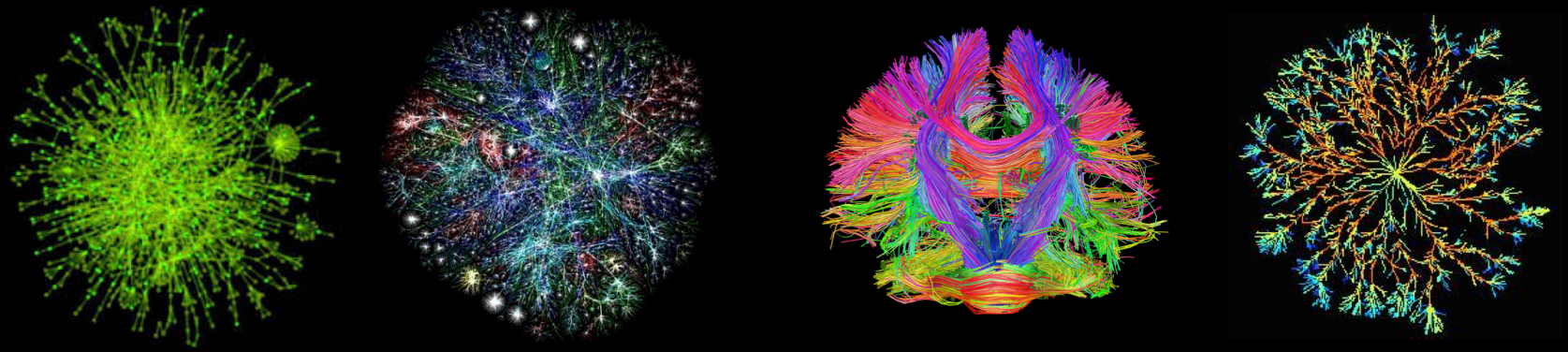
Chalmers Initiative Seminar 2019: ADVANCING AI

With official kick-off for Chalmers AI Centre

Gothenburg, 2019 03 05

AI and Cognitive Computing



GORDANA DODIG-CRNKOVIC

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

http://www.gordana.se

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

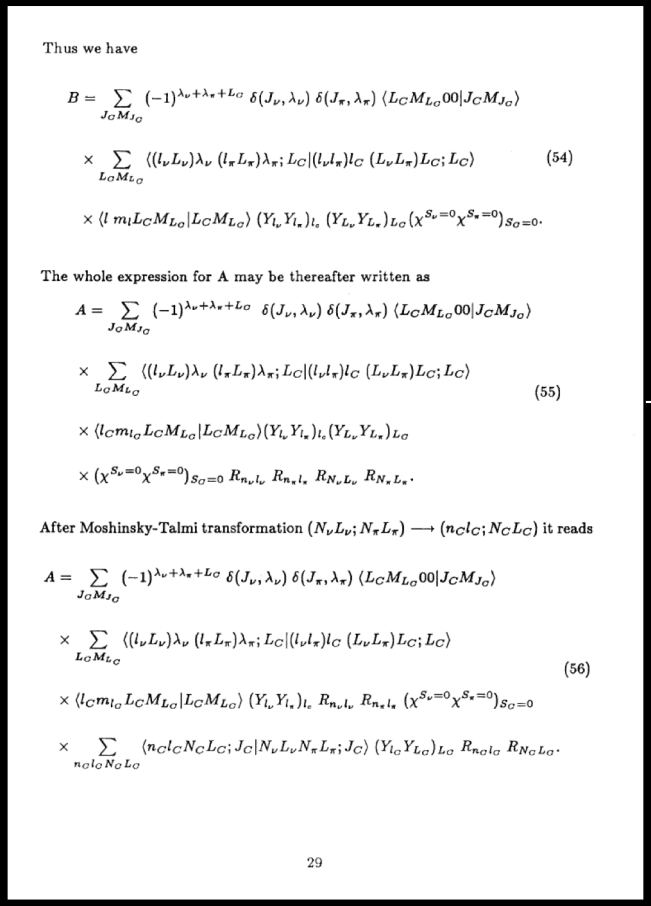
WORLD SCIENTIFIC VOLUMES ON INFORMATION STUDY (Two volumes, to appear in May (Vol 1) and September (Volume 2) 2019

