, living as non-living. It is a process of morphogenesis, which in biological systems is driven by development and evolution.

Actor Model of Concurrent Distributed Computation

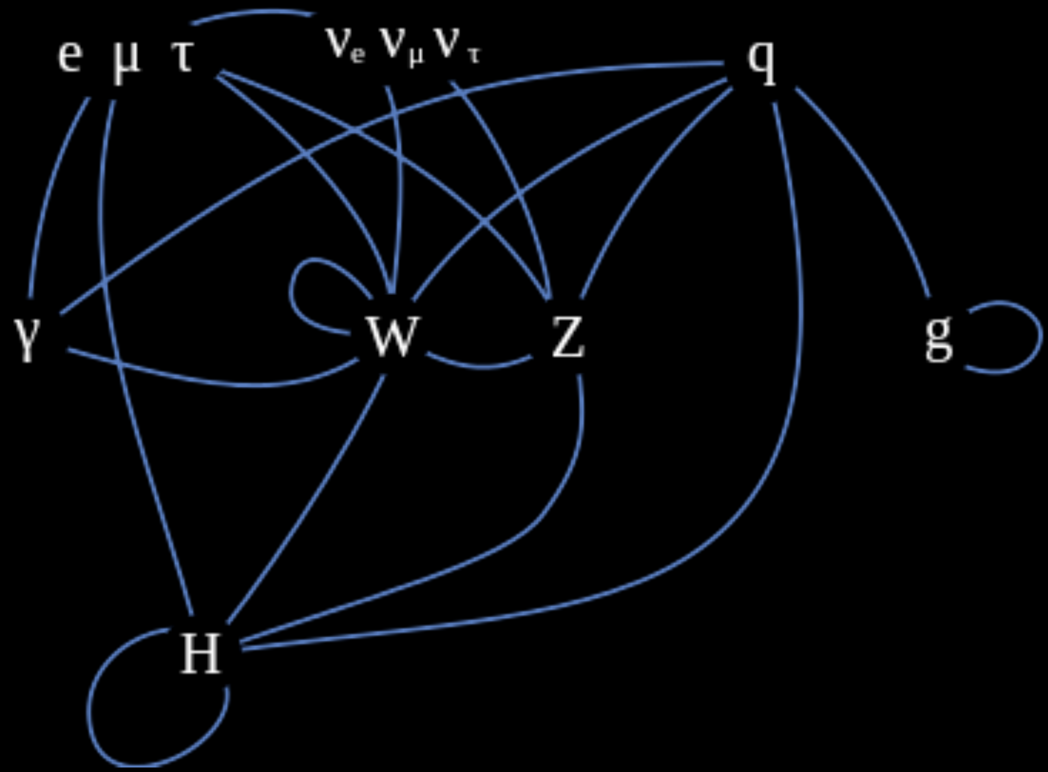


"In the Actor Model [Hewitt, Bishop and Steiger 1973; Hewitt 2010], computation is conceived as distributed in space, where computational devices communicate asynchronously, and the entire computation is not in any well-defined state.

(An Actor can have information about other Actors that it has received in a message about what it was like when the message was sent.) Turing's Model is a special case of the Actor Model." (Hewitt, 2012)

Hewitt's "computational devices" are conceived as computational agents – informational structures capable of acting on their own behalf.

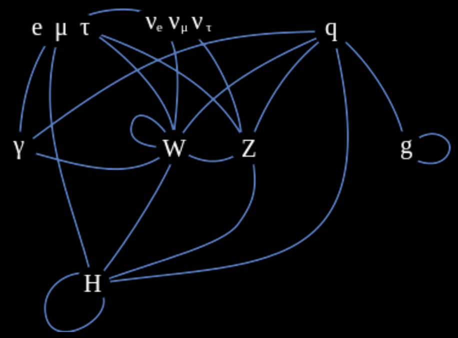
Actor Model of Concurrent Distributed Computation



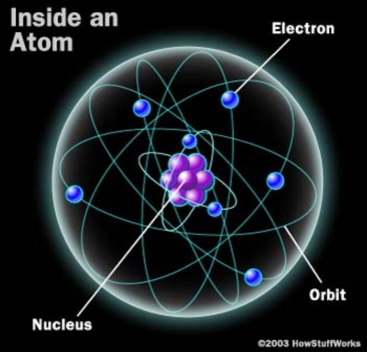
Unlike other models of computation that are based on mathematical logic, set theory, algebra, etc. the Actor model is based on physics, especially quantum physics and relativistic physics. (Hewitt, 2006)

Summary of interactions between particles described by the Standard Model.
http://en.wikipedia.org/wiki/Standard_Model

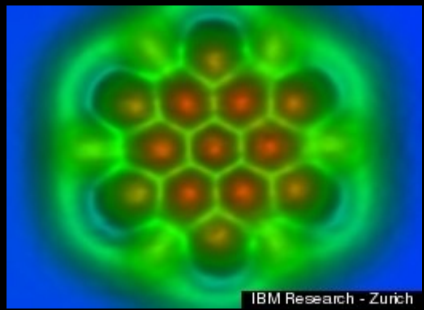
Computing Nature and Nature Inspired Computation



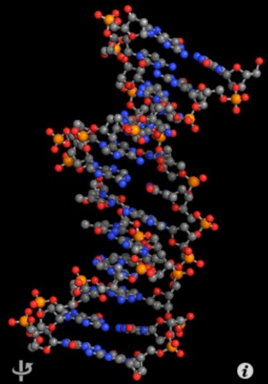
Subatomic particles



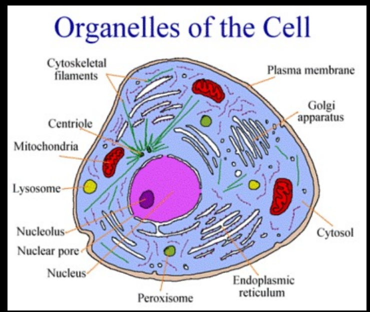
Atoms



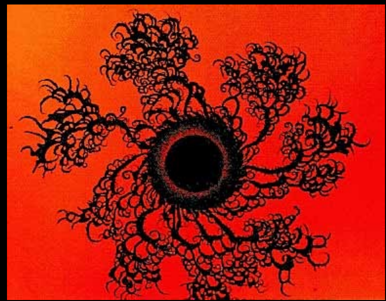
This image, by IBM scientists using an atomic force microscope, shows a nanographene molecule with carbon-carbon bonds



DNA molecule



Unicellular organism



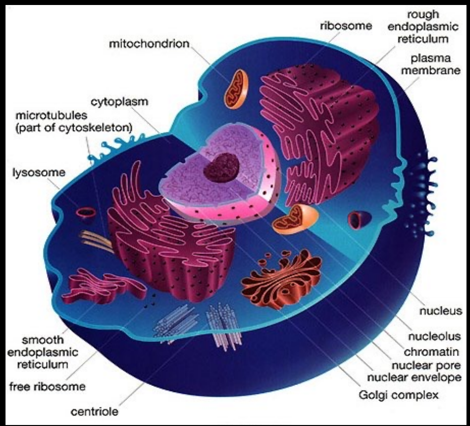
Bacterial colony a multi-cellular "organism"

Bacteria collectively "collects latent information from the environment and from other organisms, process the information, develop common knowledge, and thus learn from past experience" (Ben-Jacob, 2009)

Peter J. Denning. 2007. Computing is a natural science. Commun. ACM 50, 7 (July 2007), 13-18. DOI=10.1145/1272516.1272529 http://doi.acm.org/10.1145/1272516.1272529

http://www.ted.com/talks/bonnie_bassler_on_how_bacteria_communicate

Computing Cells: Self-generating Systems



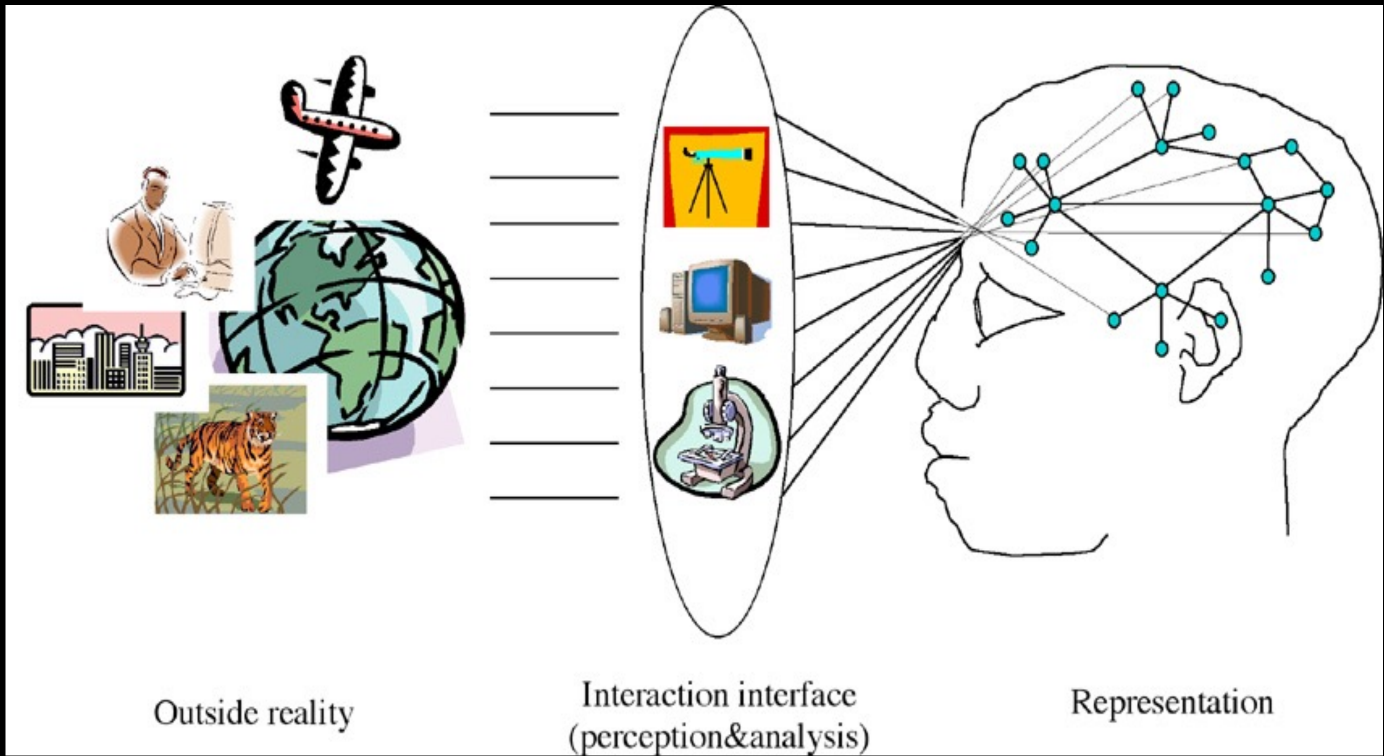
Complex biological systems must be modeled as self-referential, self-organizing "component-systems" (George Kampis) which are self-generating and whose behavior, though computational in a general sense, goes far beyond Turing machine model.

"a component system is a computer which, when executing its operations (software) builds a new hardware.... [W]e have a computer that re-wires itself in a hardware-software interplay: the hardware defines the software, and the software defines new hardware. Then the circle starts again." Kampis (1991) p. 223

Kampis (1991) Self-Modifying Systems in Biology and Cognitive Science. A New Framework For Dynamics, Information, and Complexity, Pergamon Press

Dodig Crnkovic, G. (2011). Significance of Models of Computation from Turing Model to Natural Computation. *Minds and Machines*, (R. Turner and A. Eden guest eds.) Volume 21, Issue 2, p.301.

