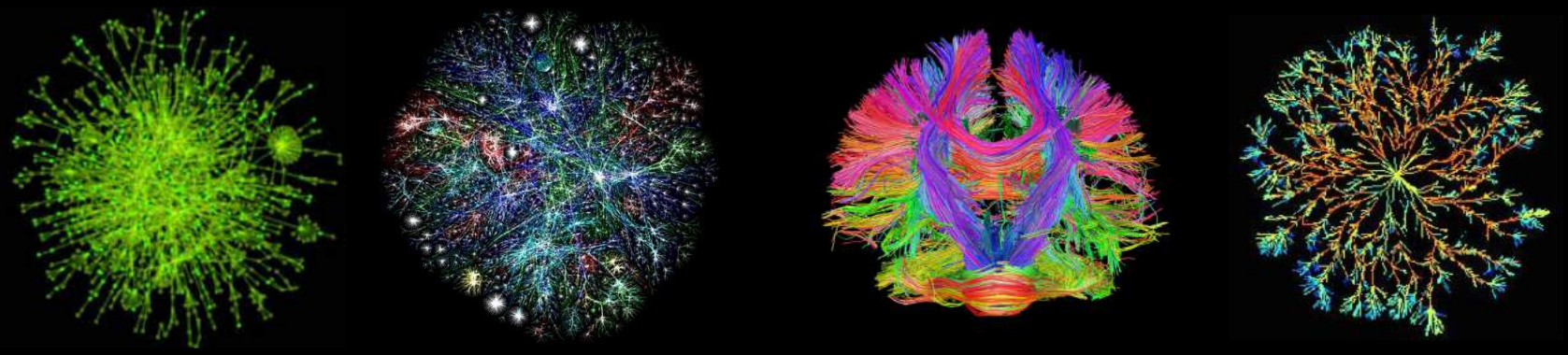
ICPI@IS4SI 2019 Berkeley, 2019 06 03

Morphological Computing In Cognitive Systems, Connecting Data To Intelligent Agency



GORDANA DODIG-CRNKOVIC

Chalmers University of Technology and University of Gothenburg
& Mälardalen University, Sweden

http://www.gordana.se

RESEARCH BACKGROUND

Gordana Dodig-Crnkovic, 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 https://is4si2019.com/en/

Board member, Past President, Co-organizer

SPECIAL ISSUES

"Contemporary Natural Philosophy and Philosophies", Philosophies journal

"Information-Processing and Embodied, Embedded, Enactive Cognition, Part 2: Morphological Computing and Cognitive Agency", Entropy

BOOKS

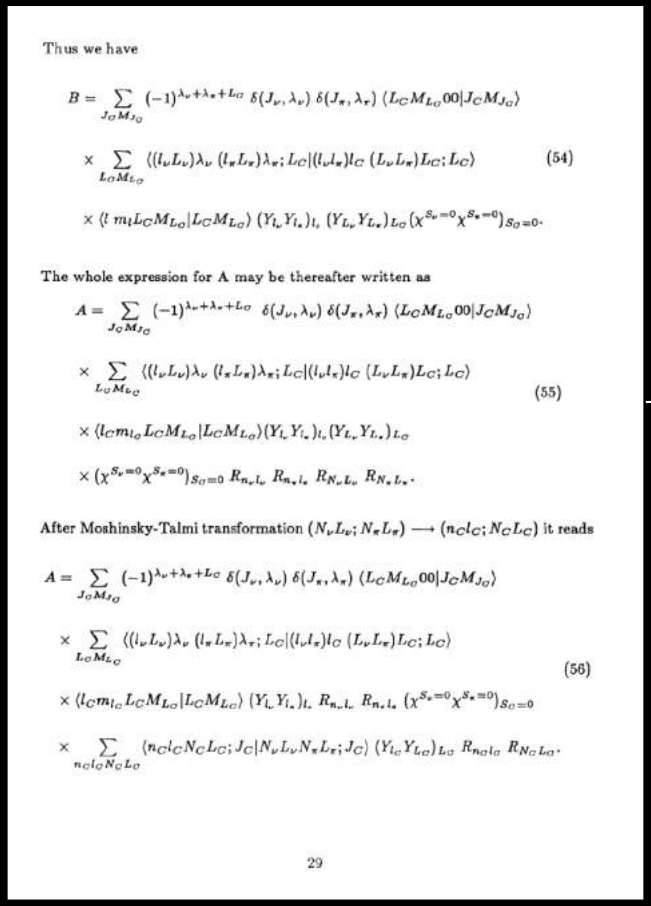
WORLD SCIENTIFIC VOLUMES ON INFORMATION STUDY (Two volumes, to appear in May (Vol 1) and September (Volume 2) 2019

PHD SUPERVISION

Josef Wideström (Chalmers),
Markus Wallmyr & Tobias Holstein (MDH)

From formal language to natural language

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



Thus we have

$$B = \sum_{J_C M_{J_C}} (-1)^{\lambda_\nu+\lambda_\pi+L_C}\ \delta(J_\nu,\lambda_\nu)\ \delta(J_\pi,\lambda_\pi)\ \langle L_C M_{L_C} 00|J_C M_{J_C}\rangle$$

$$\times \sum_{L_C M_{L_C}} \langle (l_\nu L_\nu)\lambda_\nu\ (l_\pi L_\pi)\lambda_\pi; L_C|(l_\nu l_\pi)l_C\ (L_\nu L_\pi)L_C; L_C\rangle \qquad (54)$$

$$\times \langle l\ m_l L_C M_{L_C}|L_C M_{L_C}\rangle\ (Y_{l_\nu} Y_{l_\pi})_{l_i}\ (Y_{L_\nu} Y_{L_\pi})_{L_C} (\chi^{S_\nu=0}\chi^{S_\pi=0})_{S_C=0}.$$

The whole expression for A may be thereafter written as

$$A = \sum_{J_C M_{J_C}} (-1)^{\lambda_\nu+\lambda_\pi+L_C}\ \delta(J_\nu,\lambda_\nu)\ \delta(J_\pi,\lambda_\pi)\ \langle L_C M_{L_C} 00|J_C M_{J_C}\rangle$$

$$\times \sum_{L_C M_{L_C}} \langle (l_\nu L_\nu)\lambda_\nu\ (l_\pi L_\pi)\lambda_\pi; L_C|(l_\nu l_\pi)l_C\ (L_\nu L_\pi)L_C; L_C\rangle \qquad (55)$$

$$\times \langle l_C m_{l_C} L_C M_{L_C}|L_C M_{L_C}\rangle (Y_{l_\nu} Y_{l_\pi})_{l_i} (Y_{L_\nu} Y_{L_\pi})_{L_C}$$

$$\times (\chi^{S_\nu=0}\chi^{S_\pi=0})_{S_C=0}\ R_{n_\nu l_\nu}\ R_{n_\pi l_\pi}\ R_{N_\nu L_\nu}\ R_{N_\pi L_\pi}.$$

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

$$A = \sum_{J_C M_{J_C}} (-1)^{\lambda_\nu+\lambda_\pi+L_C}\ \delta(J_\nu,\lambda_\nu)\ \delta(J_\pi,\lambda_\pi)\ \langle L_C M_{L_C} 00|J_C M_{J_C}\rangle$$

$$\times \sum_{L_C M_{L_C}} \langle (l_\nu L_\nu)\lambda_\nu\ (l_\pi L_\pi)\lambda_\pi; L_C|(l_\nu l_\pi)l_C\ (L_\nu L_\pi)L_C; L_C\rangle \qquad (56)$$

$$\times \langle l_C m_{l_C} L_C M_{L_C}|L_C M_{L_C}\rangle\ (Y_{l_\nu} Y_{l_\pi})_{l_i}\ R_{n_\nu l_\nu}\ R_{n_\pi l_\pi}\ (\chi^{S_\nu=0}\chi^{S_\pi=0})_{S_C=0}$$

$$\times \sum_{n_C l_C N_C L_C} \langle n_C l_C N_C L_C; J_C|N_\nu L_\nu N_\pi L_\pi; J_C\rangle\ (Y_{l_C} Y_{L_C})_{L_C}\ R_{n_C l_C}\ R_{N_C L_C}.$$

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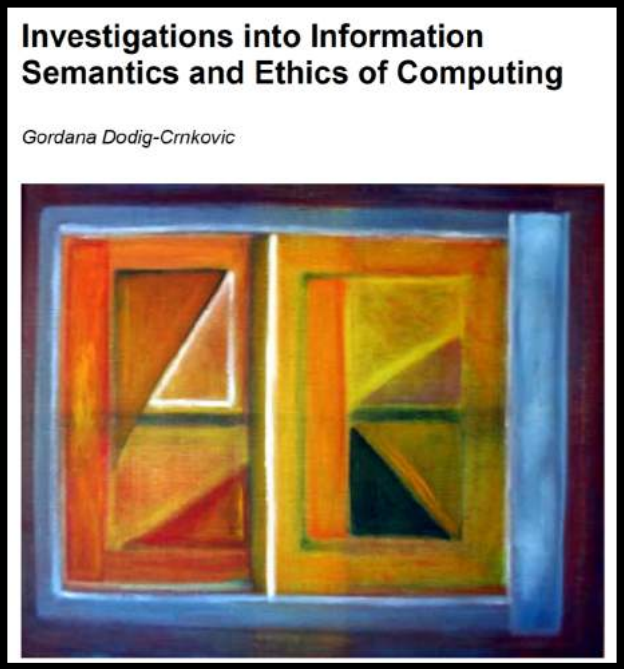
PhD in Computing, 2006
Computer Science, Mälardalen University



Investigations into Information Semantics and Ethics of Computing

Gordana Dodig-Crnkovic

Morphological Computing and Cognition

The first version of this presentation

International Conference on Intelligence Science - ICIS2016
University of Chengdu, China, 31/10 - 1/11
http://www.intsci.ac.cn/ICIS2016/

Further development is4si 2017

IS4SI Gothenburg
Morphological Computing and Cognitive Agency@Gothenburg summit of the International Society for the Study of Information, is4si
http://is4si-2017.org/

Message of this talk

In the beginning of the development of the field, cognition was considered as the connection between information and knowledge, without elaboration either on the processes that precede information or those which come after knowledge is constructed.

This old view of cognition thus leaves bodily aspects such as feelings and emotions out of the scope of cognitive science. This old view of (disembodied) cognition is directly connected with old computationalism – symbol manipulation view of mind.

At the same time Artificial Intelligence (AI) was trying to reproduce human intelligent behavior in the computing machinery based on expert systems equipped with logical reasoning.

Both cognition and AI have been envisaged as results of logical operations, either on the information obtained directly from the perception and stored in the memory in humans, or from the data bases and online searches in the machinery.

However, as the limitations of the GOFAI (good old-fashioned AI) have shown, cognition and intelligence in humans are substantially dependent on their embodiment, thus not only logical processes of reasoning, but also on their form (morphology on different levels of organization), physics and chemistry (thus details of implementation of information processing mechanisms).

Studies of cognition and intelligence in other, simpler living beings, from the simplest ones like viruses that act like molecular machines to unicellular organisms like bacteria and up in the level of complexity) show clear connection between the physical embodiment and cognition or intelligence.

In this talk I will address the new developments of computational approaches to cognition and intelligence where body is integral part of those processes and computation is not only symbol manipulation but also physical processes know as natural computation or morphological computation. Those new models of computation appear under variety of names such as Natural computing/ Computing nature, unconventional computing, morphological computing, physical computing etc.