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

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

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

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

The whole expression for A may be thereafter written as

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

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

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

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

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

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

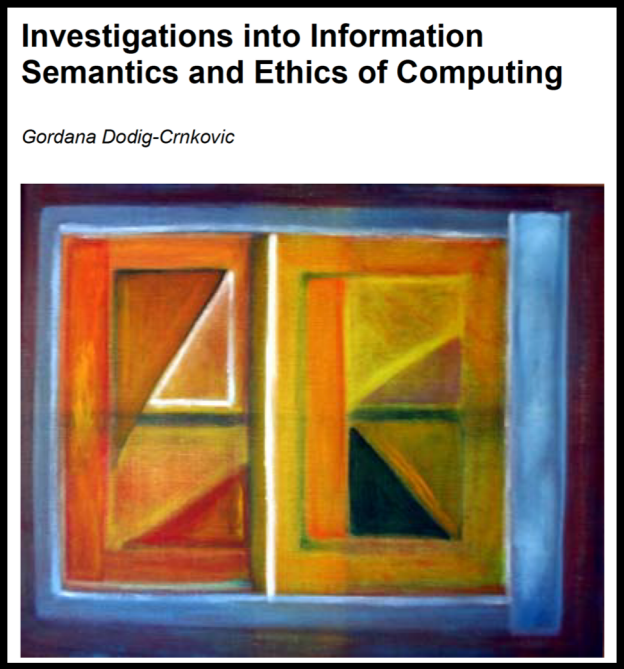
$$\times \sum_{L_C M_{L_C}} \langle (l_\nu L_\nu)\lambda_\nu\ (l_\pi L_\pi)\lambda_\pi; L_C|(l_\nu l_\pi)l_C\ (L_\nu L_\pi)L_C; L_C\rangle \qquad (56)$$

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

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

29

PhD in Computing, 2006
Computer Science, Mälardalen University



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/

Researchers…

"Scientists are people of very dissimilar temperaments doing different things in very different ways.
Among scientists are collectors, classifiers and compulsive tidiers-up; many are detectives by temperament,
and many are explorers; some are artists and other artisans.
There are poet-scientists and philosopher-scientists and even a few mystics."

Peter Medawar, Pluto's Republic

The Nobel Prize in Physiology or Medicine 1960

After Chengdu conference, several events on the related topics

2016
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

2017
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

2018
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

2019
Morphological Computing in Search for Understanding of Natural and Artificial Intelligence

@IS4SI2019 Berkeley, https://is4si2019.com/en/

Co-organized with Marcin Schroeder

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:

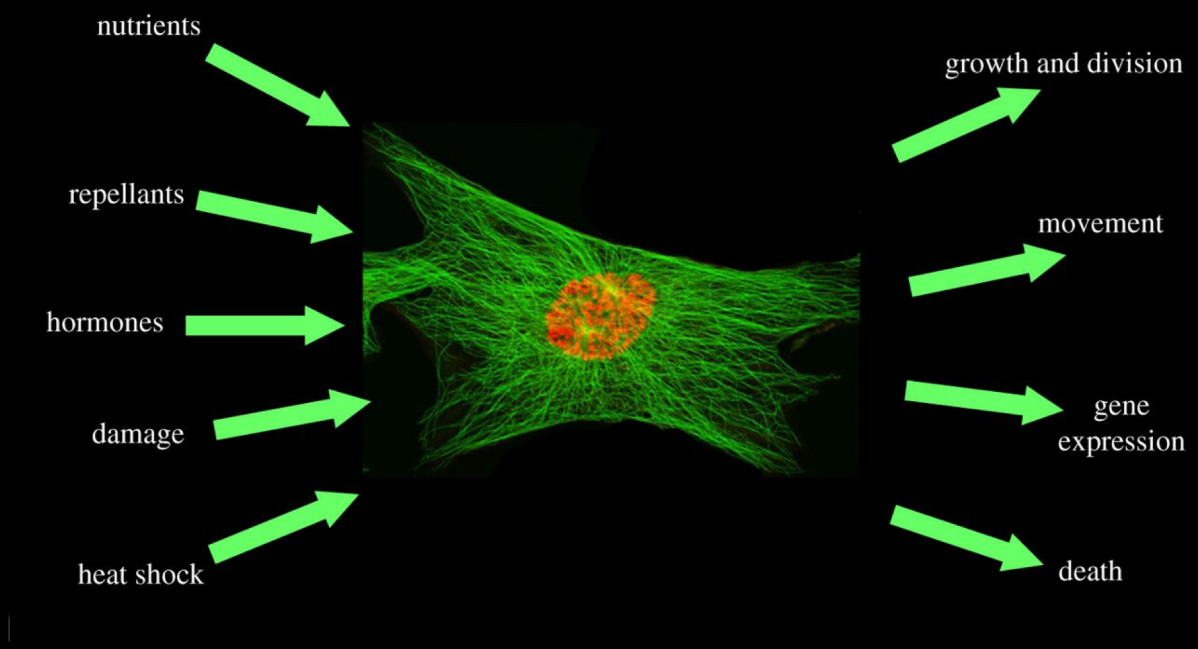
Cognition = Process of "being in the world" of an agent