Cognition: Agency-based Hierarchies of Levels. World as Information for an Agent

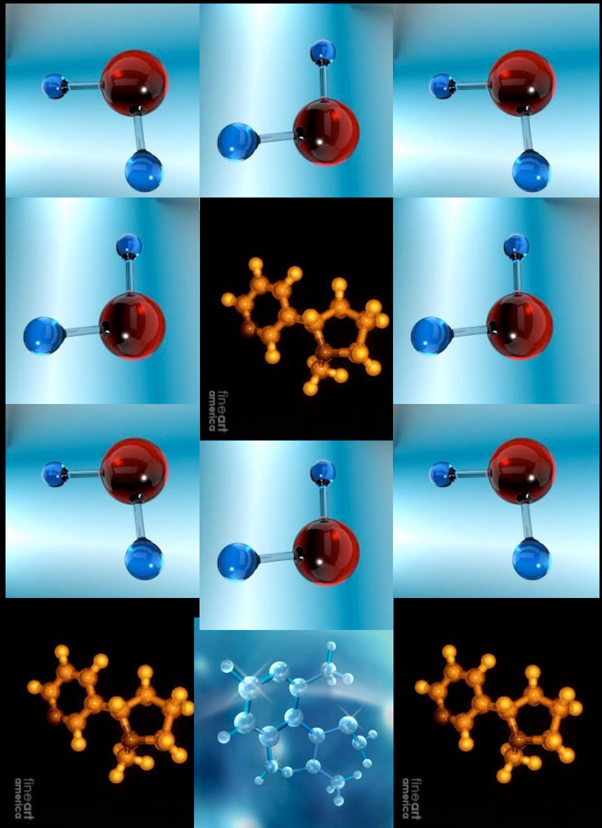


World as potential information   Cognition   Actual information for an agent

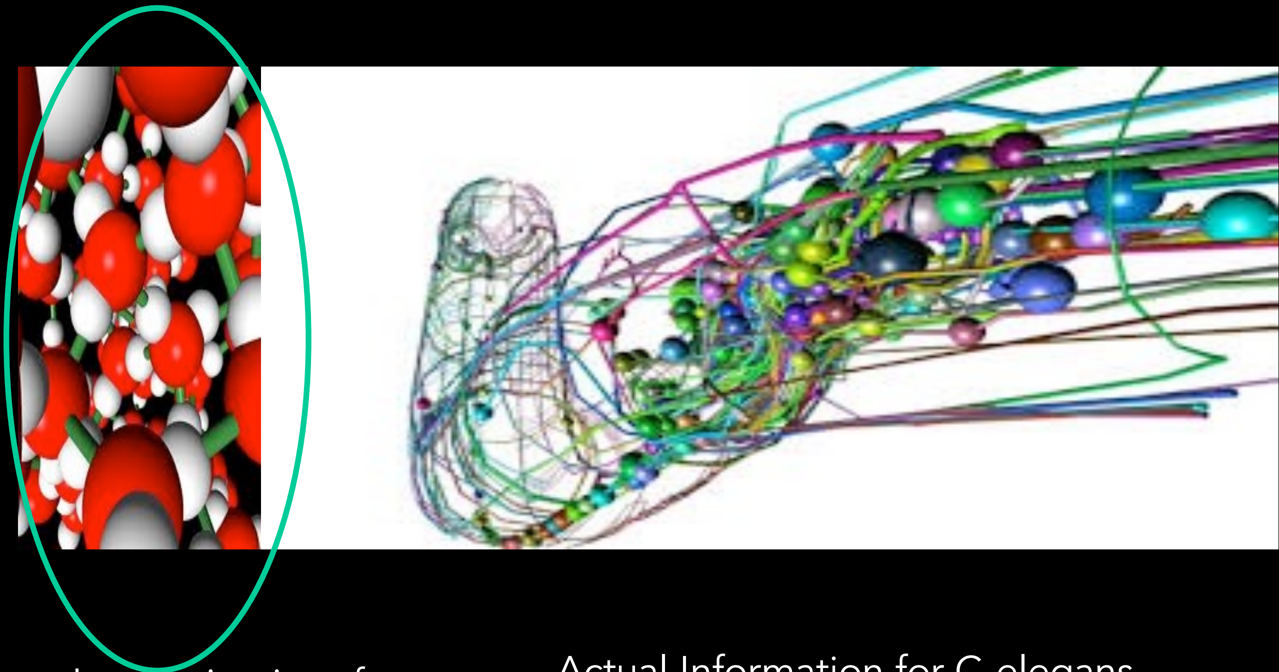
From: http://www.alexeikurakin.org

http://www.tbiomed.com/content/8/1/4 scale-invariance of self-organizational dynamics of energy/matter at all levels of organizational hierarchy

Agency-based hierarchies of levels. World as information for an agent



Potential information
Outside reality for C-elegans



Interaction interface

Actual Information for C-elegans

C. Elegans has 302 neurons (humans have 100 billion). The pattern of connections between neurons has been mapped out decades ago using electron microscopy, but knowledge of the connections is not sufficient to understand (or replicate) the information processor they represent, for some connections are inhibitory while others are excitatory.

http://www.33rdsquare.com/2013/07/david-dalrymple-update-on-project.html

Cognition = Life*

Cognitive architectures generated by natural (morphological) computation are realized in a specific substrate of matter/energy self-organized in living cells [Dodig-Crnkovic, 2012].

Cognition in living systems/agents constitutes life-organizing, life-sustaining goal-directed processes, while in artifactual systems, cognition is engineered process based on sensors, actuators and computing units designed to mimic biological cognition (bio-mimetic design).

Currently, cognitive computing mimics human-level cognition such as in:

D. S. Modha, R. Ananthanarayanan, S. K. Esser, A. Ndirango, A. J. Sherbondy, R. Singh (2011) Cognitive Computing. Communications of the ACM, Vol. 54 No. 8, pp 62-71

* Stewart, John. 1996. "Cognition = Life: Implications for Higher-Level Cognition." Behavioral Processes 35: 311-326.

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.

P. C. Marijuán∗, J. Navarro, R. del Moral (2010) On prokaryotic intelligence: Strategies for sensing the environment. BioSystems 99. pp. 94–103

Basal Bio-cognition

Work of Michael Levin suggests broad range of applications for nature-inspired cognitive architectures based on biological cognition connecting genetic networks, cytoskeleton, neural networks, tissue/organ, organism with the group (social) levels of information processing.

Levin shows how biology has been computing through *somatic memory* (information storage) and *biocomputation/decision making* in *pre-neural bioelectric networks*, before the development of neurons and brains.

Insights from bio-cognition can help the development of new AI platforms, applications in targeted drug delivery, regenerative medicine and cancer therapy, nano-technology, synthetic biology, artificial life, and much more.

Basal Cognition

Recent research finds that "*cognitive operations we usually ascribe to brains—sensing, information processing, memory, valence, decision making, learning, anticipation, problem solving, generalization and goal directedness—are all observed in living forms that don't have brains or even neurons.*" (Levin et al. 2021).

Thus, we generalize cognition a step further, to include all living forms, not only those with nervous systems.

It can be useful for artificial systems that need level of intelligence but not the human level, such as nano-bots or different elements of IoT.

Learning from Basal Bio-cognition

Unlike self-organized natural cognitive agents, engineered cognitive computational agents are essentially dependent on human-made infrastructure for their existence and maintenance.

Types of physical/morphological computation in solid-state inanimate matter used for computers today are *not capable of self-organizing cognitive agency that is fundamental feature of living organisms*. Their cognition is governed by language-based information processing without ‘8real-time) intrinsic connection with 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.

Learning from Basal Bio-cognition

- The concept of biological computation proposes that living organisms perform computations, and that as such, abstract ideas of information and computation may be key to understanding biology.[1][2]*
- *Apart from human brain with nervous system, somatic cells, non-human organisms with nervous system, non –neuronal subsystems in humans such as immune system*

Gordana Dodig-Crnkovic (2021) Cognition as a Result of Information Processing in Living Agent's Morphology. Species-specific Cognition and Intelligence. Proceedings of SweCog 2021 Conference. file:///Users/dodig/gordana.se-httpd.www/work/PUBLICATIONS-files/2021-11.10-SWECOG-2021-GDC.pdf

https://en.wikipedia.org/wiki/Biological_computation#searchInput

Mitchell M (2010-09-21). "Biological Computation". Computer Science Faculty Publications and Presentations,

Bacterial Cognition And Chemical Language

For example, symbolic information processing can be found both on the level of human languages, but also on the level of chemical languages used by bacteria, as Bassler (Bacterial quorum sensing) and Ben-Jacob (Bacterial Know How: From Physics to Cybernetics) have described.

A framework of natural cognition based on info-computation in living agents enables unification of natural and artificial cognition and intelligence. Cognition in nature is a manifestation of biological processes in all living beings, that subsume chemical and physical levels.

Intelligence is considered a problem-solving ability on different levels of organization.

*https://www.ted.com/talks/bonnie_bassler_how_bacteria_talk

Continuum of Natural Cognitive Architectures

Recent comprehensive overview of 40 years of research in artificial (engineered) cognitive architectures, (Kotseruba and Tsotsos 2020), evaluates modelling of the core cognitive abilities **in humans**, but only briefly mentions biologically plausible approaches.

Unlike vast majority of artificial cognitive architectures, that target human-level cognition, we would like to focus on the development and evolution of the continuum of natural cognitive architectures, from basal cellular up, as studied by (Levin, 2021).

Evolution Provides Generative Mechanism

New insights about cognition and its evolution and development in nature from cellular to human cognition can be modelled as natural information processing/ natural computation/ morphological computation. In the info-computational approach, evolution in the sense of extended evolutionary synthesis is a result of interactions between natural agents, cells, and their groups.

Evolution provides generative mechanism for the emergence of increasingly more competent living organisms with increasingly complex natural cognition and intelligence which are used as a template for the artificial/computational counterparts.

Natural Computation Behind Evolution

"And how about the entire universe, can it be considered to be a computer?

Yes, it certainly can, it is constantly computing its future state from its

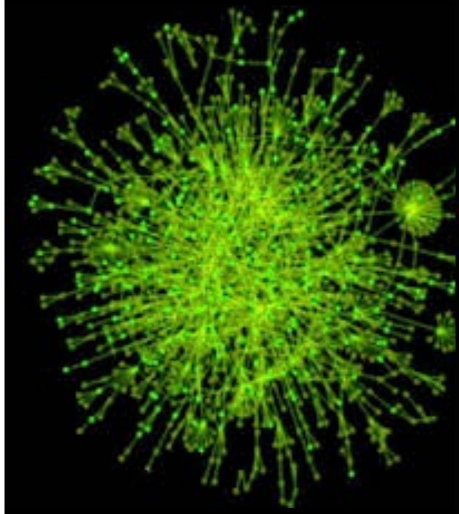
current state, it's constantly computing its own time-evolution!