I will highlight differences between cognitive computing and artificial intelligence and their connections to cognition and intelligence in nature within the framework of computing nature.

Cognition and Intelligence – Embodied, Embedded, Enacted

Traditionally, in philosophy, psychology and cognitive science (with increasing "scientificity") **all cognitive and intelligent agents were always conceived as humans**.

Today, with increasing insights into deep details and mechanisms of cognition, it is emerging that human cognition and intelligence are **based not only in activities of brain and nervous cells, but also emerges from the interaction of the body with the environment.**

Equally important is new understanding of cognitive (sensory-based) and intelligent (problem-solving) processes that regulate the state of the cell.

In other words, both cognition and intelligence have INCREASED IN SCOPE with increased insights in their underlying mechanisms – from the activity on the level of the human brain, to the process on the cell level. And those cells need not be part of a human body in order to be seen as performing cognitive and intelligent behaviour.

Cognition and Intelligence

Finally, inspired by the models of "minimal cognition" computational and robotic cognitive systems are developed with certain degree of cognition and intelligence. Certain functions of AI surpass humans (calculation, search, memory, in some cases processing speed and even sensor power) but many other are far below human level, such as common-sense reasoning or self-preservation mechanisms.

Intelligence is a capacity closely connected with cognition:

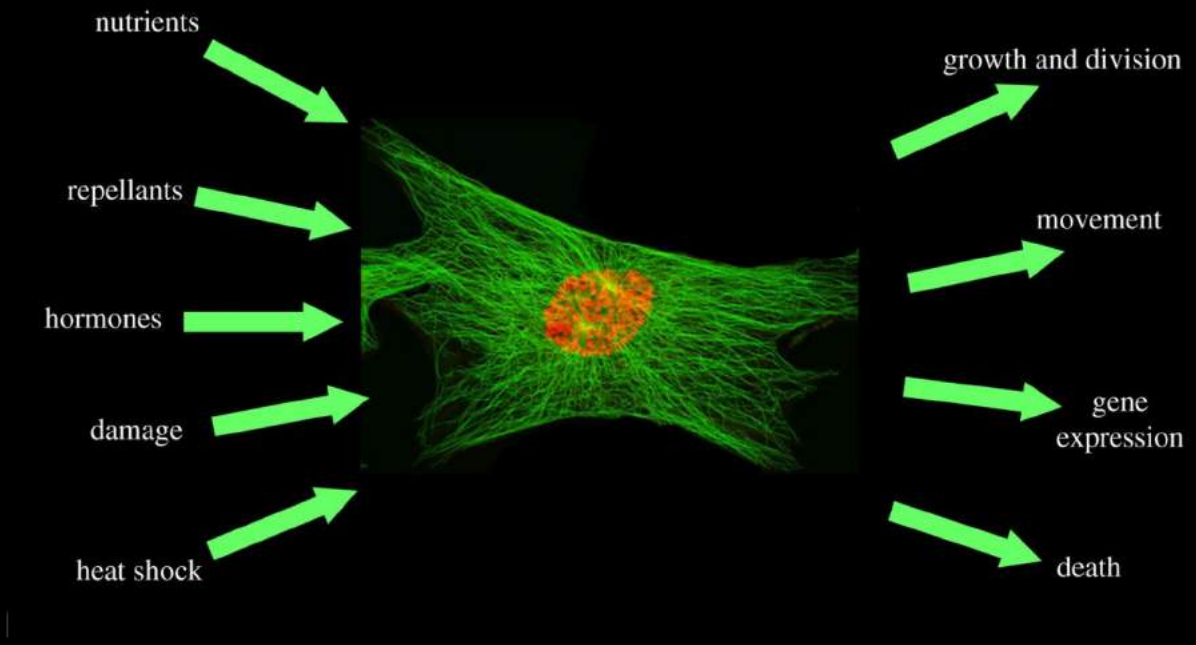
Cognition = Process of "being in the world" of an agent

For living organisms cognition = process of life (perception, internal process control by information, actuation/agency)

Intelligence = Problem solving and learning adaptive behaviours of an agent within an environment / context

Even though today intelligence is often considered to be a multidimensional phenomenon, that includes both classical problem-solving and decision-making ability (logical-mathematical reasoning), Existential (ability to survive), Visual-Spatial, Musical, Bodily-kinesthetic, Naturalist, Linguistic, Interpersonal (social), Intra-personal (inner insight),

NATURAL COGNITION & INTELLIGENCE
Basic level: Cells processing information

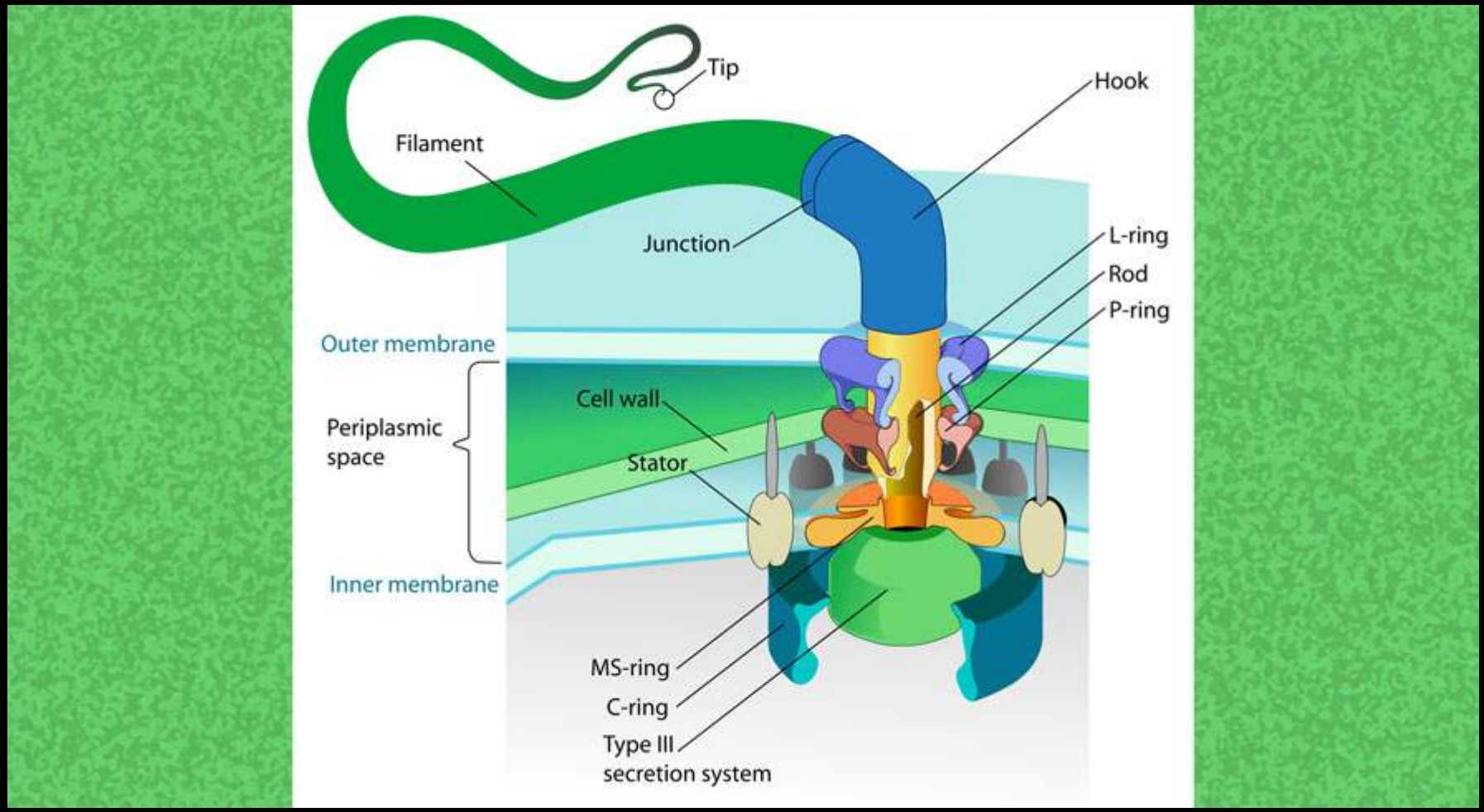


http://rsfs.royalsocietypublishing.org/content/4/3/20130070

https://www.youtube.com/watch?v=wJyUtbn0O5Y&list=PLXPeXawEy4EcPneclV1FaZA6bgVDujLzm&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

Some details of a molecular machinery



https://www.youtube.com/watch?v=cwDRZGj2nnY The Bacterial Flagellar Motor
https://www.youtube.com/watch?v=X_tYrnv_o6A Body's Molecular Machines

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

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

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.

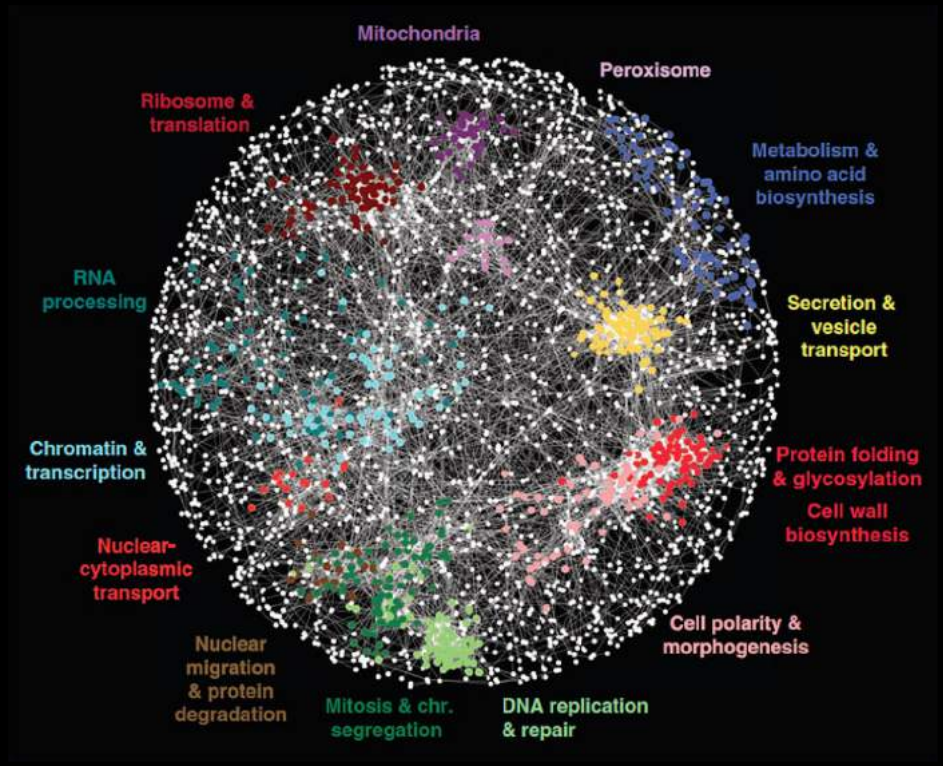
Plant behaviour and communication.
Karban, Richard (2008). " Ecology Letters. 11 (7): 727–739. doi:10.1111/j.1461-0248.2008.01183.x. PMID 18400016.