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

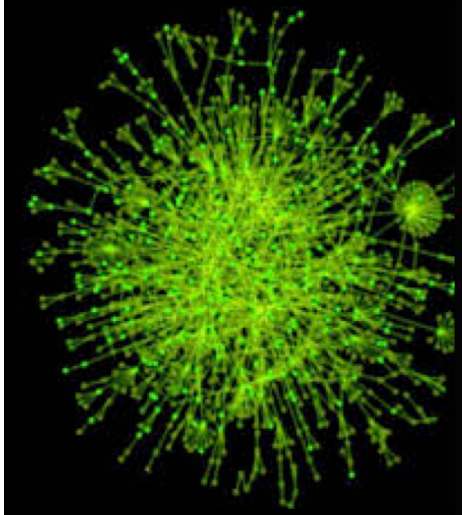


http://rsfs.royalsocietypublishing.org/content/4/3/20130070

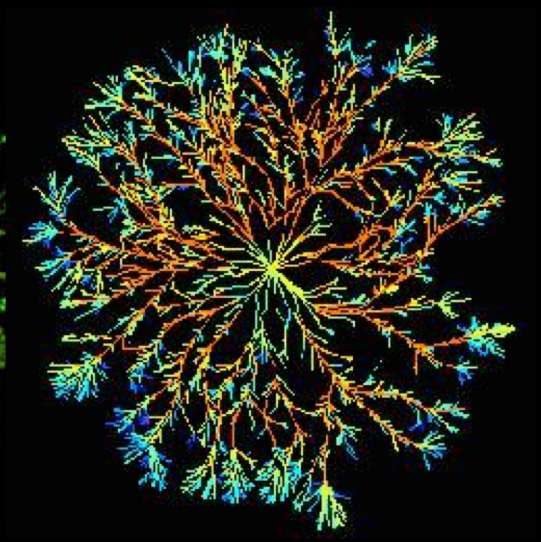
https://www.youtube.com/watch?v=wJyUtbn0O5Y&list=PLXPeXawEy4EcPneclV1FaZA6bgVDujLzm&index=7
Harvard University XVIVO animation showing inner world of a cell

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

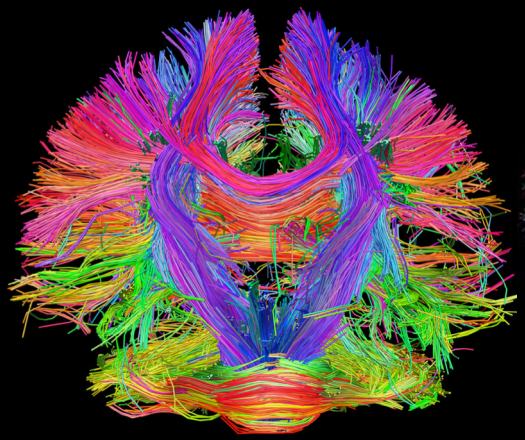
Information processing in life-networks



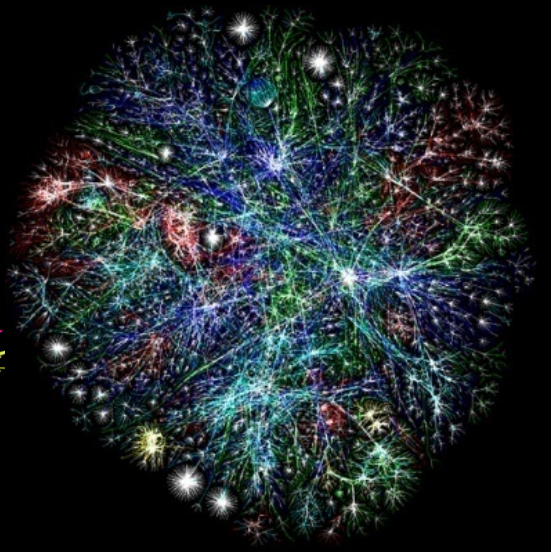
A map of protein–protein interactions in yeast cell



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

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.

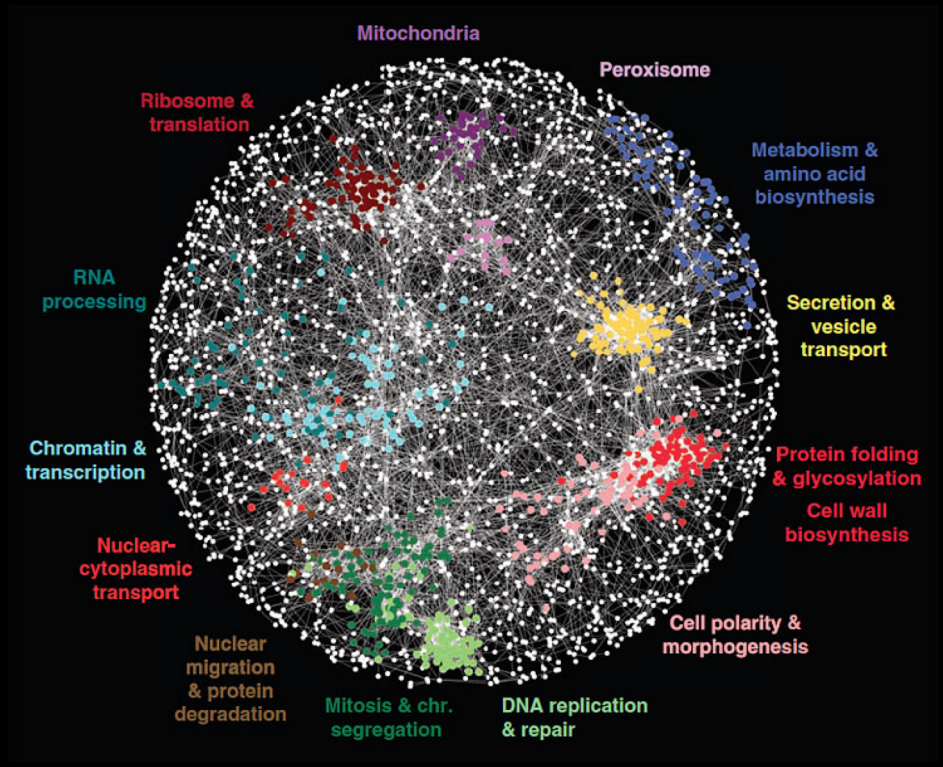
Plant behaviour and communication.
Karban, Richard (2008). " Ecology Letters. 11 (7): 727–739. doi:10.1111/j.1461-0248.2008.01183.x. PMID 18400016.