And as I believe Tom Toffoli pointed out, actual computers like your PC just hitch a ride on this universal computation!"* (Chaitin, 2006)

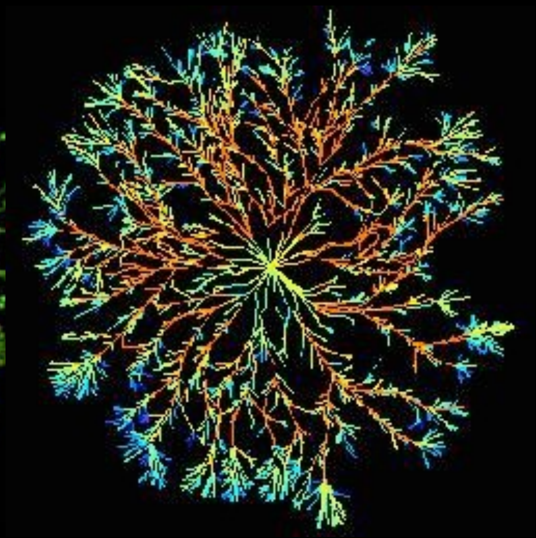
https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.414.4009&rep=rep1&type=pdf
What is Computation? (How) Does Nature Compute? David Deutsch in A Computable Universe by Hector Zenil

*http://www.gordana.se/work/PUBLICATIONS-files/2007-Epistemology%20Naturalized.pdf

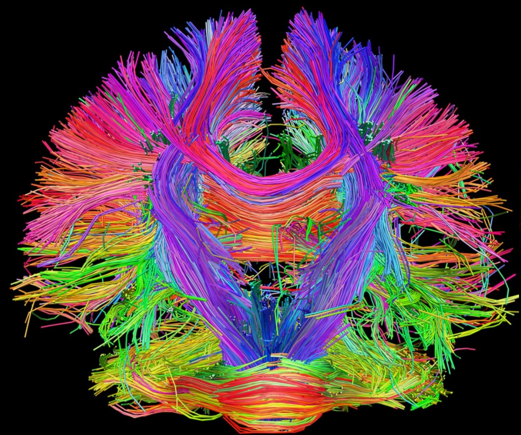
Information Processing in Life-networks



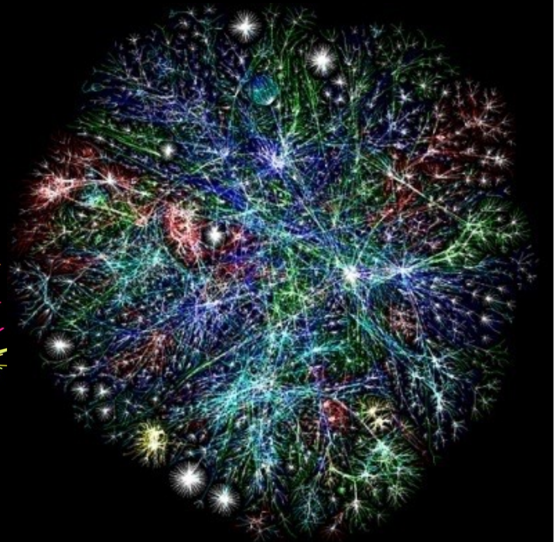
A map of protein–protein interactions in yeast cell



Bacteria Network Ben-Jacob
Bacteria display various multicellular behaviors: emitting, receiving and processing a large vocabulary of chemical symbols



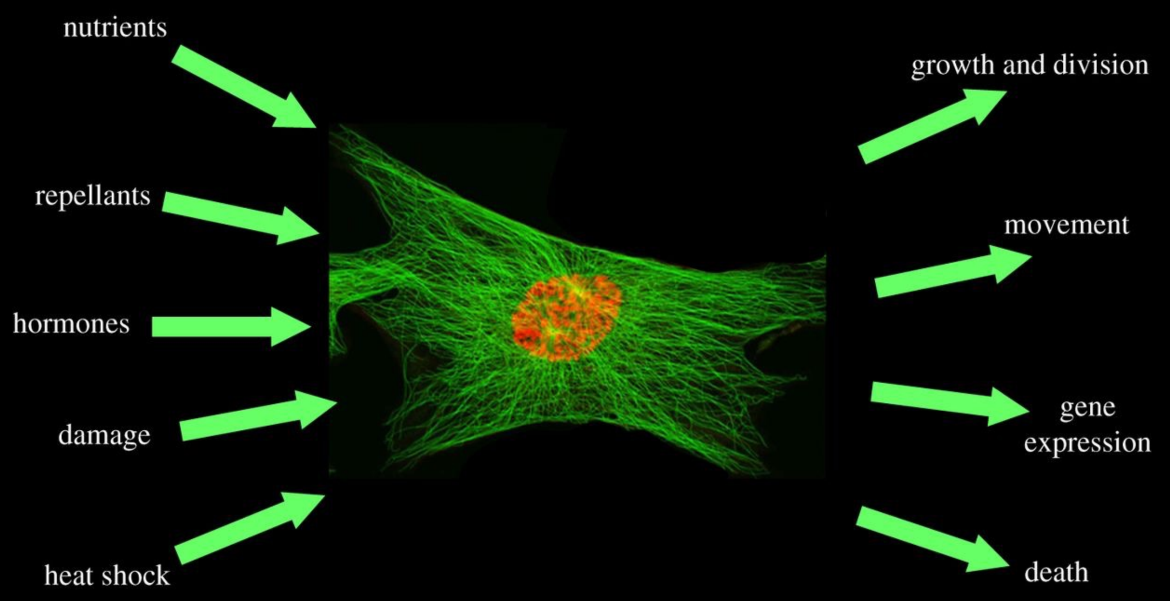
Human brain connectome



Internet map

http://www.nature.com/nrg/journal/v5/n2/fig_tab/nrg1272_F2.html
http://microbes-mind.net/ben-jacob/ https://en.wikipedia.org/wiki/ Eshel_Ben-Jacob
http://eldar.cz/cognition/complexEshel Ben Jacob Learning from Bacteria about Social Networks
http://www.nature.com/news/neuroscience-making-connections-1.10260
http://www.humanconnectomeproject.org
https://en.wikipedia.org/wiki/Opte_Project

Natural Cognition & Intelligence
Basal Level: Cells Processing Information



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

https://www.youtube.com/watch?v=wJyUtbn0O5Y&list=PLXPeXawEy4EcPnecIV1FaZA6bgVDujLzm&index=7
Harvard University XVIVO animation showing inner world of a cell

http://www.youtube.com/watch?v=NJxobgkPEAo&feature=related From RNA to Protein Synthesis
http://www.youtube.com/watch?v=3aVT2DTbtA8&feature=related Replication, Transcription, and Translation

Microorganismic cognition (basal 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

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

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

Basal Cognition

Despite decades of research into the subject, no agreement exists about where cognition is found in the living world. Is a nervous system needed? If so, why? If not, why not? A new two-part theme issue of Phil Trans B on the emerging field of 'Basal Cognition', edited by Pamela Lyon, Fred Keijzer, Detlev Arendt and Michael Levin, explores these questions.

Part 1 https://royalsocietypublishing.org/toc/rstb/2021/376/1820
Part 2 https://royalsocietypublishing.org/toc/rstb/2021/376/1821

Basal Cognition and Intelligence

"cognitive operations we usually ascribe to brains—sensing, information processing, memory, valence, decision making, learning, anticipation, problem solving, generalization and goal directedness—are all observed in living forms that don't have brains or even neurons." (Levin et al. 2021).

We generalize cognition to include all living forms, not only those with nervous systems.

It can be useful for artificial systems that need level of intelligence but not human level, such as nano-bots or different elements of IoT.

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

Light (quality, quantity, duration, direction)

Mechanical, constant (substrate, support)
Mechanical, variable (wind, herbivores)

Atmospheric humidity
Other plants proximity
Temperature
Nutrients
Water
CO_2
Pathogenes
Gravity

Endogeneous signals

Growth regulators (cytokinin, ethylene, gibberellin, auxin, abscisic acid, brassinosteroids)

Mechanical, growth related tissue compression and tension

Defence signals
Jasmonic acid
Salicylic acid

Developmental regulators (mobile RNA)

Metabolites (sugars, glutamate)

Signal processing and transduction in plant cells: the end of the beginning?
S. Gilroy and A. Trewavas (2001) Nature Reviews Molecular Cell Biology 2, 307-314

Dynamics of Long-distance Signaling via Plant Vascular Tissues
Notaguchi Michitaka, Okamoto Satoru (2015) Frontiers in Plant Science. Vol. 6 No. 00161
http://journal.frontiersin.org/article/10.3389/fpls.2015.00161/full

Plants: Adaptive behavior, root-brains, and minimal cognition.
Garzon, Paco; Keijzer, Fred (2011). " Adaptive Behavior. 19 (3): 155–171.

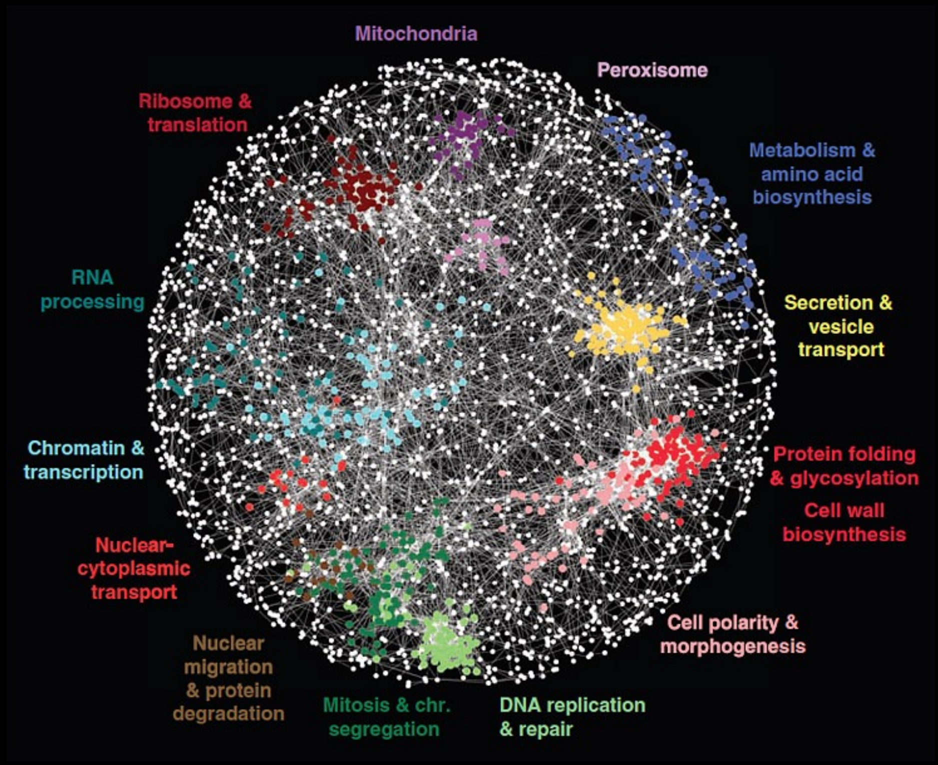
Plant behaviour and communication.
Karban, Richard (2008). " Ecology Letters. 11 (7): 727–739. doi:10.1111/j.1461-0248.2008.01183.x. PMID 18400016.

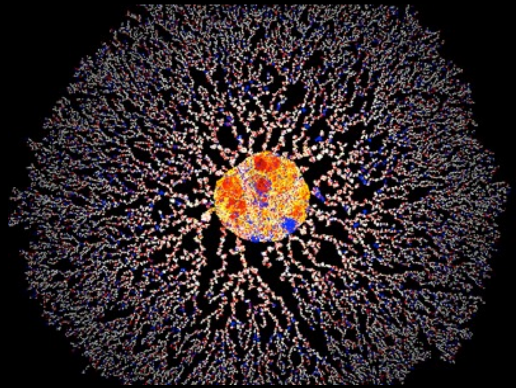
http://www.nature.com/nrm/journal/v2/n4/images/nrm0401_307a_f1.gif

Animal cognition

Rudimentary forms of language

http://www.cellcognition.org/ The cell cognition project
https://en.wikipedia.org/wiki/Molecular_cellular_cognition
Molecular cellular cognition

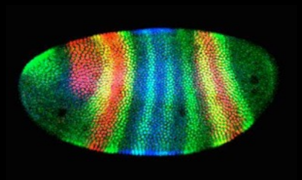




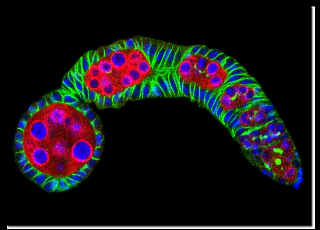
http://phys.org/news/2009-11-conquer-social-network-cells.html