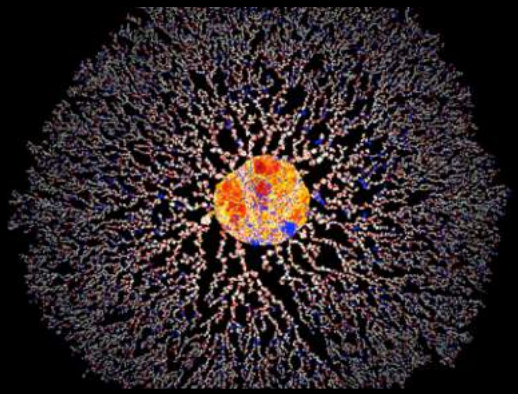
http://www.nature.com/nrm/journal/v2/n4/images/nrm0401_307a_f1.gif

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

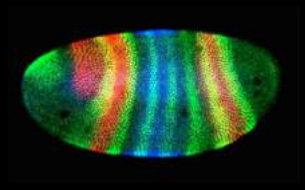




http://phys.org/news/2009-11-conquer-social-network-cells.html

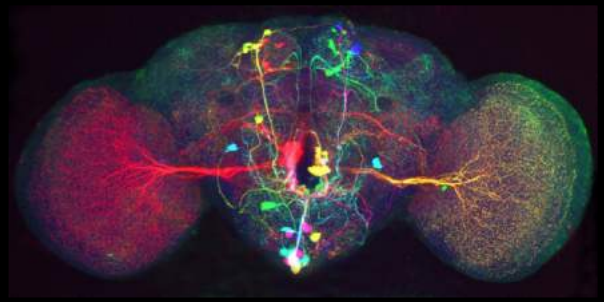
http://www.hhmi.org/research/global-mapping-genetic-networks A functional network for a yeast cell

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



Fruit fly embrio

Fruit fly larva



Fruit fly brain neurons

Fruit fly head

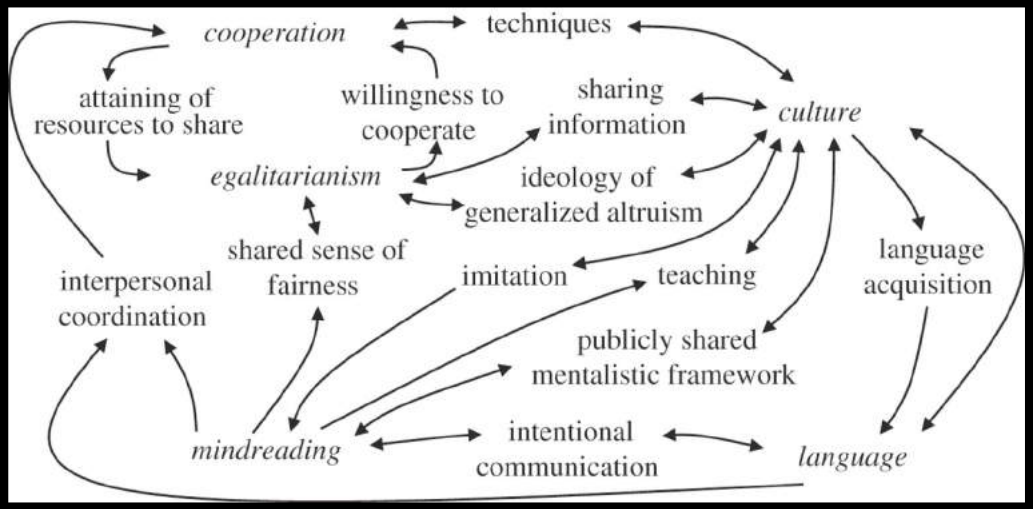
Human cognition

Complex language and material culture

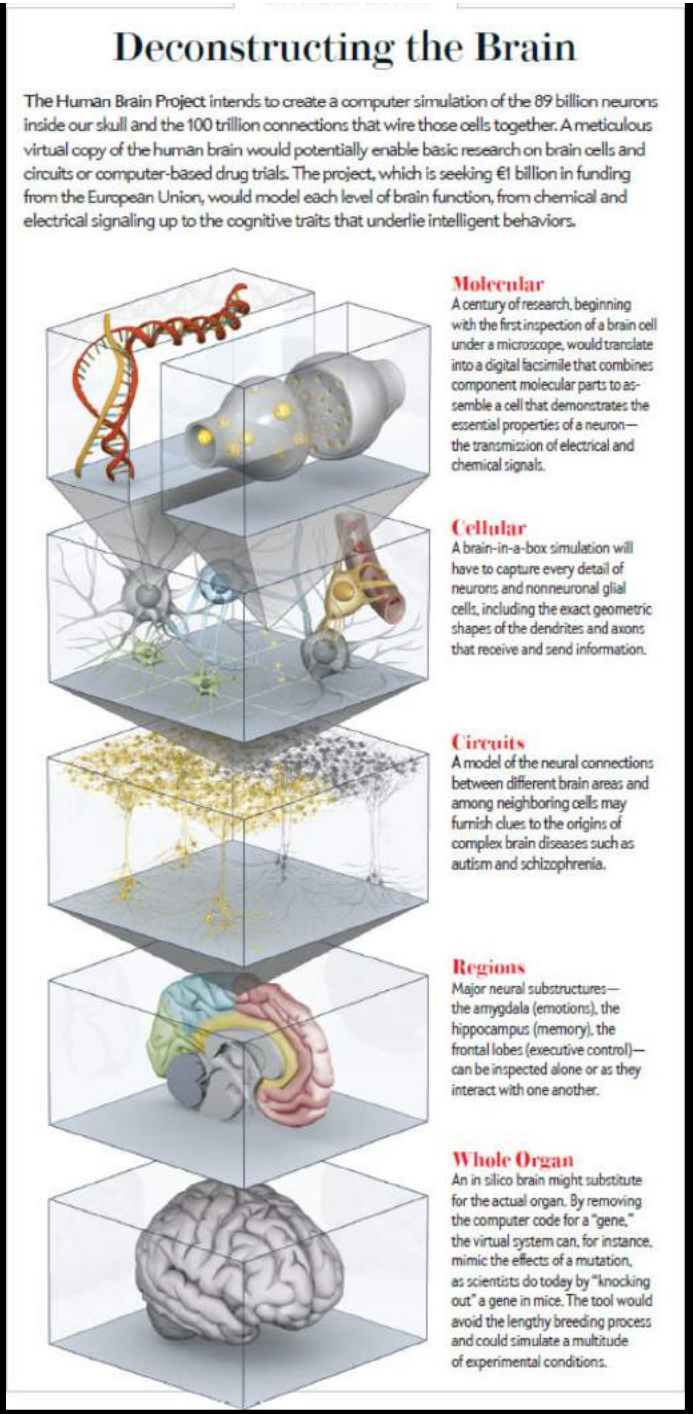
Human connectome

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

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



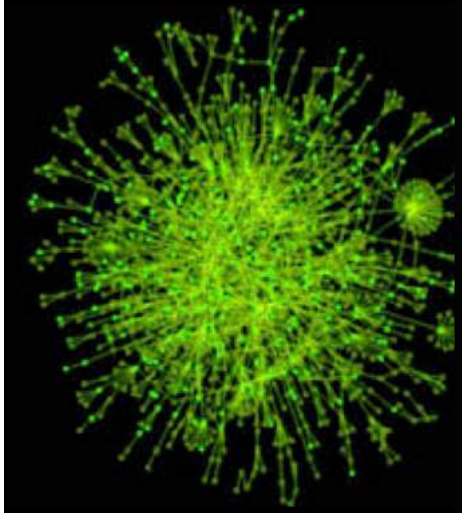
http://d1vn86fw4xmcz1.cloudfront.net/content/royptb/367/1599/2119/F1.large.jpg



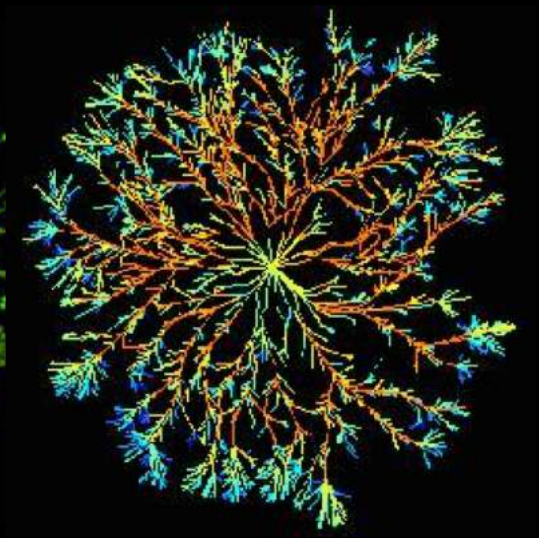
http://www.nature.com/scientificamerican/journal/v306/n6/pdf scientificamerican0612-50.pdf p. 16

The Human Brain Project

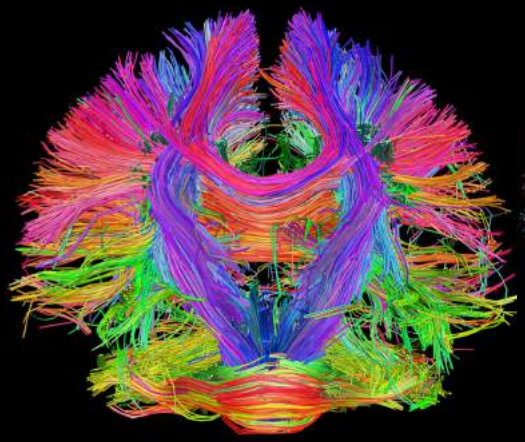
Information processing in life-networks



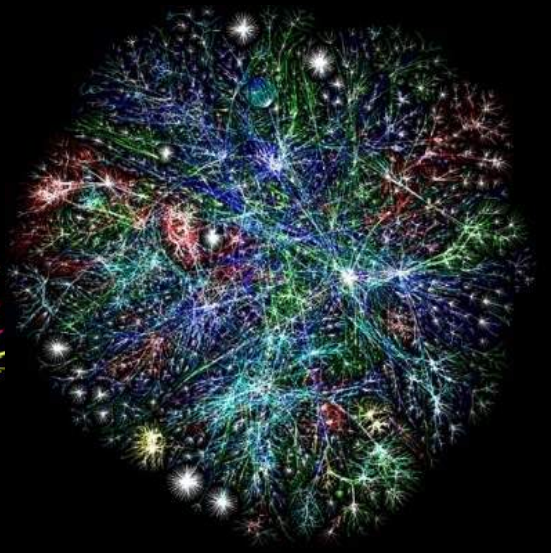
A map of protein–protein interactions in yeast cell