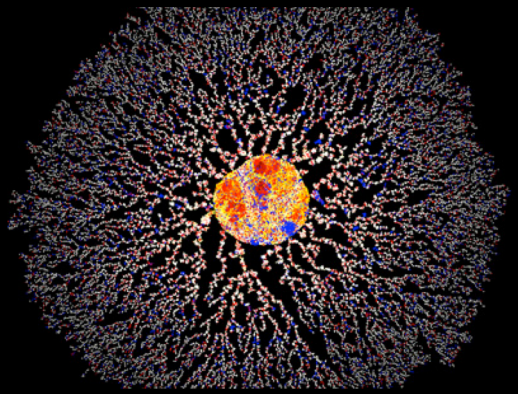
http://www.nature.com/nrm/journal/v2/n4/images/nrm0401_307a_f1.gif

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

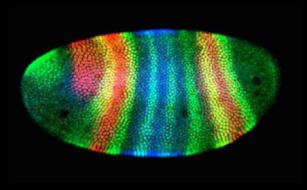




http://phys.org/news/2009-11-conquer-social-network-cells.html

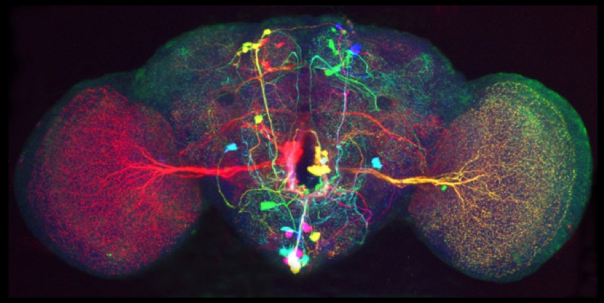
http://www.hhmi.org/research/global-mapping-genetic-networks A functional network for a yeast cell