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

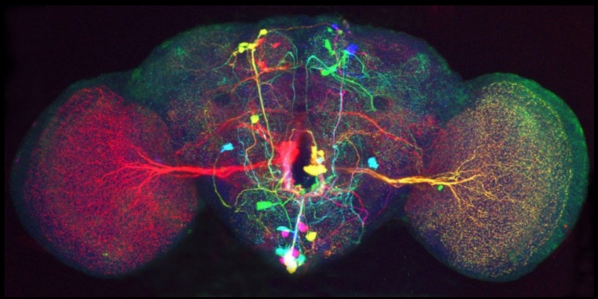
http://www.visualcomplexity.com/vc/images/122_big01.jpg Protein network



Fruit fly embrio



Fruit fly larva

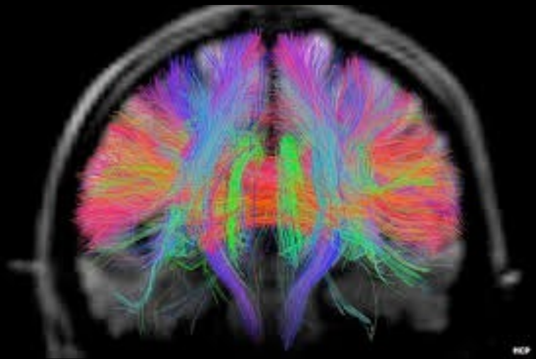


Fruit fly brain neurons

Fruit fly head

Human cognition

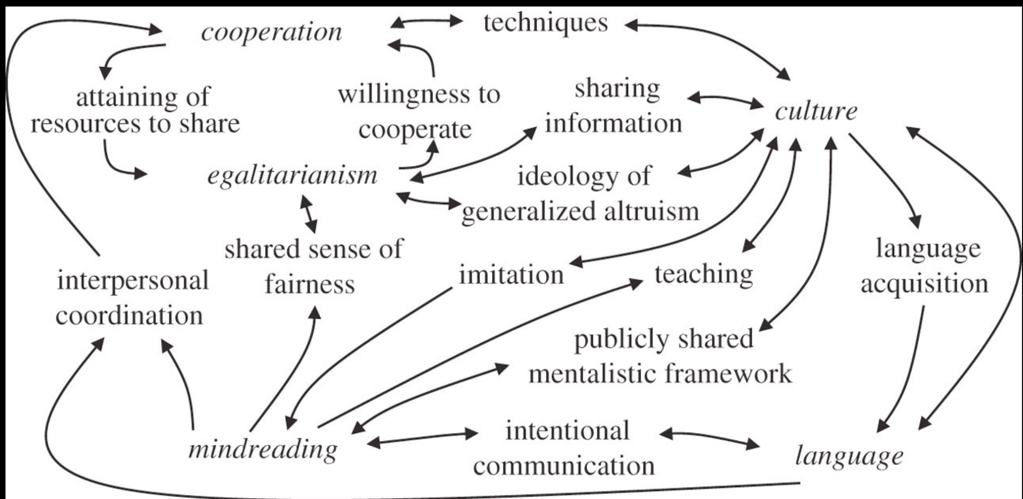
Complex language and material culture



Human connectome

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

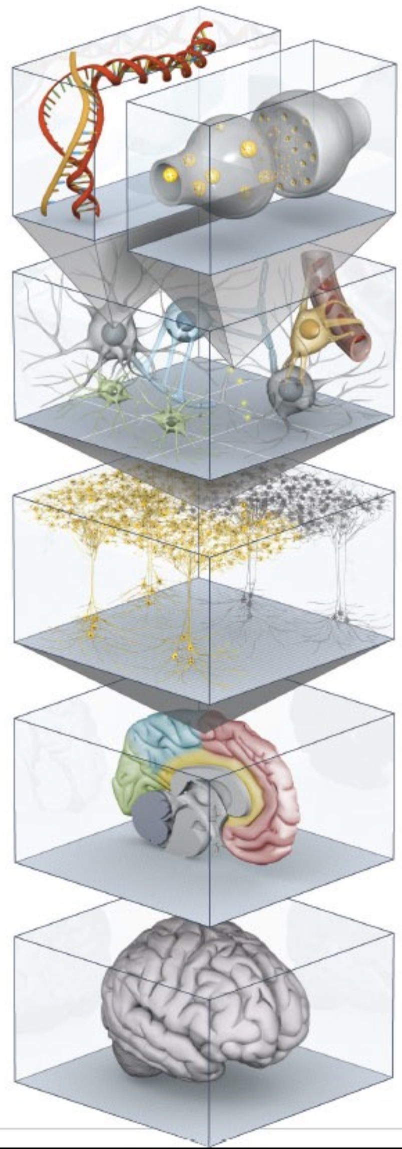
Connecting **domain specific language accounts**, from molecules to human languages:



http://d1vn86fw4xmcz1.cloudfront.net/content/royptb/367/1599/2119/F1.large.jpg

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.

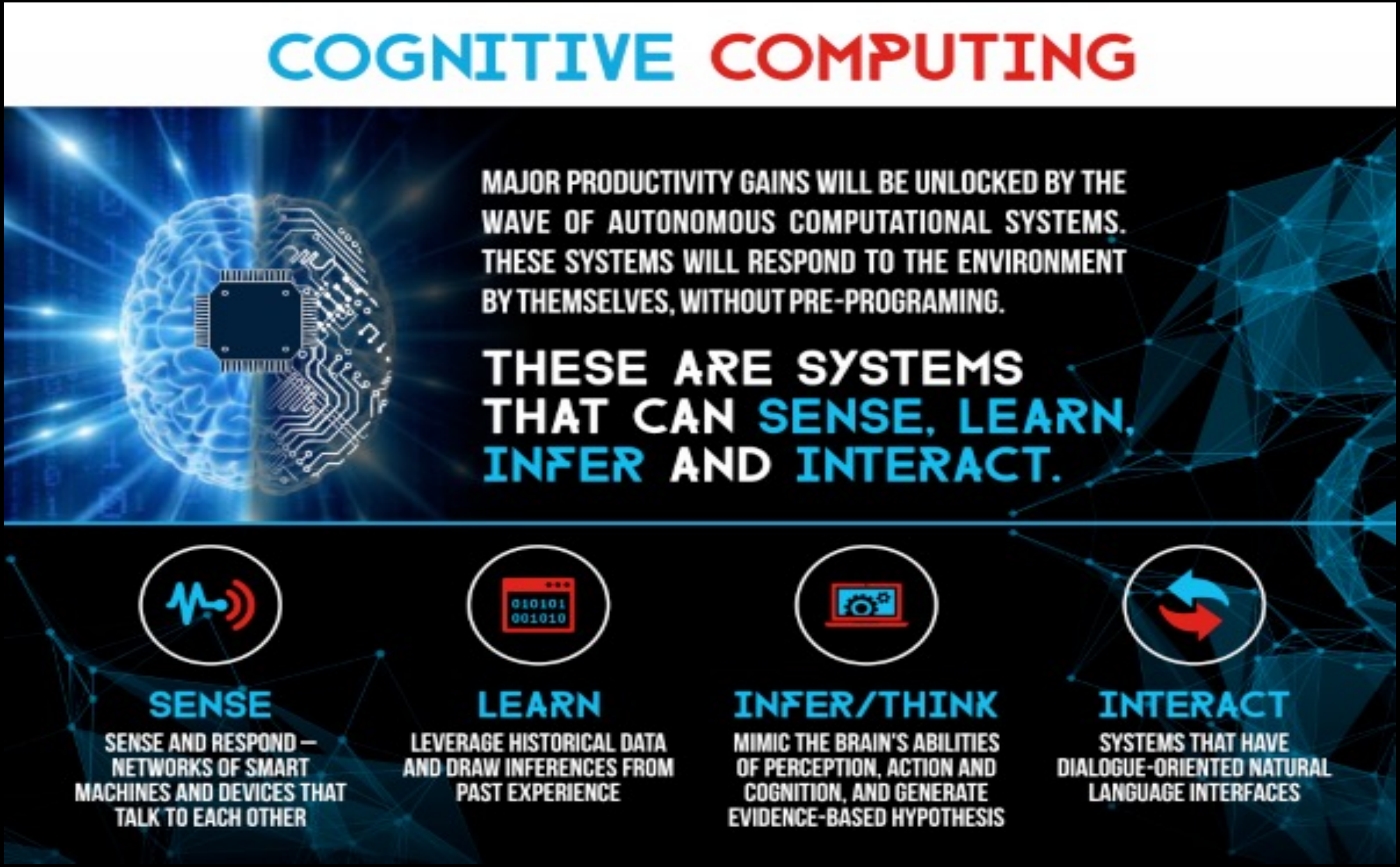
Whole Organ
An in silico brain might substitute for the actual organ. By removing the computer code for a "gene," the virtual system can, for instance, mimic the effects of a mutation, as scientists do today by "knocking out" a gene in mice. The tool would avoid the lengthy breeding process and could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

http://www.nature.com/scientificamerican/journal/v306/n6/pdf scientificamerican0612-50.pdf

The Human Brain Project

Machine Cognition

Machines that sense, learn, reason/think and interact with us in natural language



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

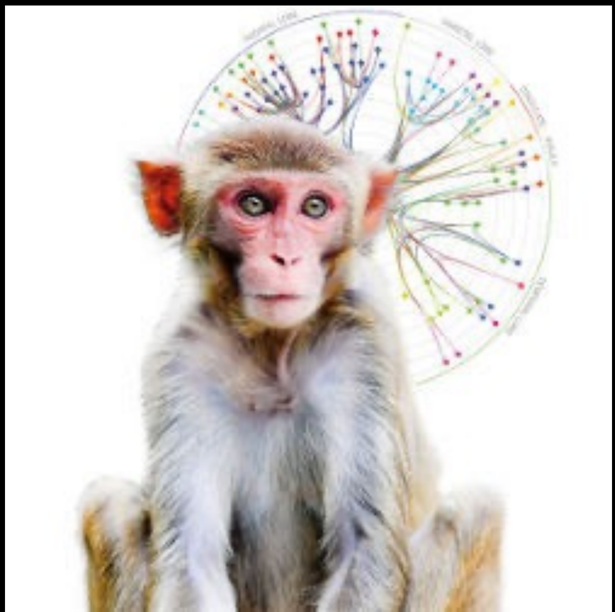
Cognitive computing

IBM have been working on a cognitive computing project called Systems of Neuromorphic Adaptive Plastic Scalable Electronics (SyNAPSE).

http://www.ibm.com/smarterplanet/us/en/business_analytics/article/cognitive_computing.html

http://cacm.acm.org/magazines/2011/8/114944-cognitive-computing/fulltext

Communications of the ACM , Vol. 54 No. 8, Pages 62-71



The quest for intelligent machines ultimately requires new breakthroughs in philosophy, neuroanatomy, neurophysiology, computational neuroscience, supercomputing, and computer architecture orchestrated in a coherent, unified assault on a challenge of unprecedented magnitude. The state of today's effort in cognitive computing was best captured by Winston Churchill: "Now this is not the end. It is not even the beginning of the end. But it is, perhaps, the end of the beginning."

Connecting Anthropogenic with Biogenic and Abiotic Cognition

We propose the common framework for understanding Anthropogenic, Biogenic and Abiotic Cognition.

As in the all of biology, nothing makes sense except for in the light of evolution (Dobzhansky, 1973)
and the cognition as a process can only be understood in the light of evolution.

Regarding abiotic systems we will compare their "cognitive behavior" with living organisms and draw conclusions.

Theodosius Dobzhansky (1973) Nothing in Biology Makes Sense except in the Light of Evolution. The American Biology Teacher 35 (3): 125–129. https://doi.org/10.2307/4444260

Morphology

Morphology: A form, shape, structure or pattern

Morphogenesis: generation of form, shape, structure, patterns, formation and transformation, patterns of formation

Anatomy vs. Morphology

Anatomy studies the presence of structures while morphology studies the relationships of structures. Anatomy is a subdivision of morphology, whereas morphology is a branch of biology.

External features such as gross *size, shape, colour, and other physical features of the biological structures* are studied in morphology while anatomy is concerned about the cellular and tissue level composition of the biological structures.