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



Human brain connectome

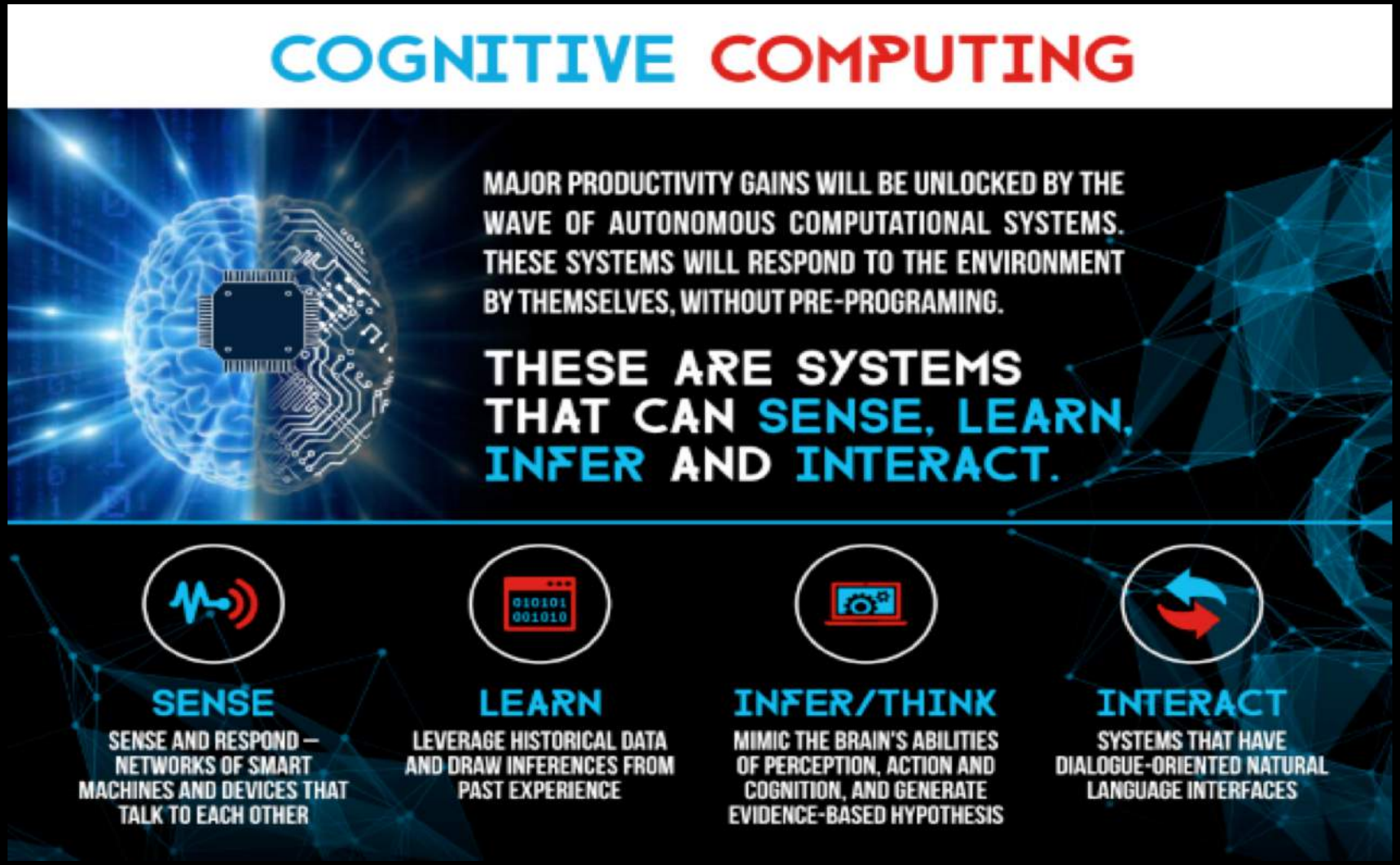


Internet map

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

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

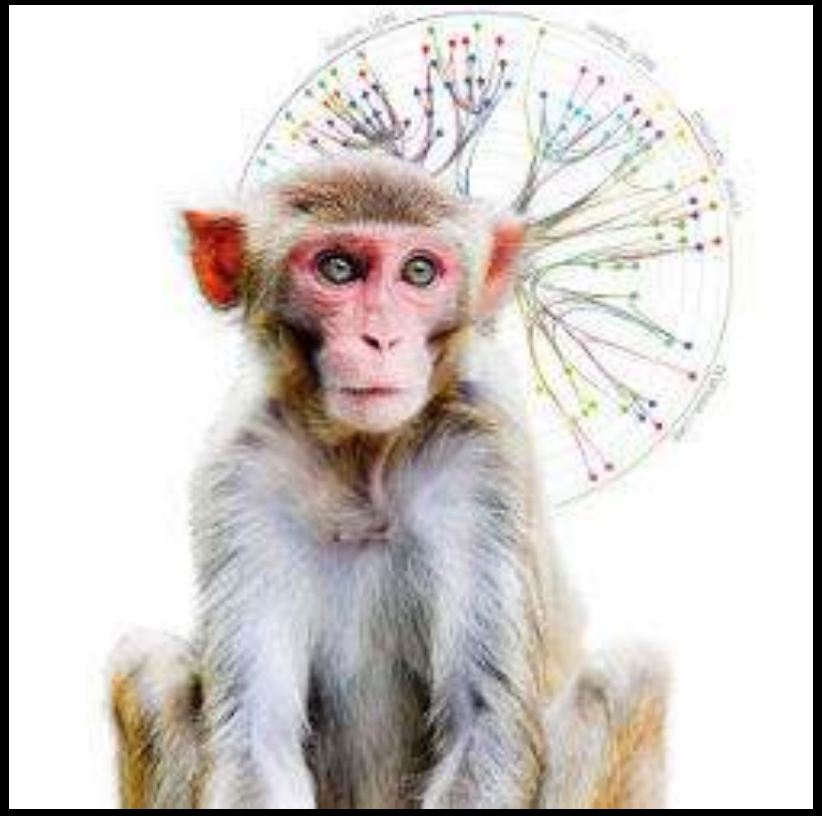
IBM have been working on a cognitive computing project called Systems of Neuromorphic Adaptive Plastic Scalable Electronics (SyNAPSE).

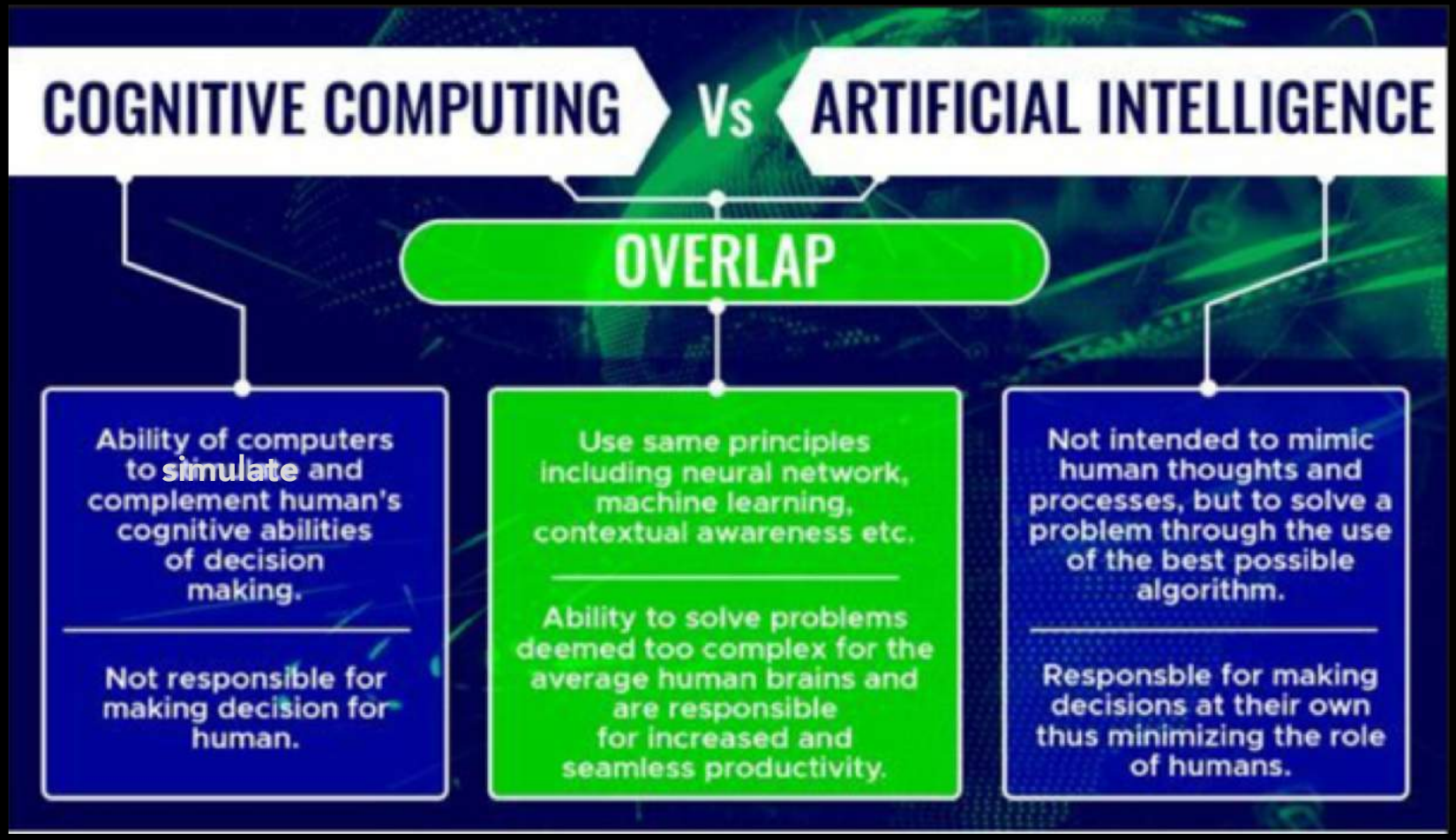
http://www.ibm.com/smarterplanet/us/en/business_analytics/article/cognitive_computing.html

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

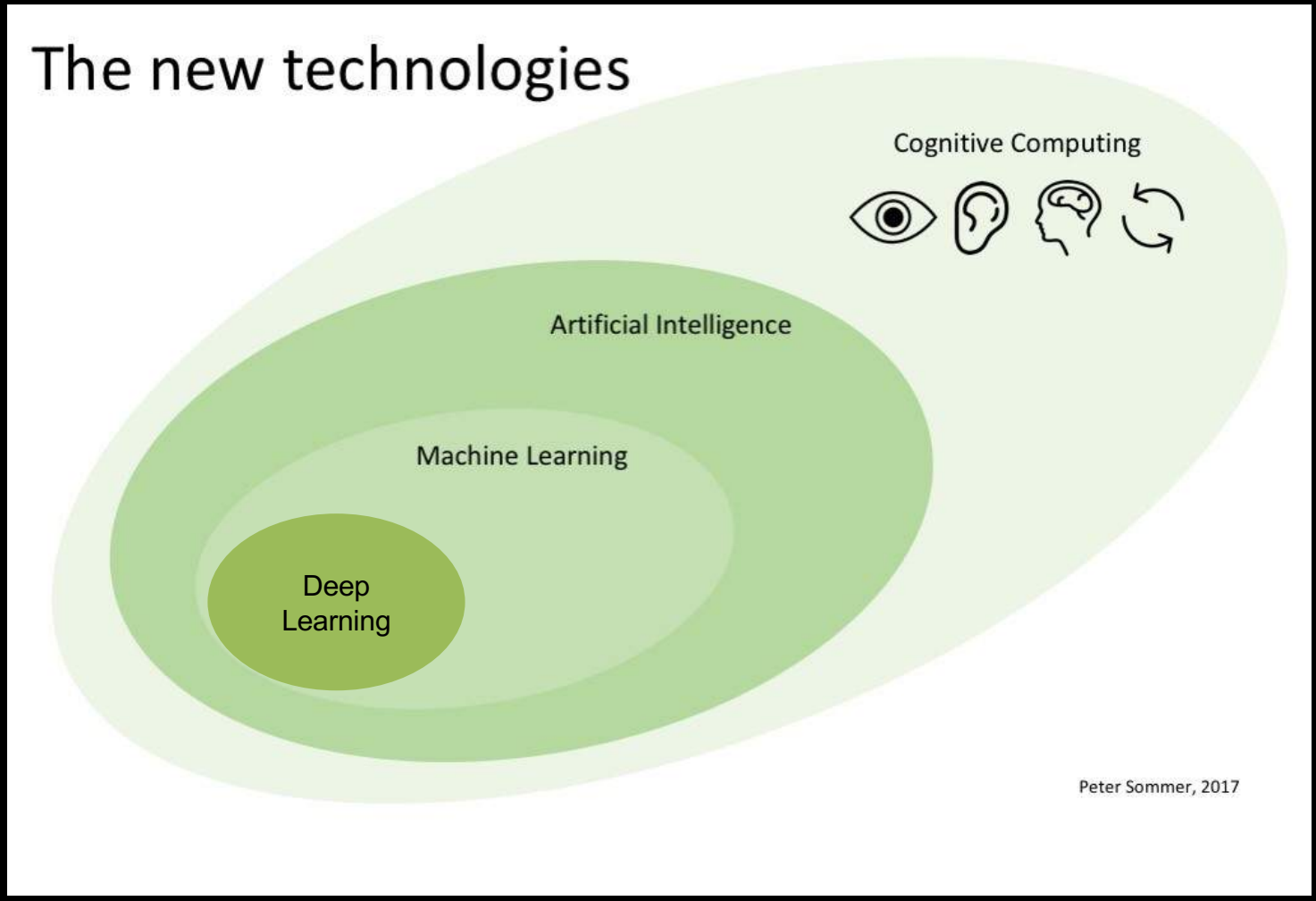
Communications of the ACM , Vol. 54 No. 8, Pages 62-71

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."