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



Fruit fly embrio

Fruit fly larva



Fruit fly brain neurons

Fruit fly head

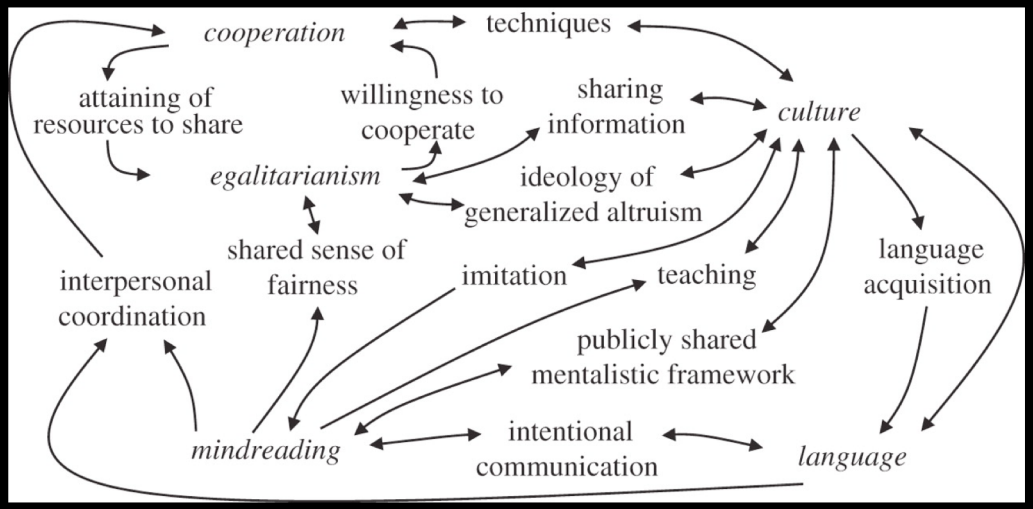
Human cognition

Complex language and material culture