Learning From Nature to Cognitively/Intelligently Compute Requires Understanding Evolution

In the info-computational approach to cognition and intelligence, evolution is understood in the sense of extended evolutionary synthesis (Laland et al. 2015; Ginsburg and Jablonka 2019; Jablonka and Lamb 2014) and it is a result of interactions between natural agents, cells and their groups on variety of levels of organization as Jablonka and Lamb argue in their "Evolution in Four Dimensions: Genetic, Epigenetic, Behavioral, and Symbolic Variation in the History of Life". These dimensions can be found on different level of organization of life.

Morphological computing in biology

The essential property of morphological computing is that it 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 compared to individual organisms, through social (distributed) cognition.

In general, groups of smaller organisms (cells) in nature cluster into bigger ones (multicellular assemblies) 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.

Evolution Provides Generative Mechanism for Increasingly Complex Cognitive Systems

New insights about cognition and its evolution and development in nature from cellular to human cognition can be modelled as natural information processing/ natural computation/ morphological computation. In the info-computational approach, evolution in the sense of extended evolutionary synthesis is a result of interactions between natural agents, cells, and their groups.

Evolution provides generative mechanism for the emergence of increasingly more competent living organisms with increasingly complex natural cognition and intelligence which are used as a template for the artificial/computational counterparts.

Continuum of Natural Cognitive Architectures

Recent comprehensive overview of 40 years of research in cognitive architectures, (Kotseruba and Tsotsos 2020), evaluates modelling of the core cognitive abilities in humans, but only briefly mentions biologically plausible approaches.

However, there is an important new development of biologically inspired computational models that can lead to biologically more realistic cognitive architectures.

Unlike vast majority of artificial cognitive architectures, that target human-level cognition, we would like to focus on the development and evolution of the continuum of natural cognitive architectures, from basal cellular up, as studied by (Levin, 2021).

Continuum of Biological Computation

"We have previously argued that the deep evolutionary conservation of ion channel and neurotransmitter mechanisms highlights a fundamental isomorphism between developmental and behavioral processes. Consistent with this, membrane excitability has been suggested to be the ancestral basis for psychology (). Thus, it is likely that the cognitive capacities of advanced brains lie on a continuum with, and evolve from, much simpler computational processes that are widely conserved at both the functional and mechanism (molecular) levels.

The information processing and spatio-temporal integration needed to construct and regenerate complex bodies arises from the capabilities of single cells, which evolution exapted and scaled up as behavioral repertoires of complex nervous systems that underlie familiar examples of Selves."

Michael Levin (2019) The Computational Boundary of a "Self": Developmental Bioelectricity Drives Multicellularity and Scale-Free Cognition. Front. Psychol., 13 December 2019 | https://doi.org/10.3389/fpsyg.2019.02688 https://www.frontiersin.org/articles/10.3389/fpsyg.2019.02688/full

Learning From Basal Biological Computing

- The concept of biological computation proposes that living organisms perform computations, and that as such, abstract ideas of information and computation may be key to understanding biology.[1][2]*
- *Apart from human brain with nervous system, somatic cells, non-human organisms with nervous system, non –neuronal subsystems in humans such as immune system*

Gordana Dodig-Crnkovic (2021) Cognition as a Result of Information Processing in Living Agent's Morphology. Species-specific Cognition and Intelligence. Proceedings of SweCog 2021 Conference. file:///Users/dodig/gordana.se-httpd.www/work/PUBLICATIONS-files/2021-11.10-SWECOG-2021-GDC.pdf

https://en.wikipedia.org/wiki/Biological_computation#searchInput

Mitchell M (2010-09-21). "Biological Computation". Computer Science Faculty Publications and Presentations,

Learning From Basal Biological Computing

- *Computational Efficiency* of Natural Computing. The Turing Machine model of computation is not resource-aware, unlike living systems are constantly optimizing their resource use.
- Von Neumann architecture has bottlenecks, processor and memory are separate. Memristors biomimetic solution combines memory and processor and avoids von Neumann bottlenecks.

Ihor Lubashevsky (2017) "Physics of the Human Mind", Springer

Kevin M. Passino (2005) Biomimicry for Optimization, Control, and Automation, Springer

Bernard Baars, Nicole Gag (2010) Cognition , brain, and consciousness : introduction to cognitive neuroscience

CONCLUSIONS.
Connecting Morphological Computing and Cognition to Logic: Practical Logic & Logic in Action

A cognitive agent is conceived of as a certain kind of information-processor, then a pragmatic theory of cognitive agency will provide descriptions of processors of information.

Given that a logic is a principled account of certain aspects of practical reasoning, logic too is a pragmatic affair. If we ask, 'which aspects of practical reasoning are the proper province of logic?', we say again that the answer lies in operational arrangements.

Thus we study cognition as processes of life (bio computation) on living structures (represented as bioinformation)

Cognition appears on a fundamental level of living cells in form of basal cognition that is being researched currently.

Gabbay, Dov M. & Woods, John (2003) A PRACTICAL LOGIC OF COGNITIVE SYSTEMS, Volume 1. Agenda Relevance. A Study in Formal Pragmatics. NH. Elsevier

CONCLUSIONS.
Connecting Morphological Computing and Cognition to Logic: Practical Logic & Logic in Action

Knowledge of the undelying structures and processes helps to understand cognitive behaviour of the cell – information communication, processing and memory as biocomputational processes.

Those processes result in morphogenesis – creation of new forms as well as meta-morphogenesis as addressed in the work of Aaron Sloman*.

Developmental and evolutionary processes are also being understood as computation.

*https://www.researchgate.net/project/Meta-morphogenesis Aaron Sloman Meta-morphogenesis

CONCLUSIONS.
Connecting Morphological Computing and Cognition to Logic: Practical Logic & Logic in Action

The connection between logic and information processing view of nature is two-fold:

1. Logic is underlying all reasoning about nature, even observations and experiments
2. Natural processes have their own inherent logic of agency under information exchanges. Our human-centric, language-basedlogic is an evolved, refined and complex case of logic of living organisms with basal cognition.

What is more, there are indications that information-exchanging networks within cell also possess properties of cognitive systems such as sensitivity to imput, information processing, memory and output of result information/behavior.

There is a lot of empirical and theoretical work in front of us to connect those phenomena with logic ofagency on different levels in nature.

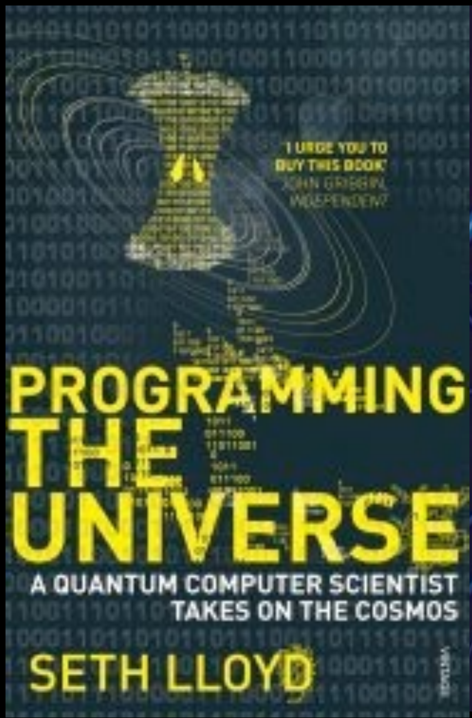
CONCLUSIONS.
Connecting Morphological Computing and Cognition to Logic: Practical Logic & Logic in Action

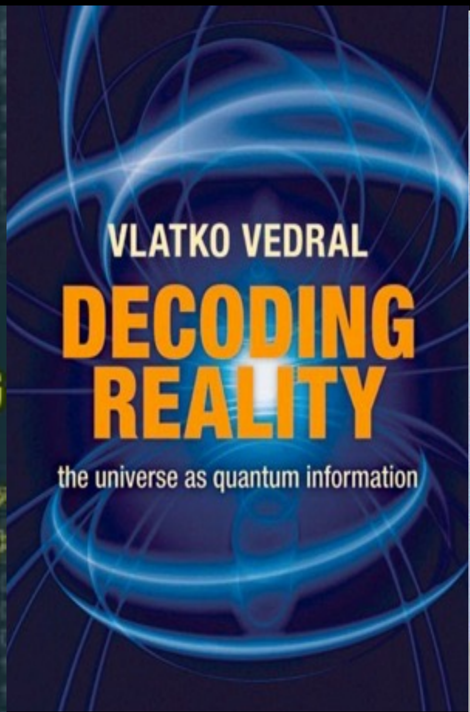
The underlying mechanisms in this framework are:

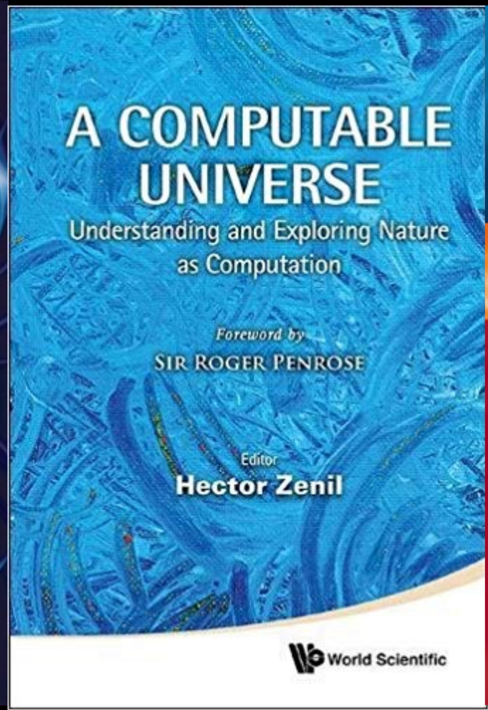
- Computing universe
- Self-organizing nature
- New computational frameworks – natural computing, unconventional computing, interactive computing
- Nature as infromation and computation
- Cognition as result of computation of information (morphological computing, morphogenesis)
- The extended mind in nature – embodied, embedded, enactive
- The Extended Evolutionary Synthesis
  (Darwinism > neo-Darwinism > Modern Synthesis > Extended Synthesis)

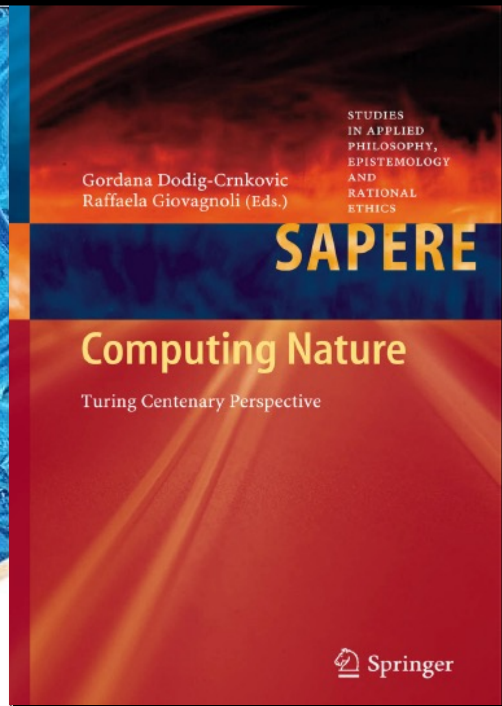
Literature, Further Reading – Mapping Territory Through Various Disciplines