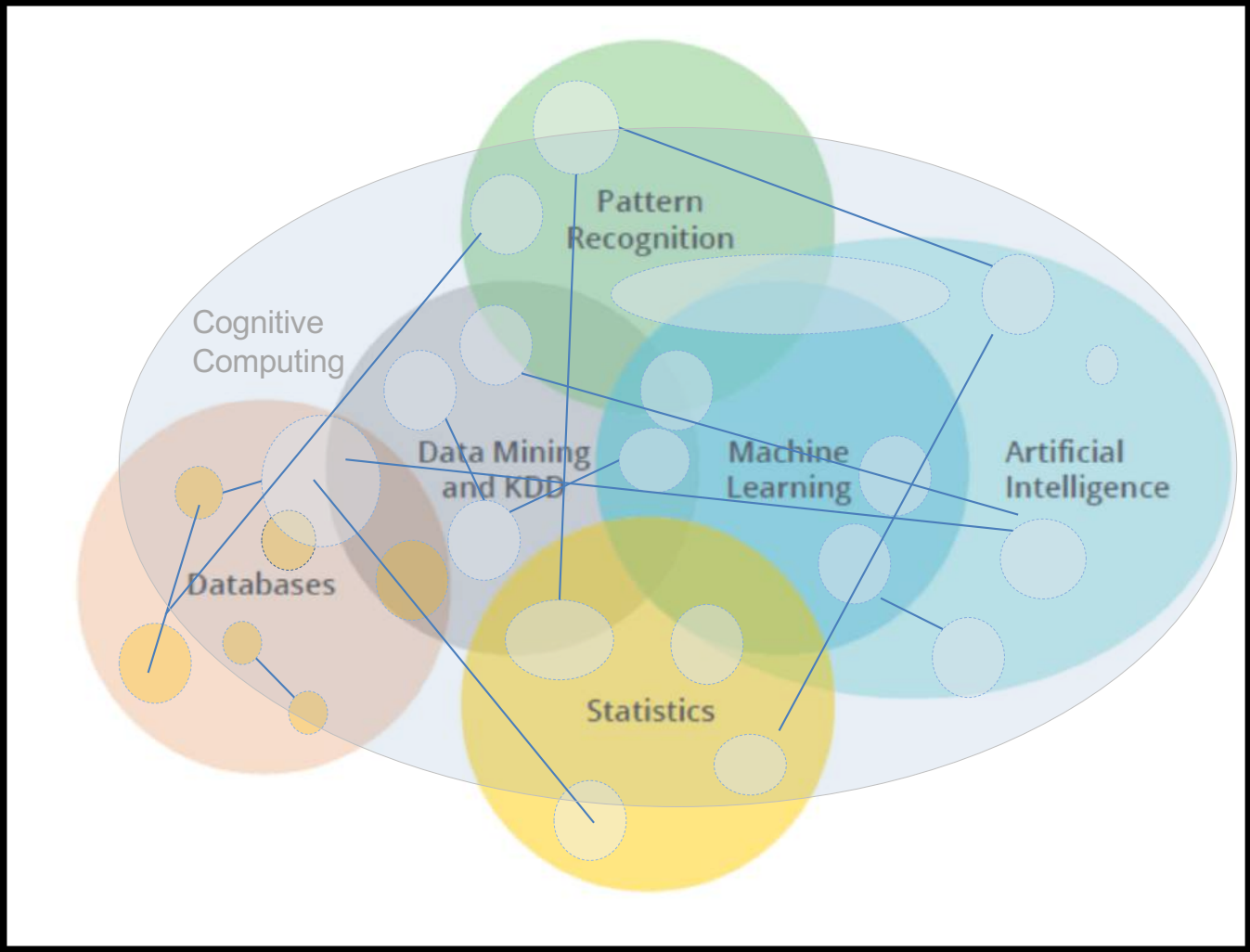

COGNITIVE COMPUTING
Vs
ARTIFICIAL INTELLIGENCE
OVERLAP
Ability of computers to simulate and complement human's cognitive abilities of decision making.
Not responsible for making decision for human.
Use same principles including neural network, machine learning, contextual awareness etc.
Ability to solve problems deemed too complex for the average human brains and are responsible for increased and seamless productivity.
Not intended to mimic human thoughts and processes, but to solve a problem through the use of the best possible algorithm.
Responsble for making decisions at their own thus minimizing the role of humans.

Machine Learning, AI & Cognitive Computing

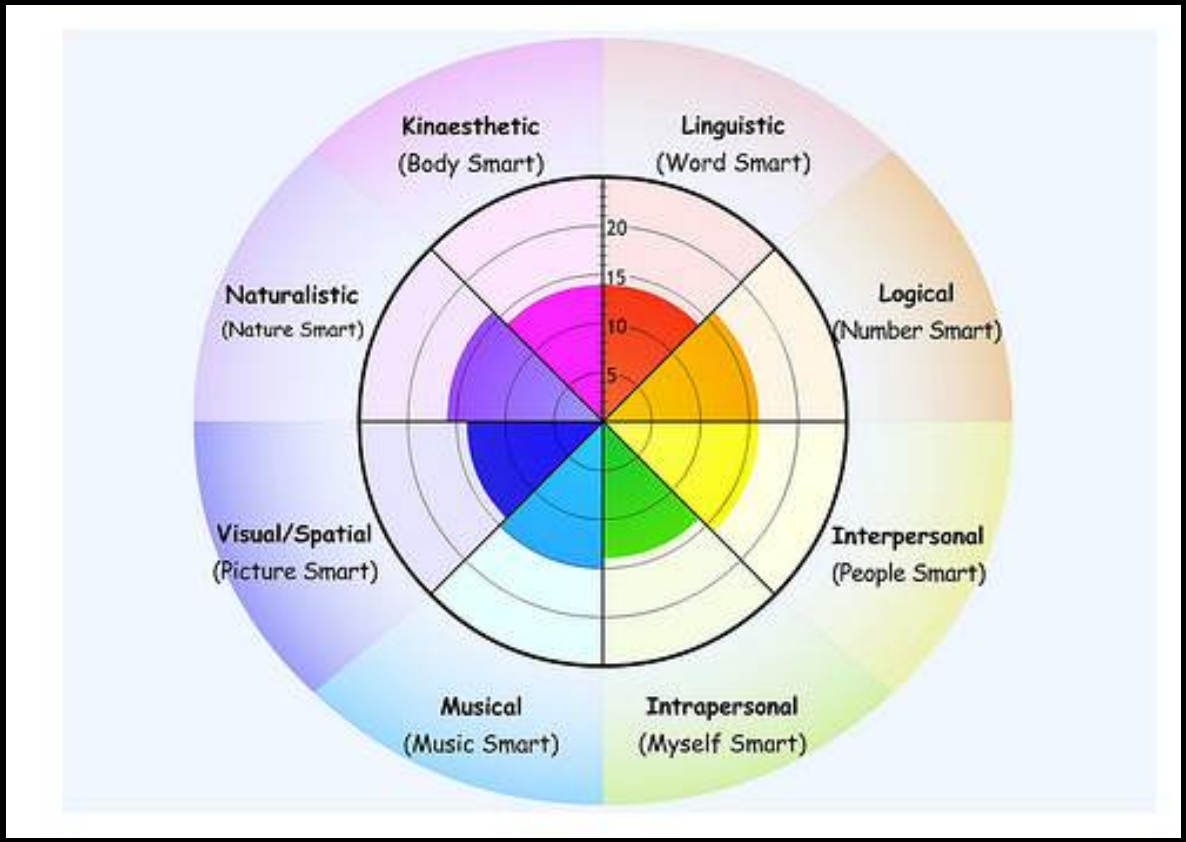


Intelligent Futures: Automation, AI and Cognitive Ecologies

Machine Intelligence and Cognition as networks



Different Kinds of Intelligence



Howard Gardner's Theory of Multiple Intelligences says that every person has a blend eight different types of intelligence

Todays machine intelligence is approaching proficiency in: logical, visual, linguistic, kinesthetic, musical, interpersonal, naturalistic and least of all (if at all) interpersonal intelligence.

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, and present as a distinct agent in the world. Even a single cell while alive constantly cognizes, that is registers inputs from the world and its own body, ensures its own continuous existence through metabolism and food hunting while avoiding dangers that could cause its disintegration or damage, 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

Morphological computing as information processing on different levels of organization in physical systems

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.

Morphological computation connecting body, brain, and environment - Rolf Pfeifer

("Brain and body" that roboticists learn from sometimes belongs to an octopus)

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 /

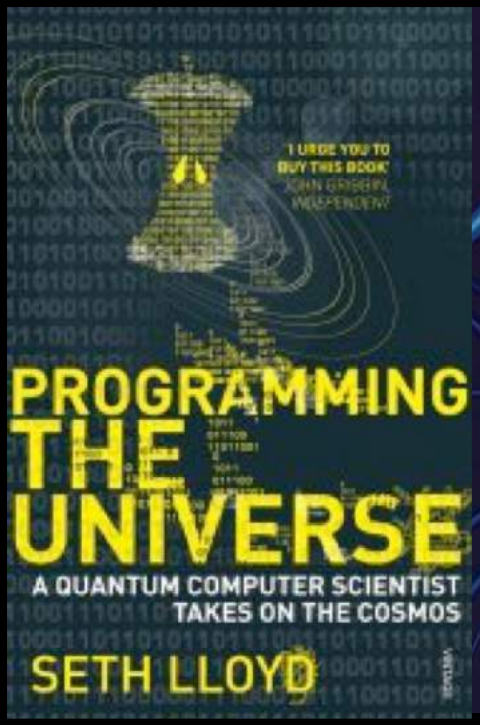
amorphous computing / molecular computing

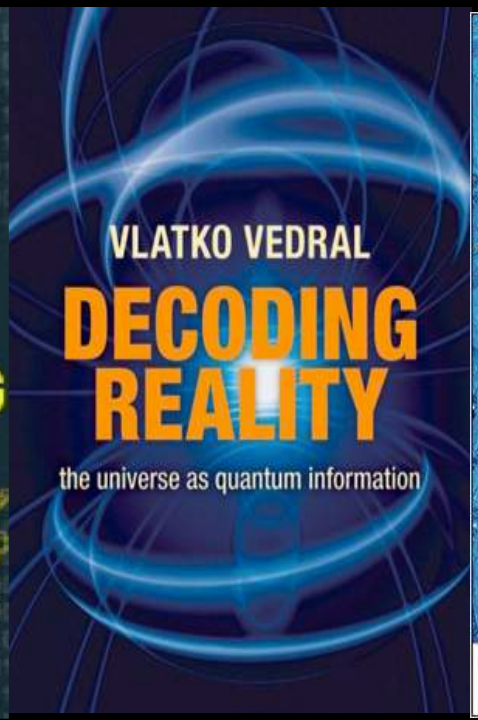
http://morphcomp.org/2nd International Conference on Morphological Computation ICMC2011.