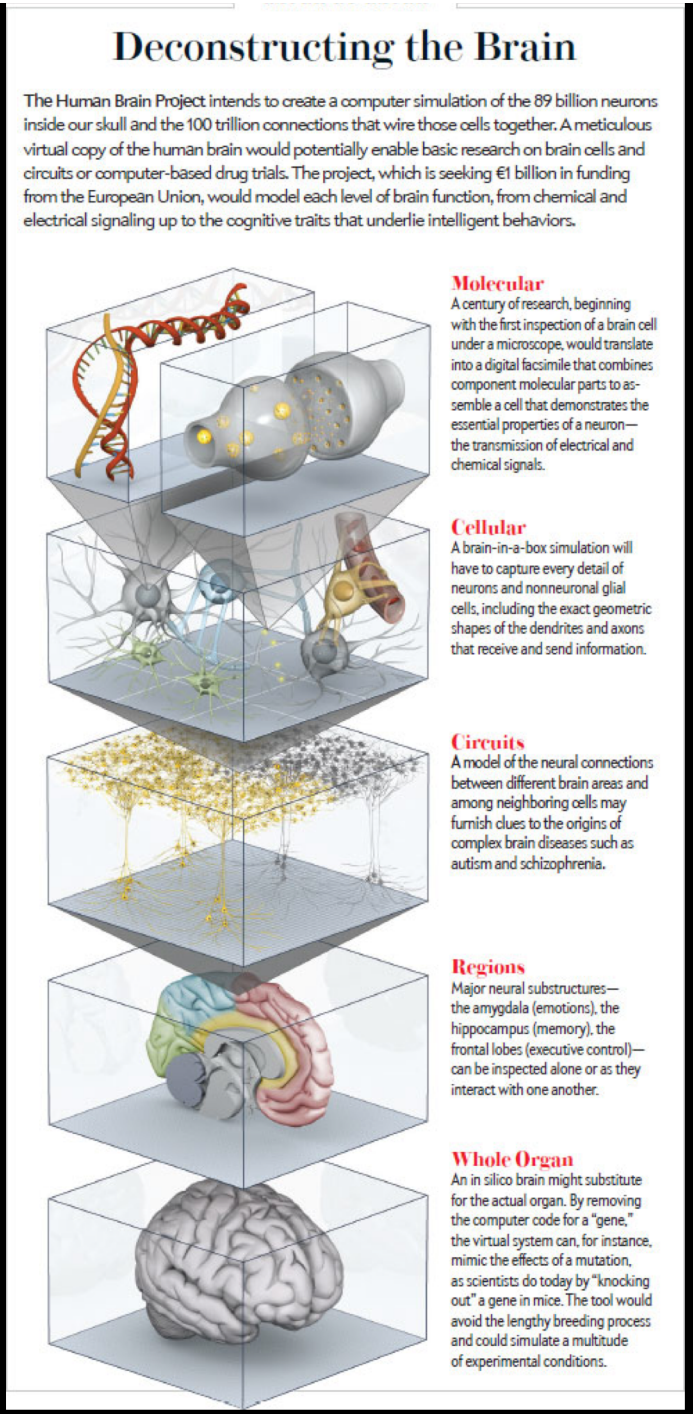
Human connectome

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

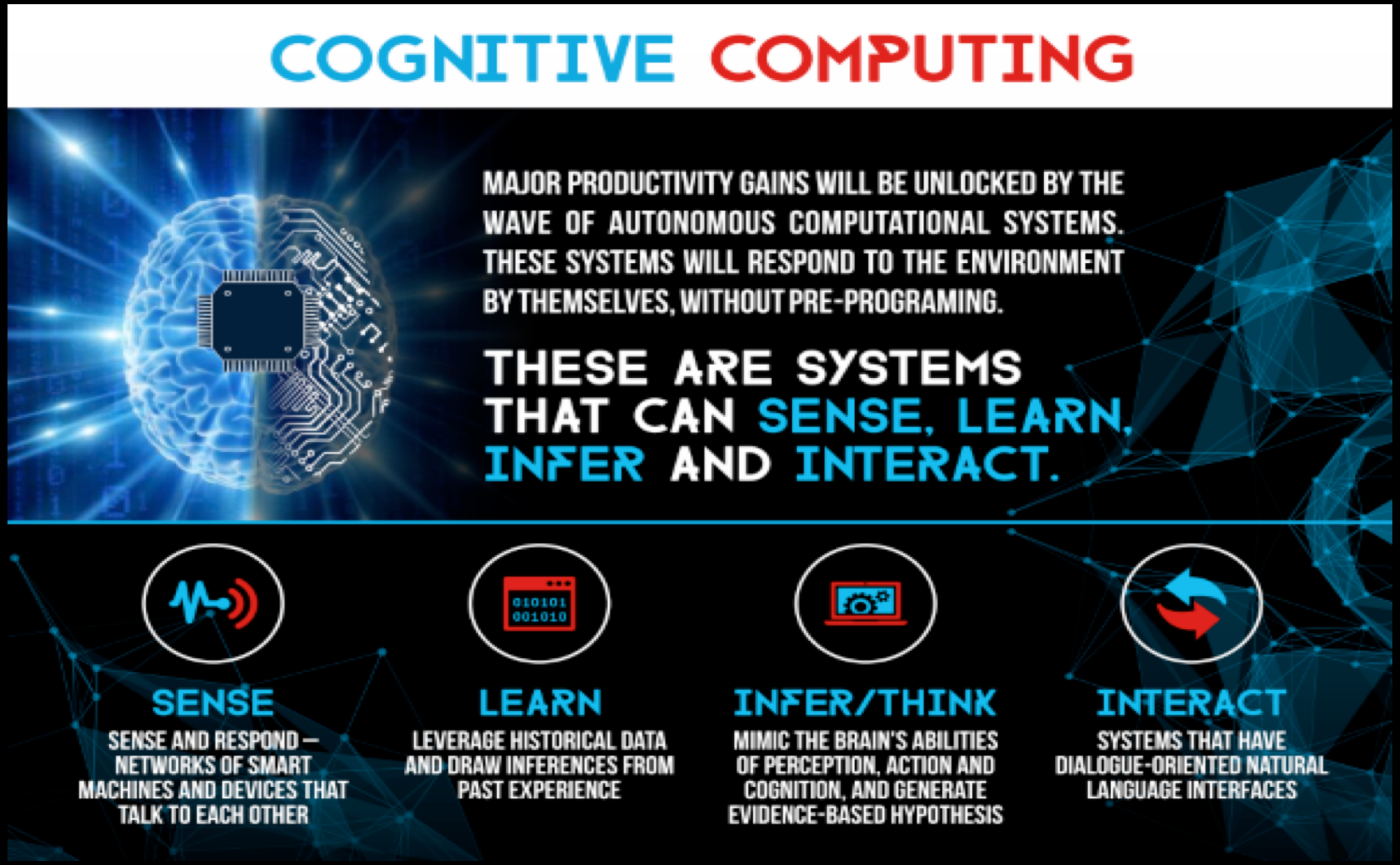


http://www.nature.com/scientificamerican/journal/v306/n6/pdf scientificamerican0612-50.pdf p. 14