Computing Universe

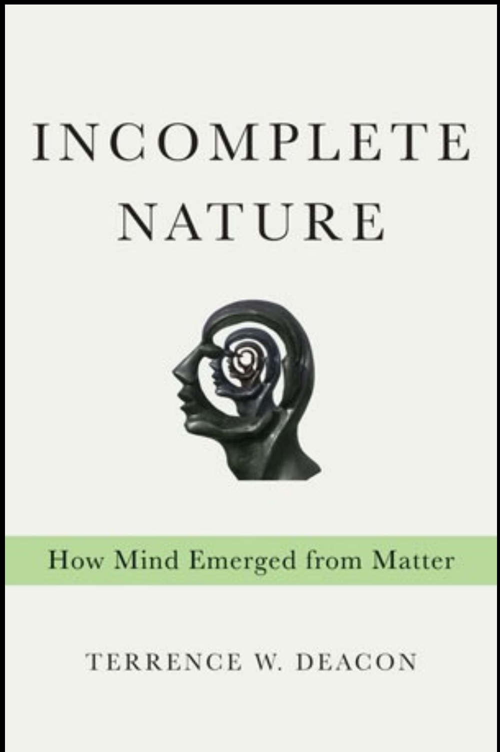


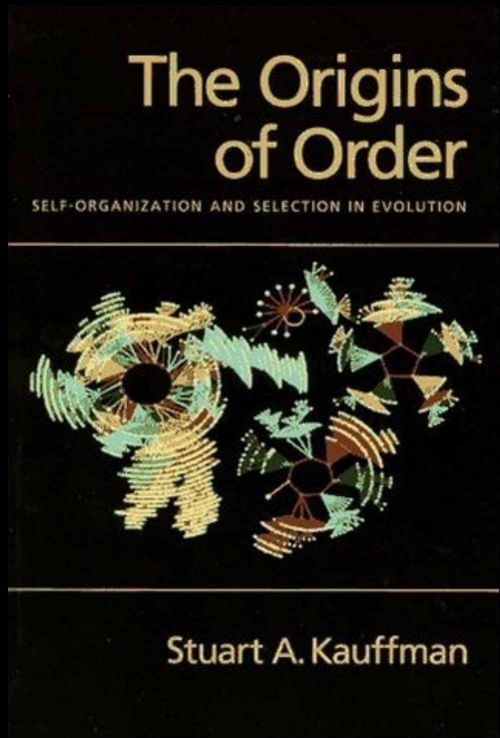


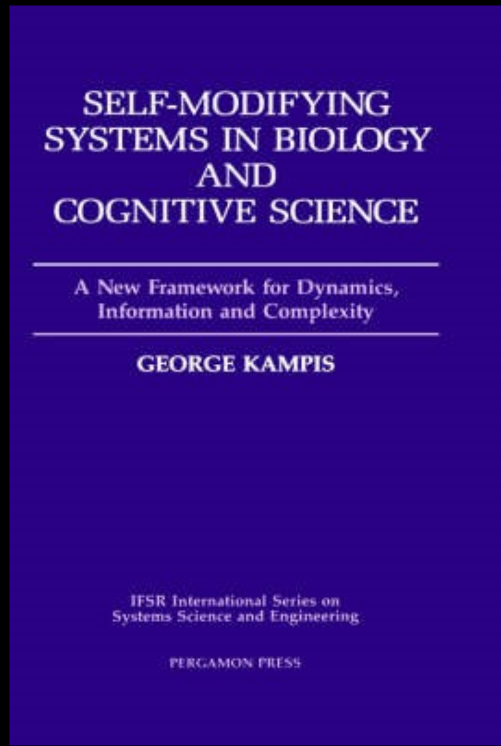




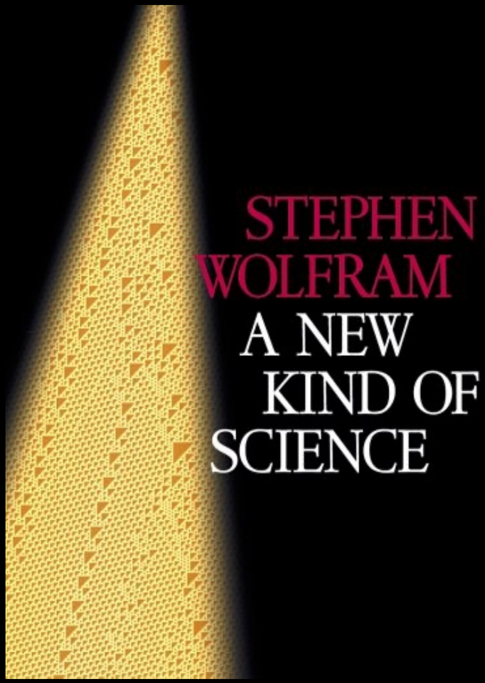
Self-organizing Nature

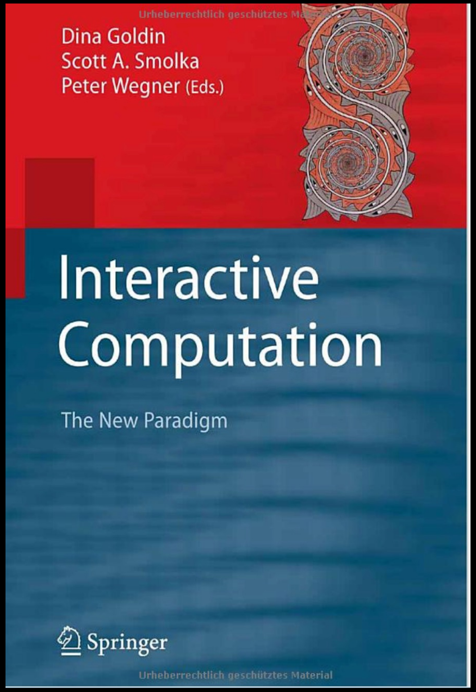


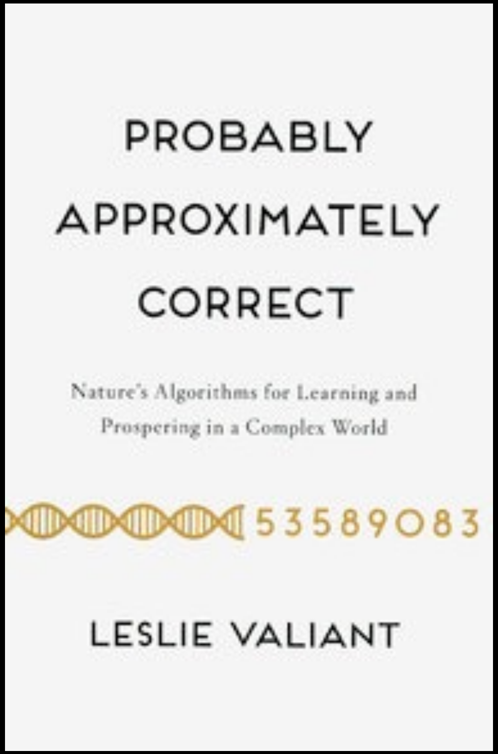




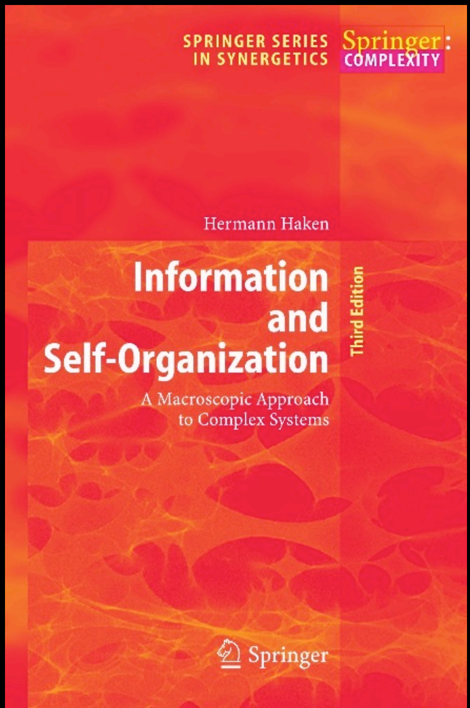
New Computational Frameworks

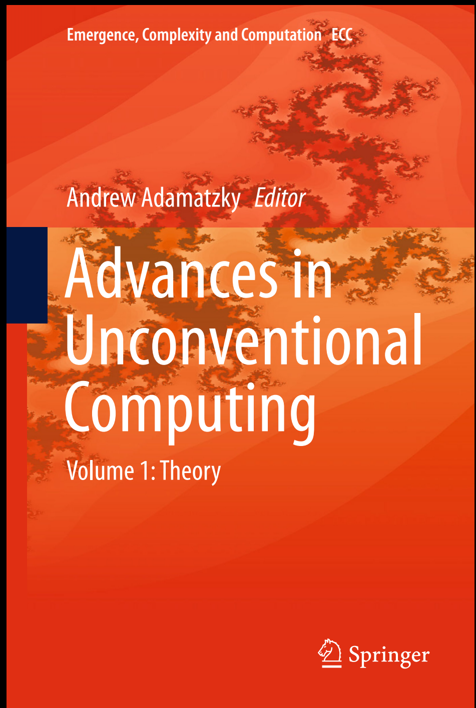


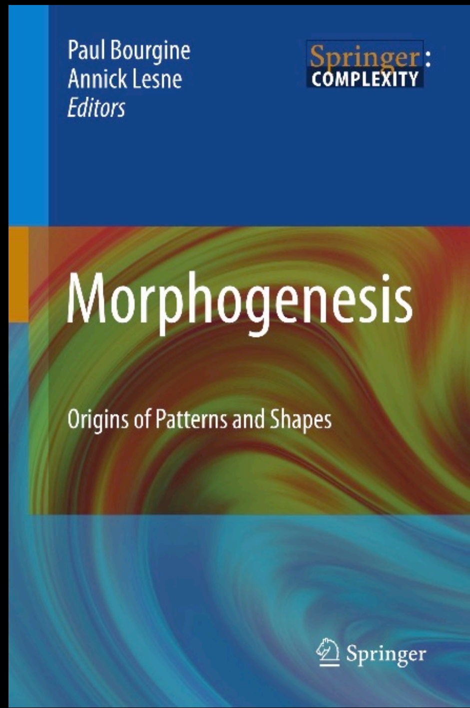




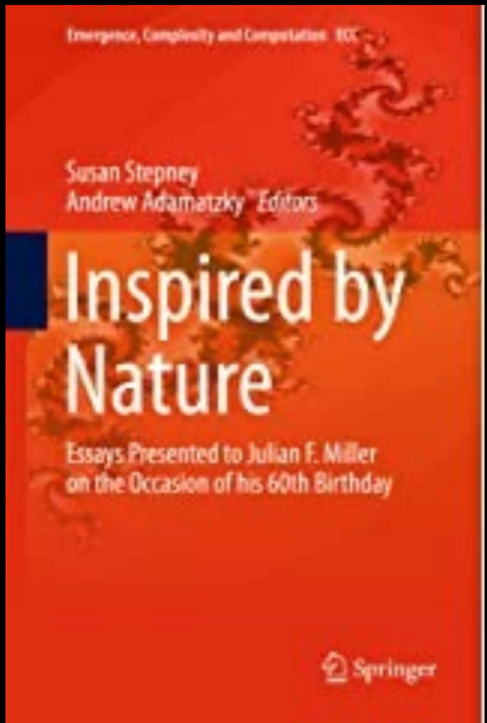
Natural/Unconventional/Morphological Computing