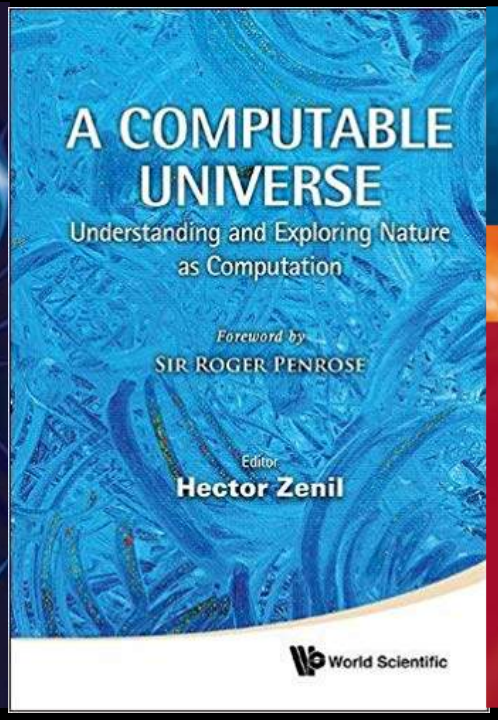
http://www.eucognition.org/index.php?page=theoretical-scheme Tutorial on Embodiment: R Pfeifer

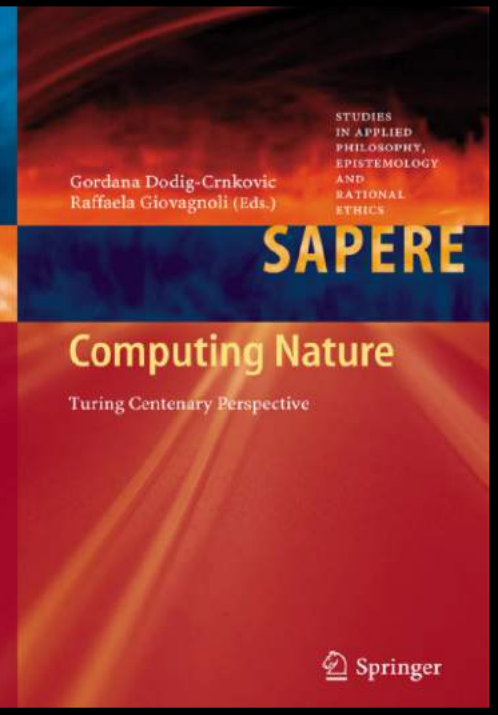
LITERATURE, FURTHER READING

The Computing Universe

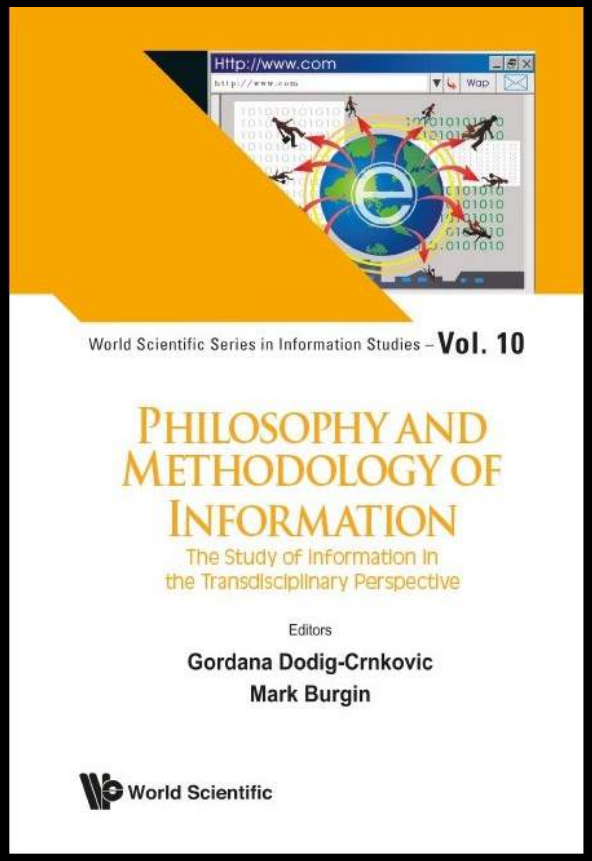








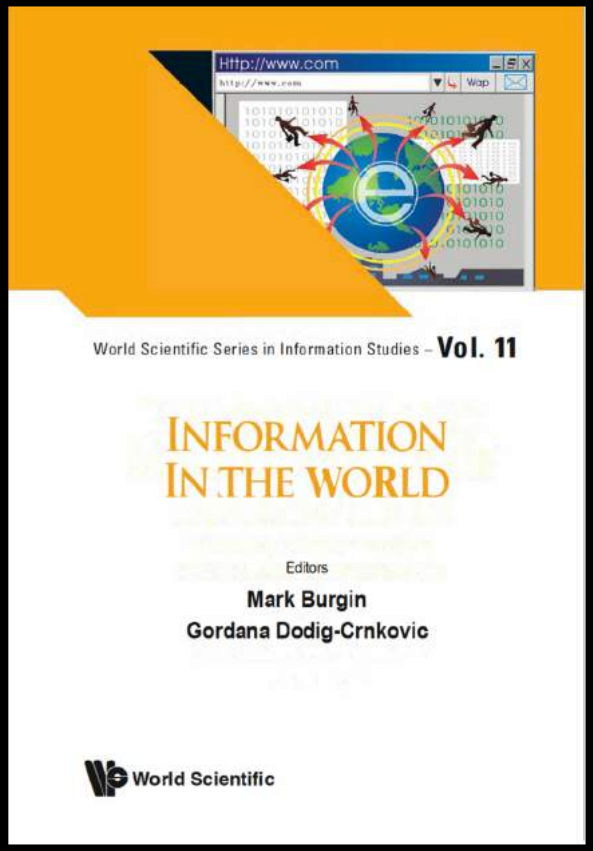
Nature, Information & Computation



PHILOSOPHY AND METHODOLOGY OF INFORMATION

Dodig-Crnkovic G. and Burgin M.

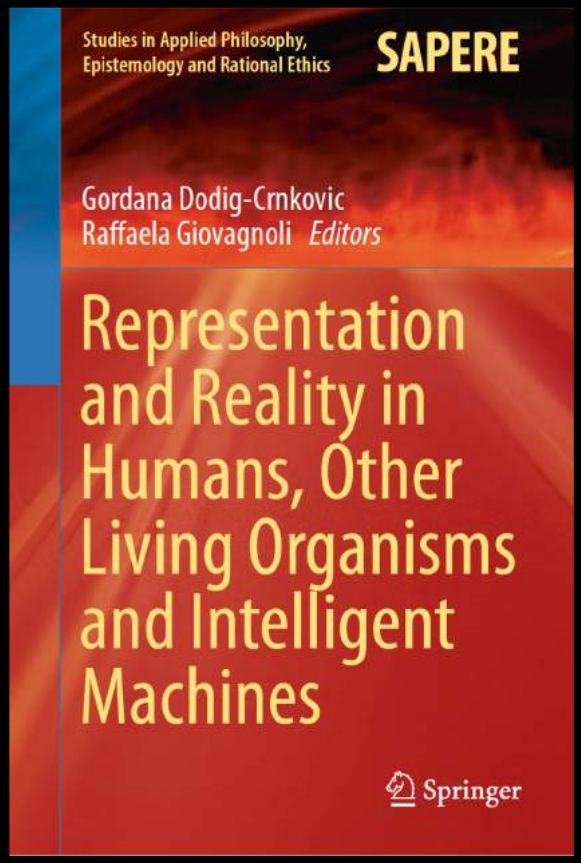
World Scientific Series in Information Studies, May 2019



Forthcoming: I*NFORMATION IN THE WORLD*

Burgin M. and Dodig-Crnkovic M.

World Scientific Series in Information Studies, September 2020



REPRESENTATION AND REALITY

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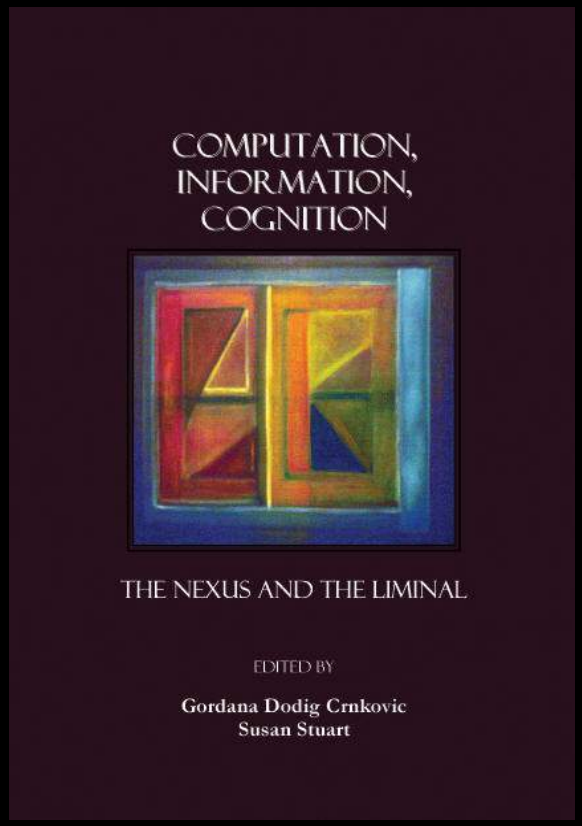
Springer, 2017

Computation, Information, Cognition



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Gordana Dodig Crnkovic and
Susan Stuart, Edts.
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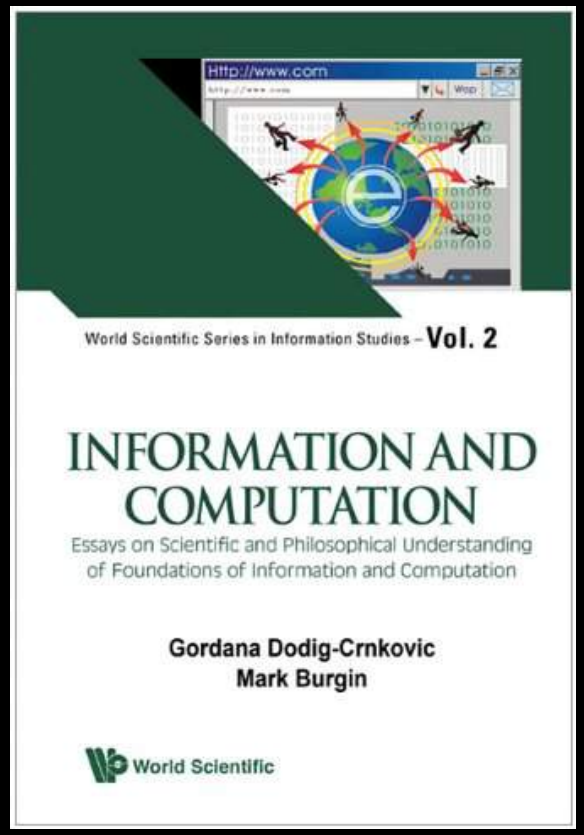