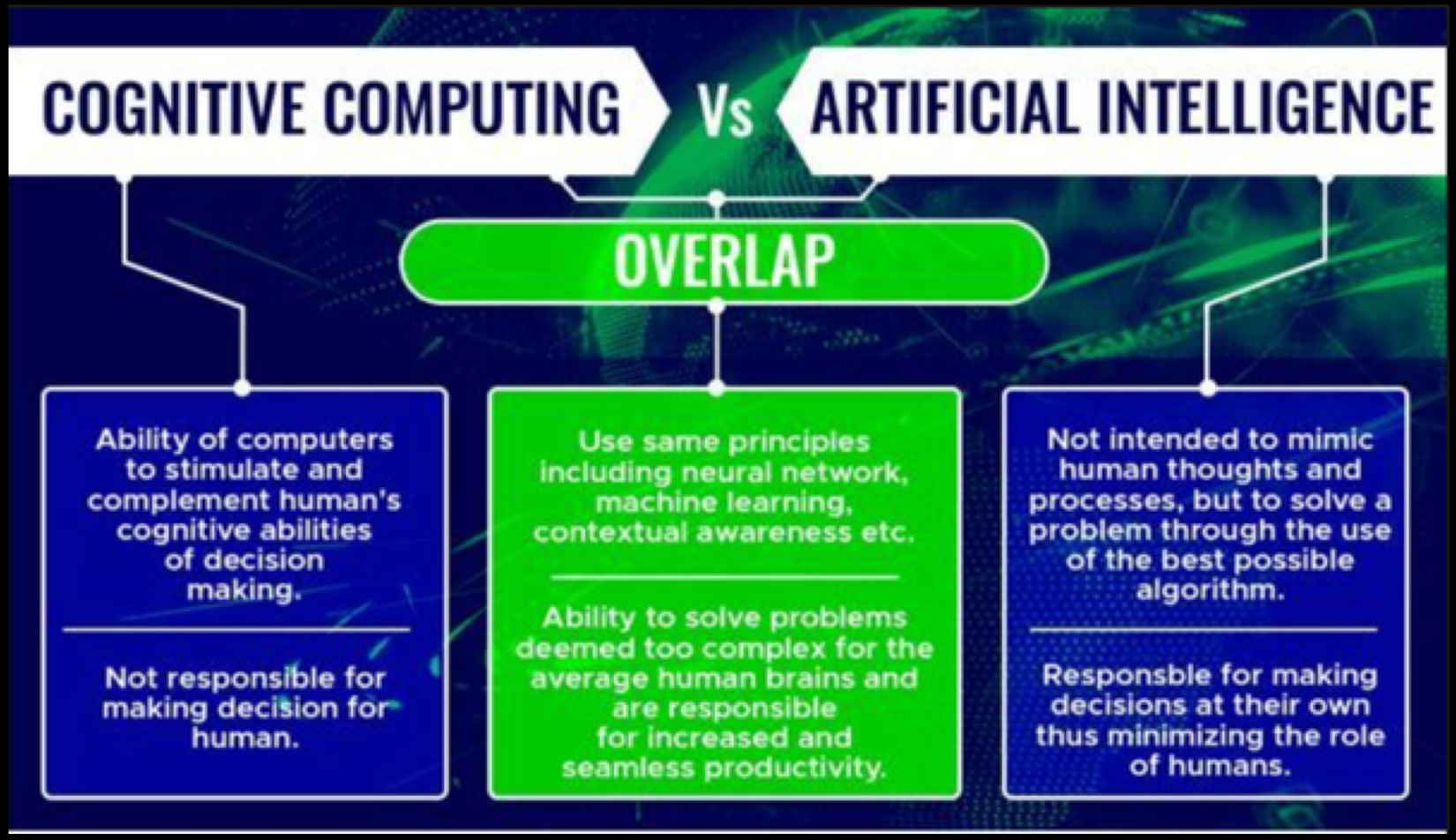
The Human Brain Project

Machine Cognition

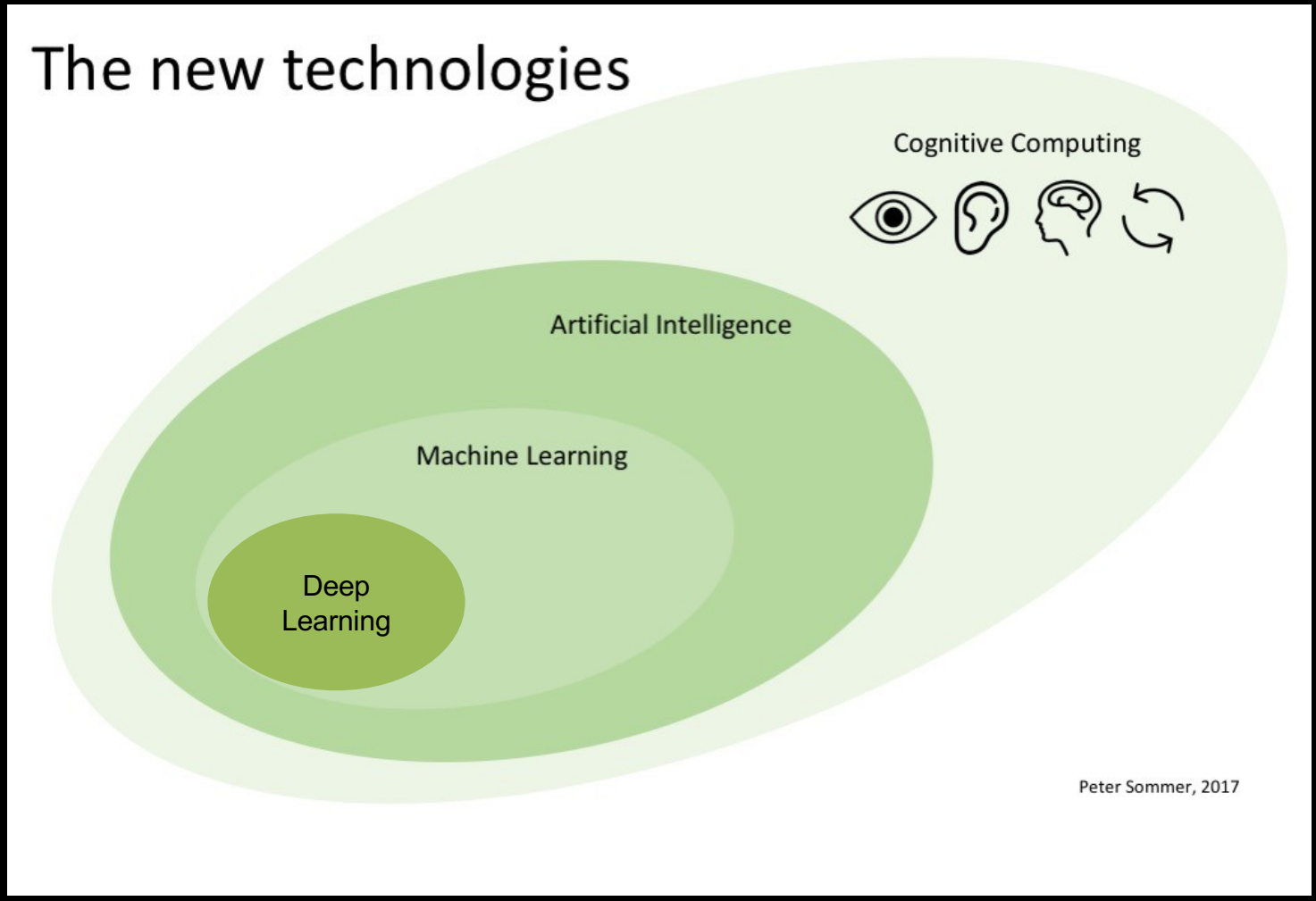
Machines that sense, learn, reason/think and interact with us in natural language