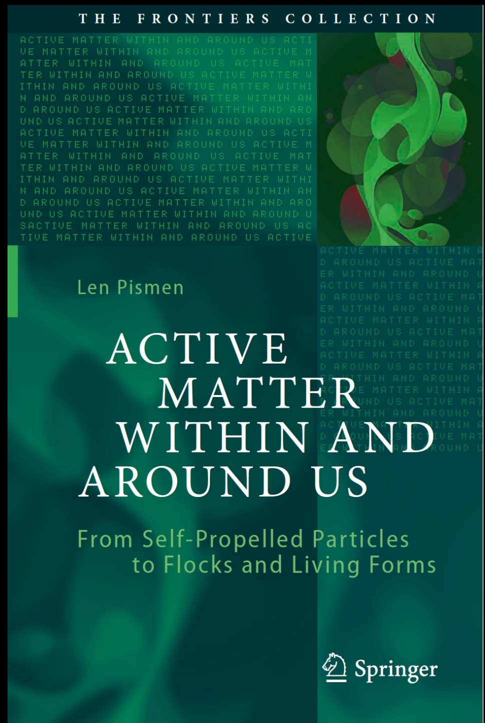


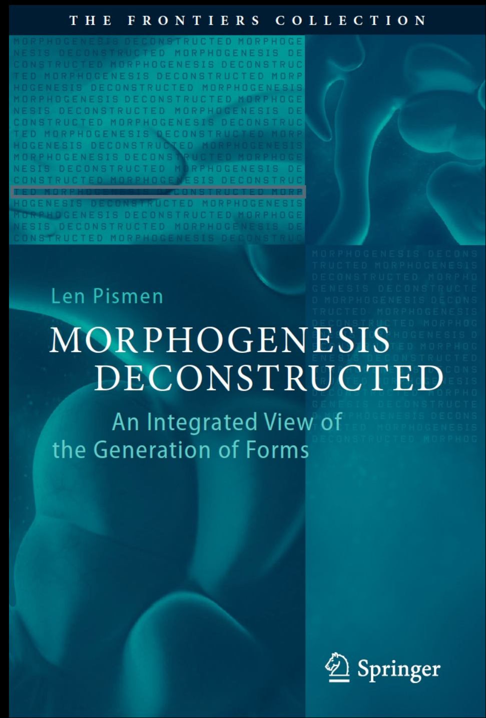


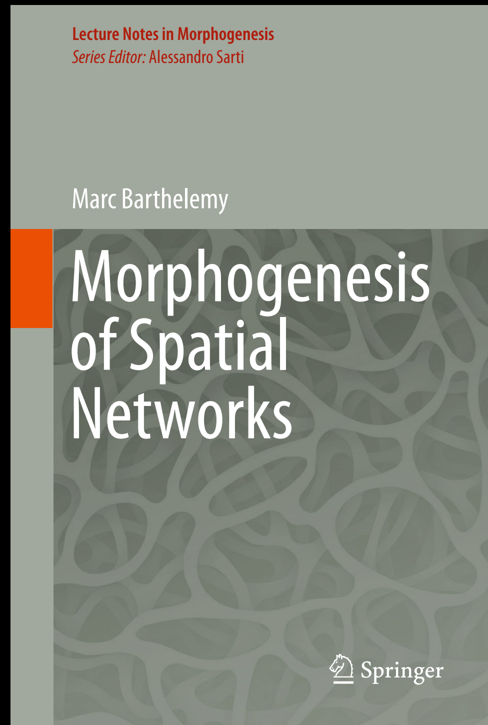


Natural/Unconventional/Morphological Computing & Active Matter

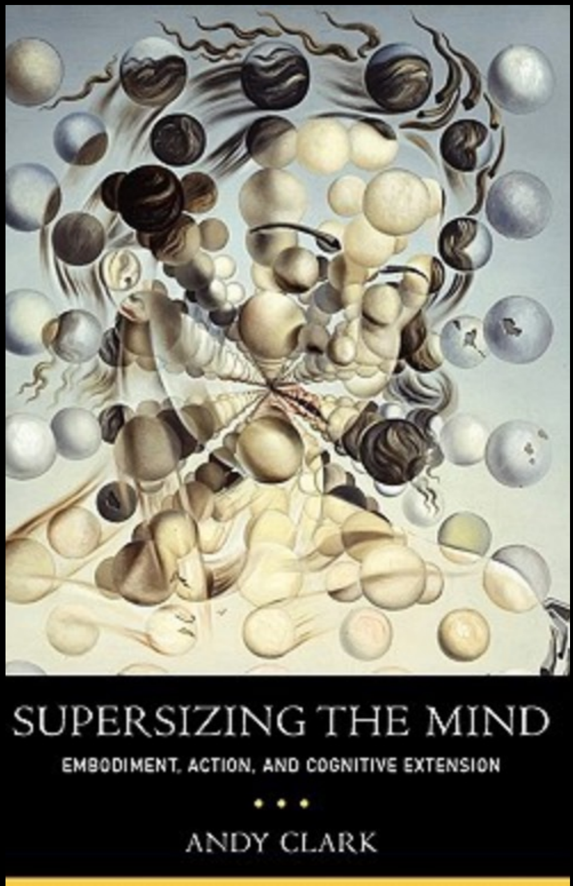


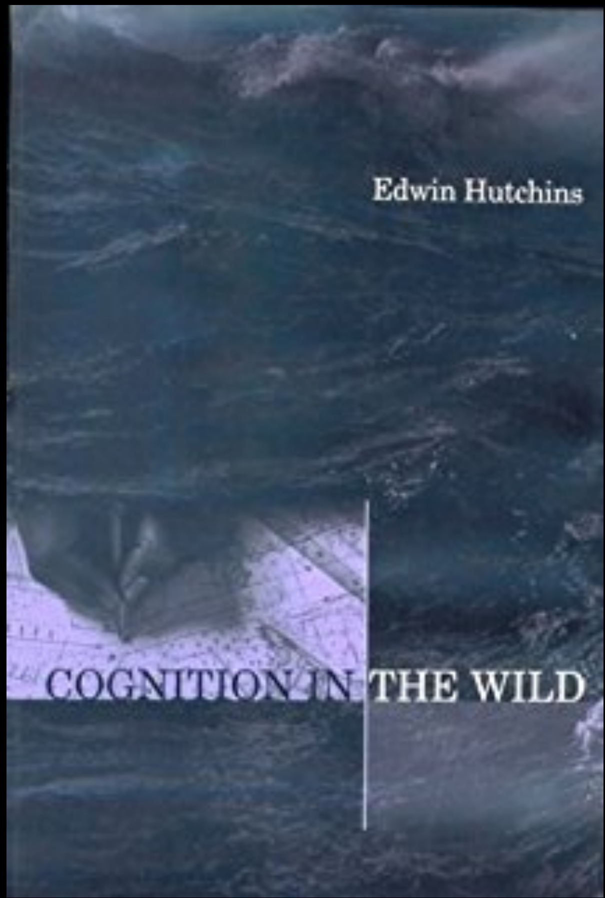


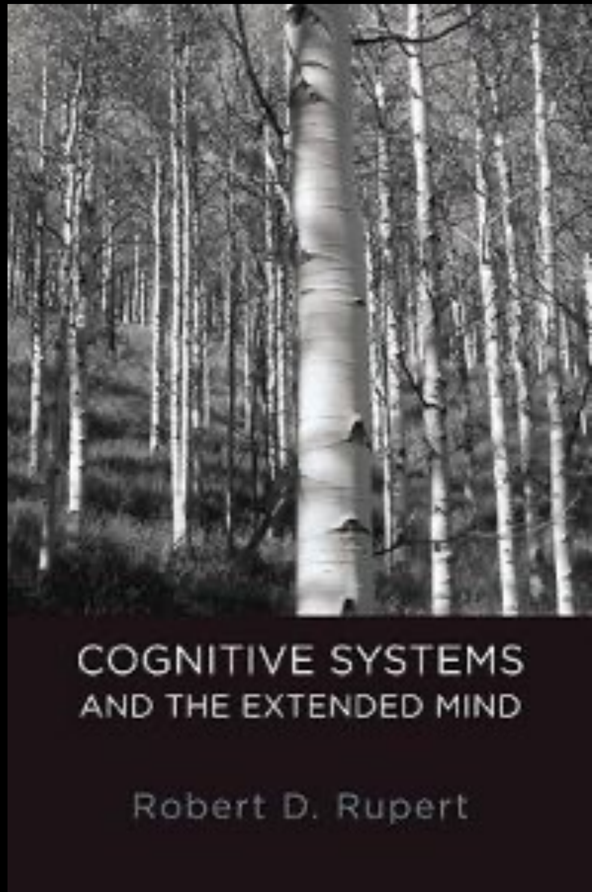




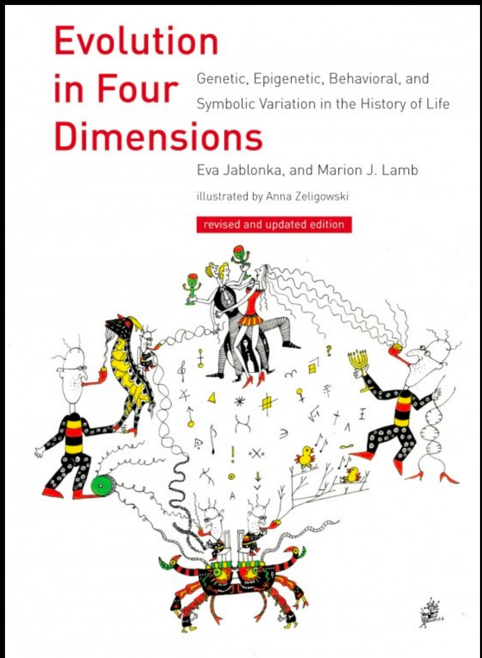
The Extended Mind in Nature

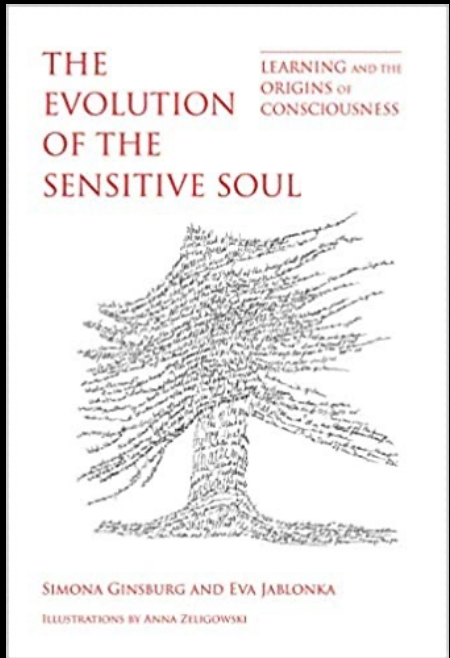


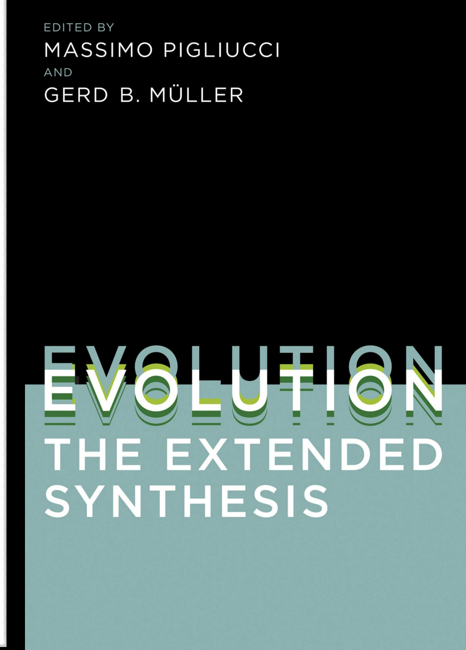


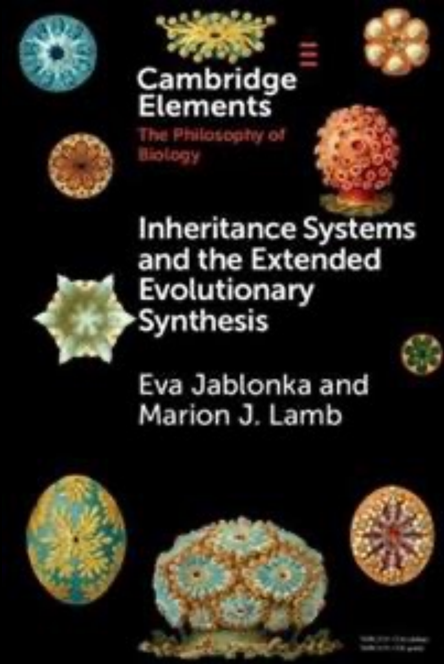


The Extended Evolutionary Synthesis as Theory of Evolution

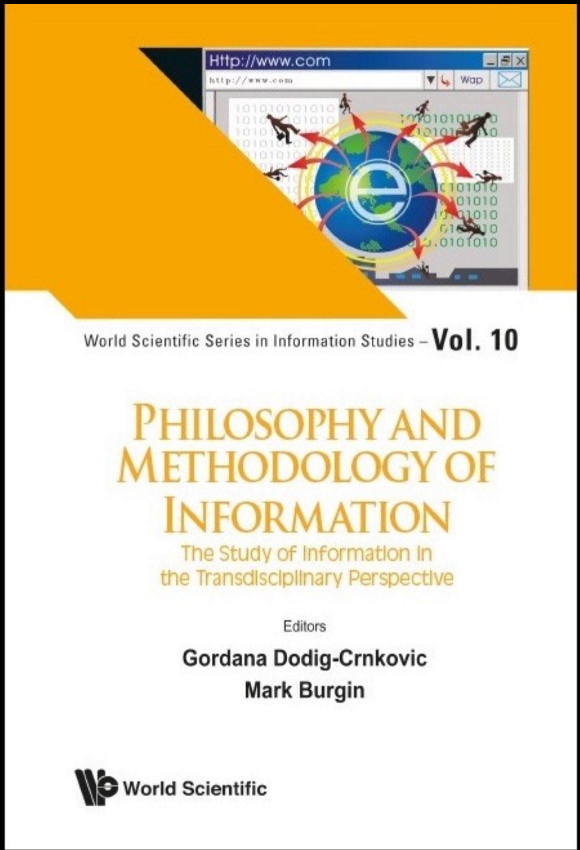








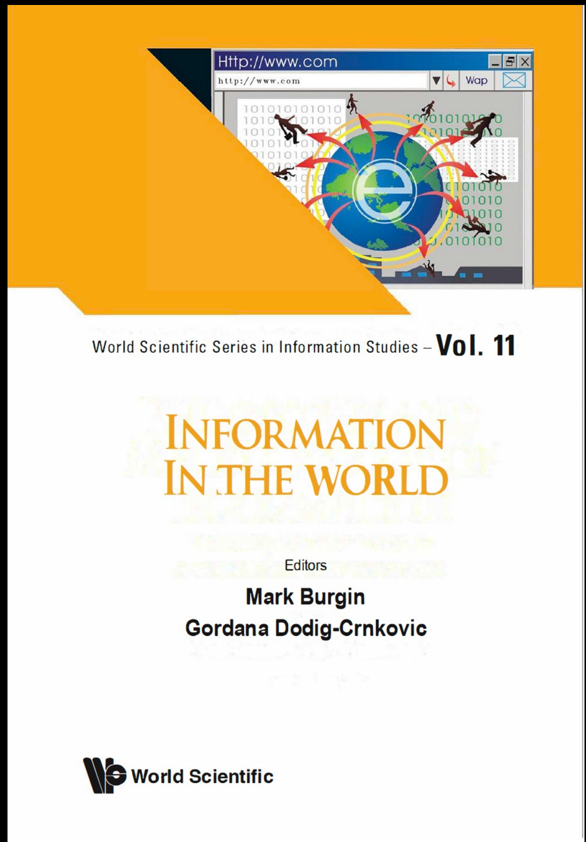
Nature, Information & Computation



PHILOSOPHY AND METHODOLOGY OF INFORMATION

Dodig-Crnkovic G. and Burgin M.

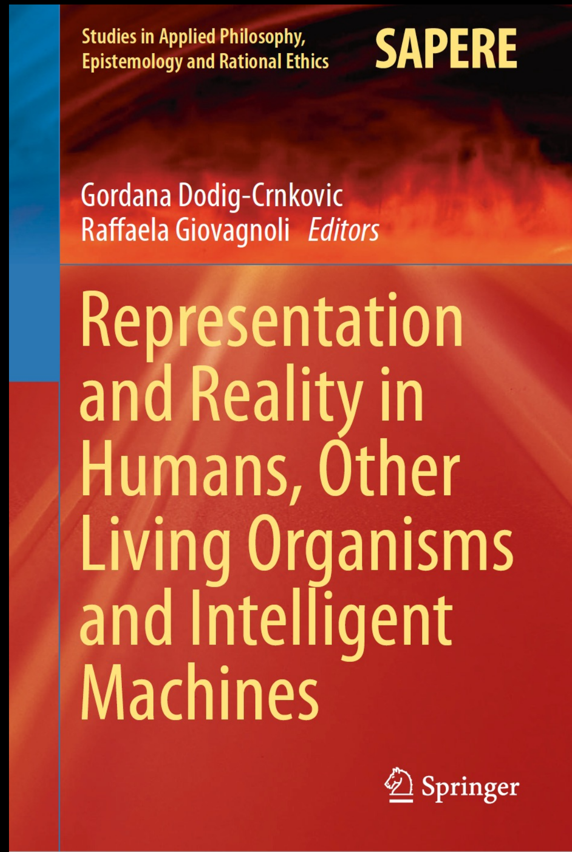
World Scientific, 2019



INFORMATION IN THE WORLD

Burgin M. and Dodig-Crnkovic M.

World Scientific, 2020