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Gordana Dodig Crnkovic and
Mark Burgin, Edts.
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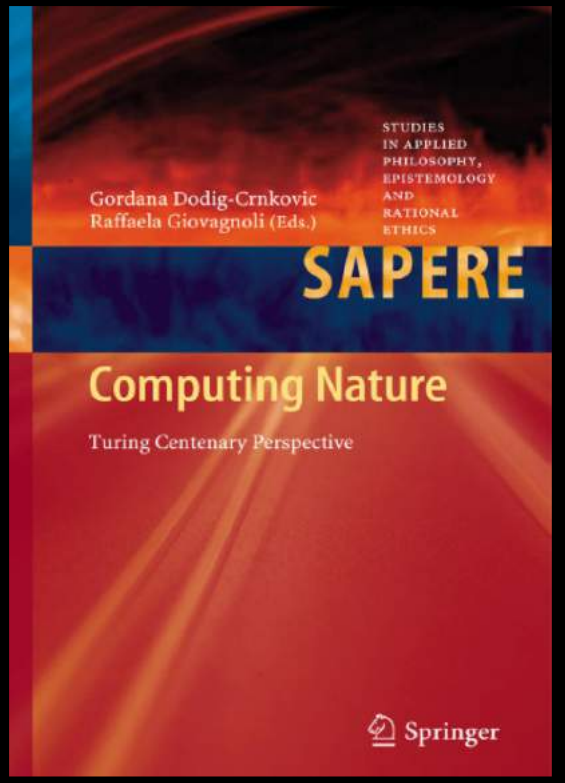

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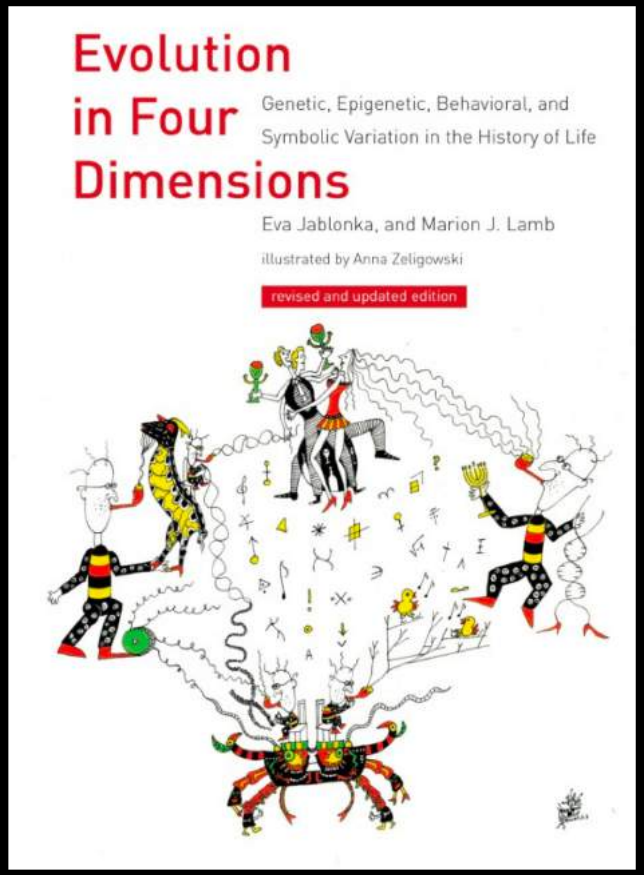
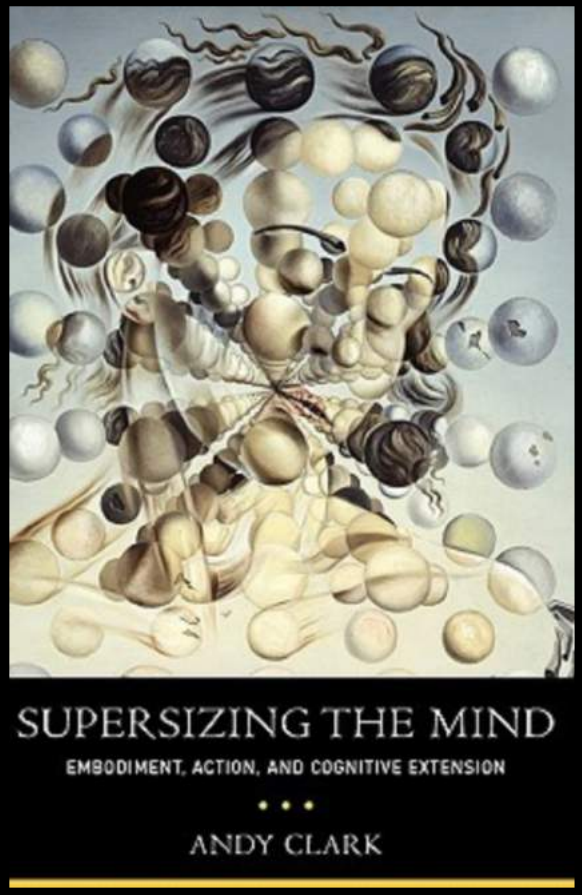
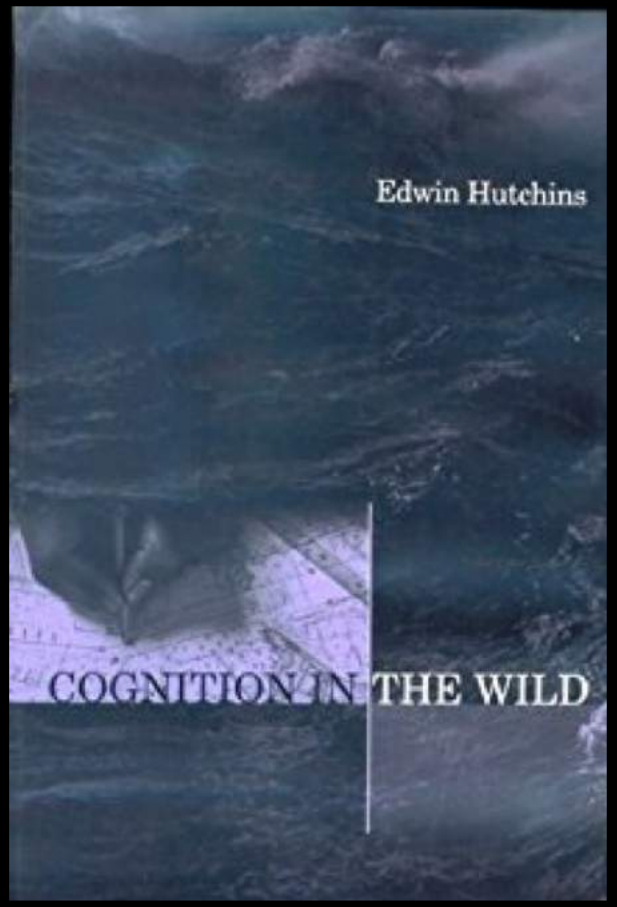
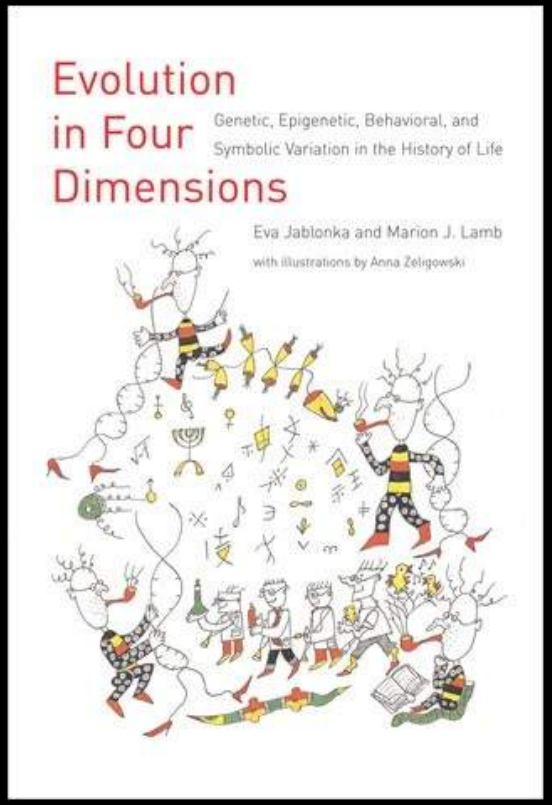
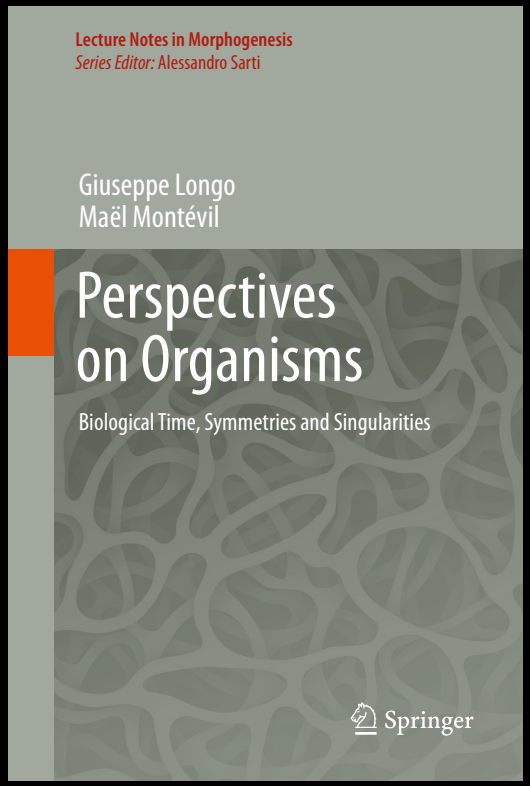