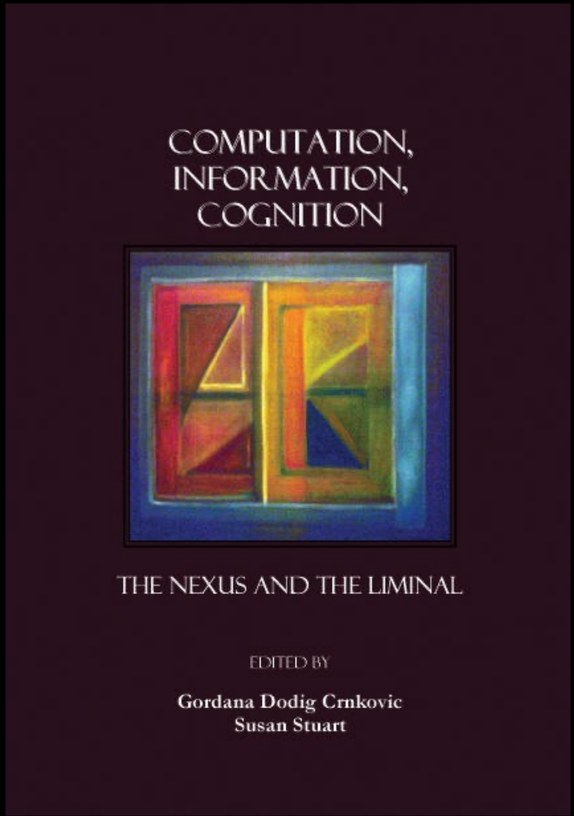
REPRESENTATION AND REALITY

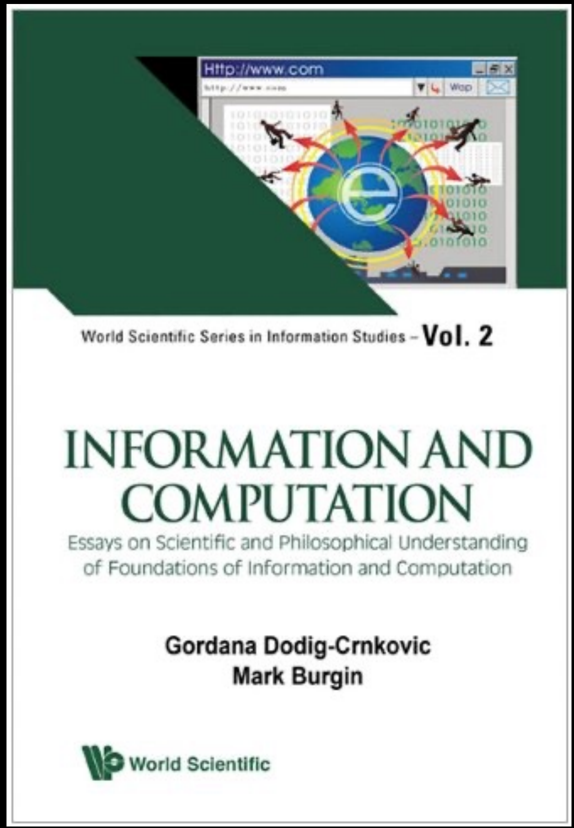
Dodig Crnkovic G. and

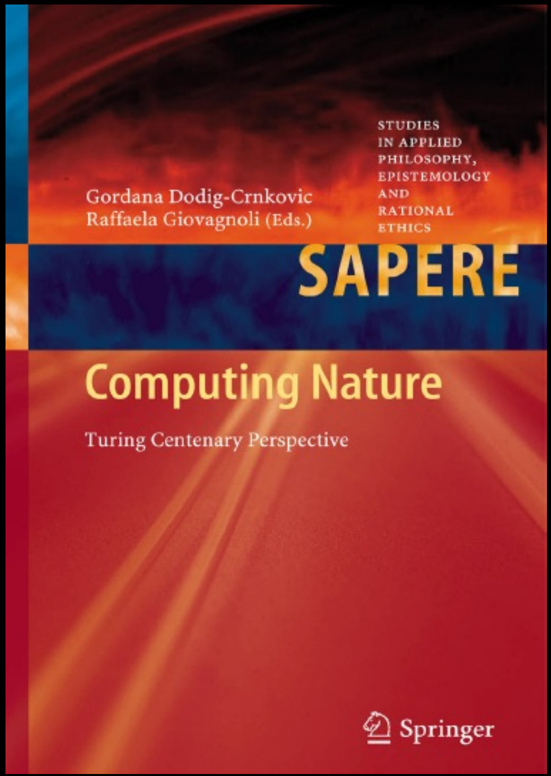
Giovagnoli, R.

Springer, 2017

Computation, Information, Cognition





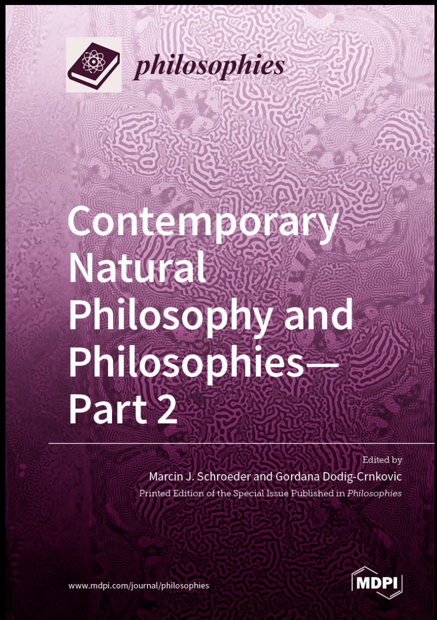


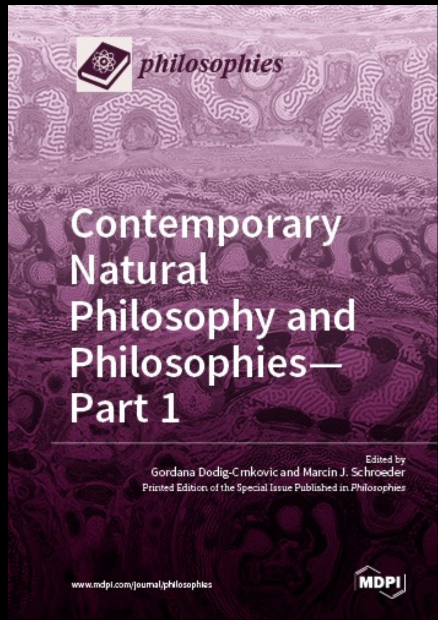
Computation, Information, Cognition
Gordana Dodig Crnkovic and
Susan Stuart, Edts.
Cambridge Scholars Publishing, 2007

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

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

Contemporary Natural Philosophy – Special Issues and Book Series





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

ISBN 978-3-03943-535-7 (Hbk);
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Acknowledgment

Swedish
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This research is supported by
Swedish Research Council grant MORCOM@COGS

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