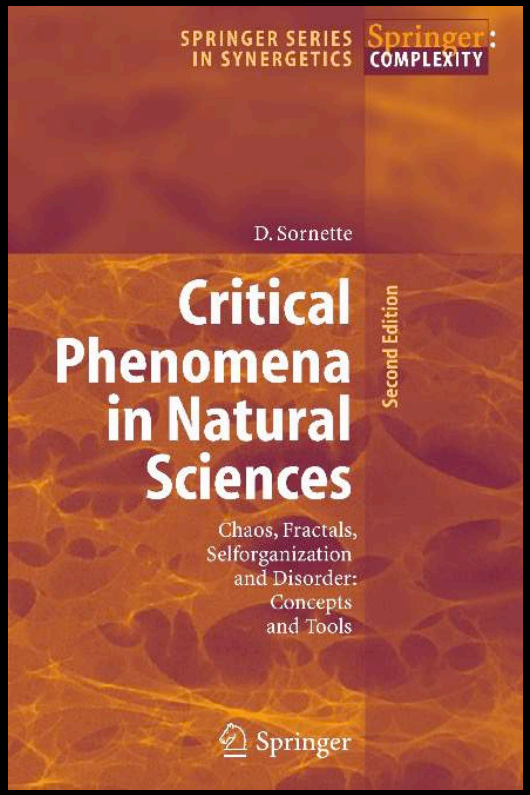


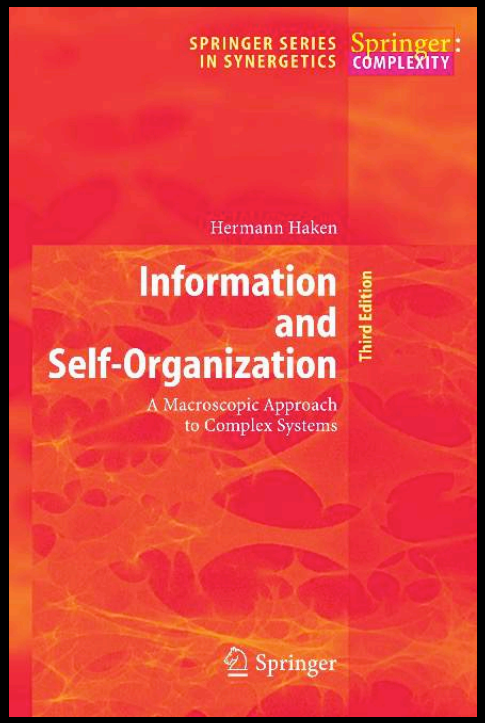


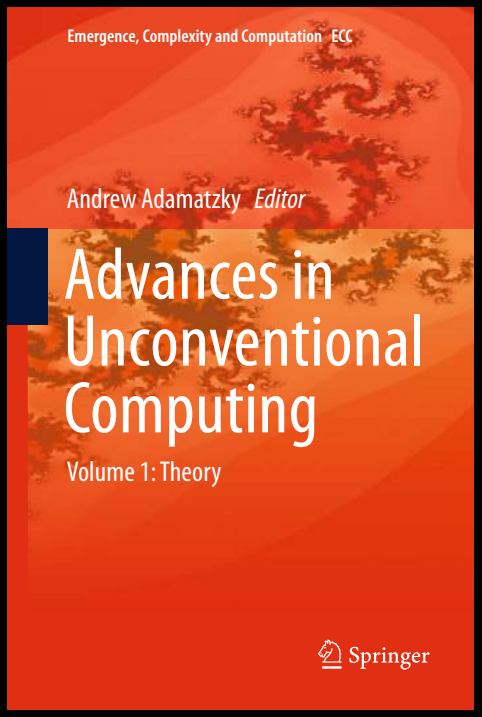
SOME BOOKS OF INTEREST

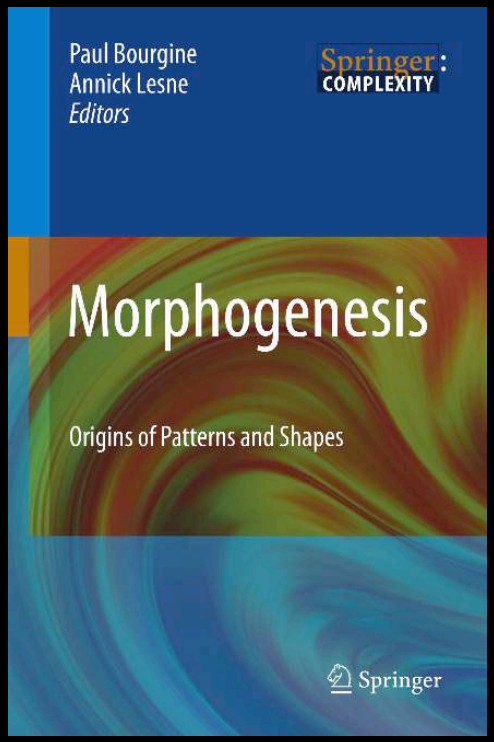


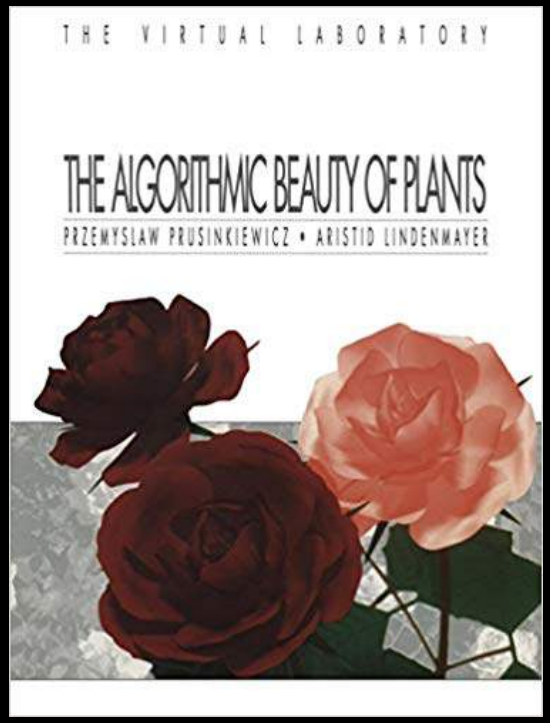


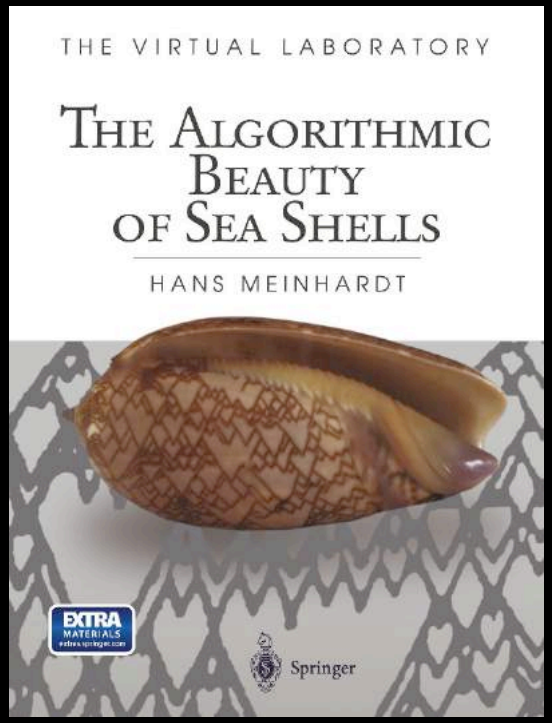


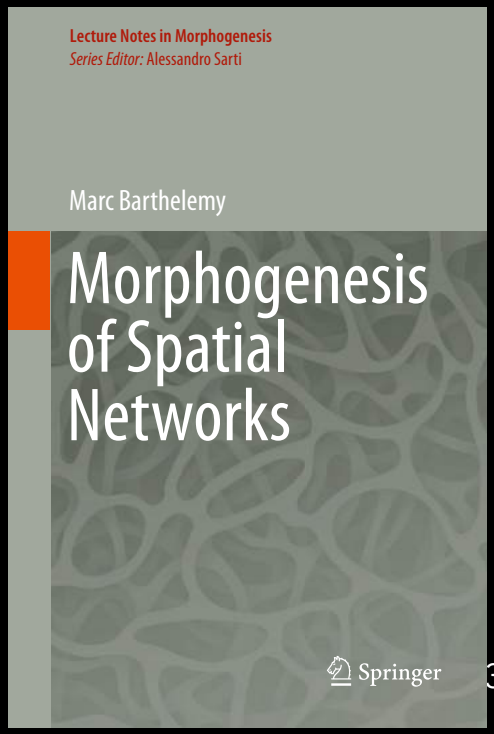

SPRINGER SERIES IN SYNERGETICS
Springer: COMPLEXITY
Hermann Haken
Information and Self-Organization
Third Edition
A Macroscopic Approach to Complex Systems
Springer


Emergence, Complexity and Computation ECC
Andrew Adamatzky Editor
Advances in Unconventional Computing
Volume 1: Theory
Springer


Paul Bourgine
Annick Lesne
Editors
Springer: COMPLEXITY
Morphogenesis
Origins of Patterns and Shapes
Springer


THE VIRTUAL LABORATORY
THE ALGORITHMIC BEAUTY OF PLANTS
PRZEMYSLAW PRUSINKIEWICZ • ARISTID LINDENMAYER


THE VIRTUAL LABORATORY
THE ALGORITHMIC BEAUTY OF SEA SHELLS
HANS MEINHARDT
EXTRA MATERIALS
Springer


Lecture Notes in Morphogenesis
Series Editor: Alessandro Sarti
Marc Barthelemy
Morphogenesis of Spatial Networks
Springer

Short message of this talk

Connecting data to intelligent agency is done by modelling cognitive systems (natural and artifactual) as information processors, equipped with physical information sensors and physical actuators acting upon information.

Underlying assumptions

1. Nature can be modelled as a network of networks of computational processes on several levels of abstraction (organization)
2. There is no information without physical implementation (Landauer)
3. Dynamics of natural information = physical /natural/morphological computation
4. Cognition/Intelligence = Natural computation in cognitive agents

Short message of this talk

Implications

1. Cognition and intelligence are abilities of all living beings and they come in degrees
2. Cognition and intelligence are both EEEE (Embodied, Embedded, Enactive, Extended)
3. For living organisms COGNITION=LIFE.
   For artifacts COGNITION = ARTIFACTUAL SURROGATE OF LIFE
4. INTELLIGENCE = PROBLEM SOLVING ABILITY for both living organisms and artifacts.
   Its basic precondition is ability to learn (biological or machine learning)
5. All cognizing systems (organisms and artifacts) are essentially dependent on information input from the surrounding and
5. Biological cognition and intelligence can only be understood in the context of evolution.
6. Evolution in the computing nature is the result of morphological computation on several levels of organization

* *That results in genetic, epigenetic, behavioral, and symbolic variation
Eva Jablonka and Marion J. Lamb (2019) Evolution in Four Dimensions. Genetic, Epigenetic, Behavioral, and Symbolic Variation in the History of Life (EXTENDED EVOLUTIONARY SYNTHESIS)

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- Dodig-Crnkovic G., Info-computationalism and Morphological Computing of Informational Structure, in Integral Biomathics, Simeonov, P., Smith, L. and Ehresmann, A. (Eds.). Springer Serie on Computational Intelligence and Complexity, Table of Contents, 2012. (Selected contributions from Conference on Integral Biomathics Stirling University, Scotland), pp. 97-105.

- Dodig-Crnkovic G., Physical Computation as Dynamics of Form that Glues Everything Together. Information 2012, 3, 204-218; doi:10.3390/info3020204

www.gordana.se

Events organized on this topic

Embodied Cognition: Constructivist and Computationalist Perspectives
IACAP 2016, Ferrara. http://www.iacap.org/conferences/iacap-2016/symposium-robert-lowe-gordana-dodig-crnkovic-embodied-cognition-constructivist-and-computationalist-perspectives/
Co-organized with: Robert Lowe, Alexander Almér, Rickard von Haugwitz

Morphological Computing and Cognitive Agency
@Gothenburg summit of International Society for the Study of Information, is4si
http://is4si-2017.org/
Co-organized with: Robert Lowe, Alexander Almér

Foundations of Cyberphysical Computation: Morphological and Embodied Computing, Theory and Applications, Marcus Wallenberg Symposium. May 7th-9th, 2018
https://sites.google.com/view/morphologicalcomputing
Co-organized with: Robert Lowe

Workshop on Software Engineering for Cognitive Services. https://www.se4cog2018.com
27/5–3/6 @ICSE 2018 Gothenburg https://sites.google.com/view/se4cog2018
Co-organized with: Rao Mikkilineni