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

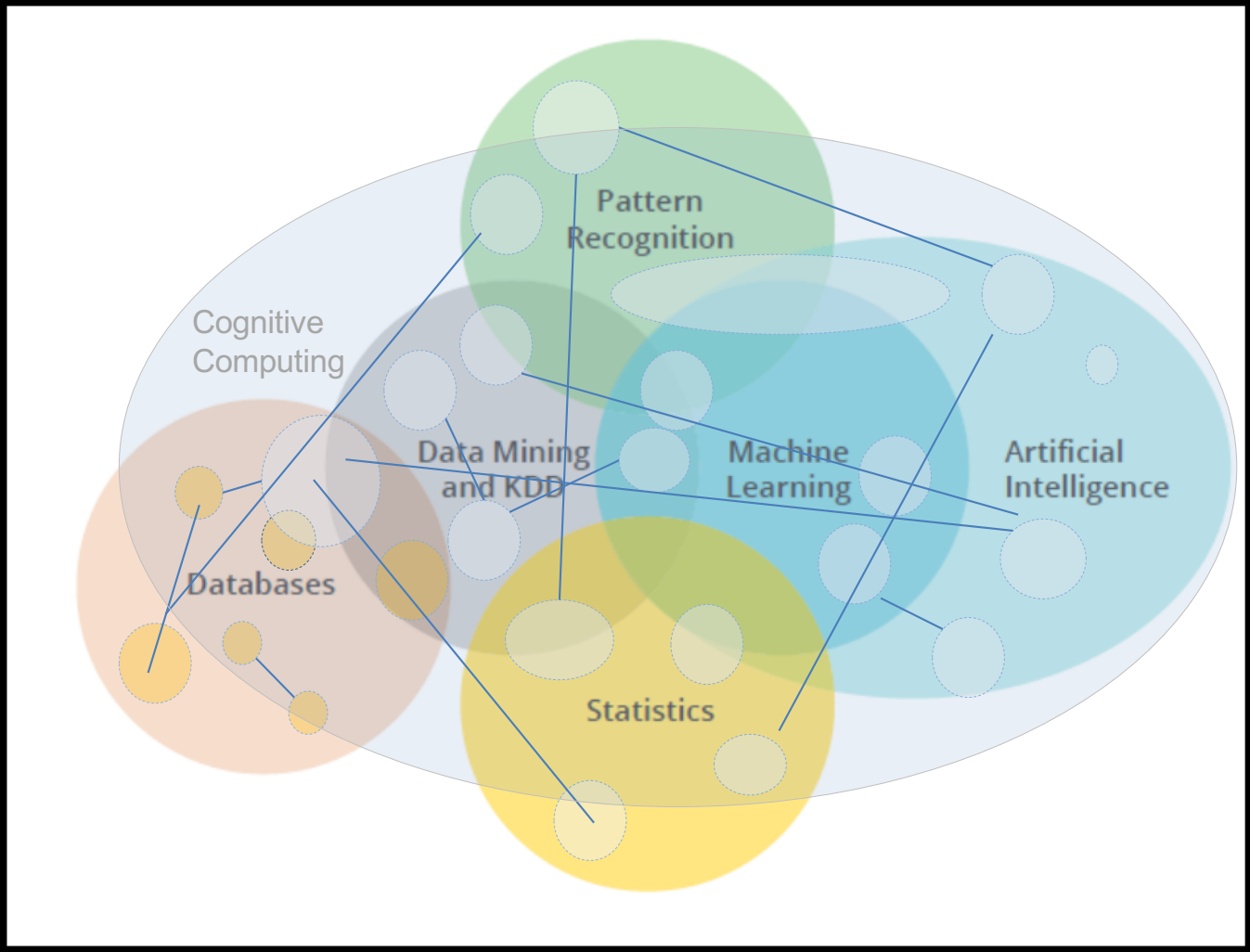

COGNITIVE COMPUTING
Vs
ARTIFICIAL INTELLIGENCE
OVERLAP
Ability of computers to stimulate and complement human's cognitive abilities of decision making.
Not responsible for making decision for human.
Use same principles including neural network, machine learning, contextual awareness etc.
Ability to solve 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



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

Morphogenesis as 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 (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 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

Problems we want to m a n a g e* computationally

- Big data
- Internet of everything
- Semantic web
- Cognitive computing
- Cognitive robotics
- Intelligent cities
- Intelligent homes
- Artificial general intelligence
- Computational neuroscience & neuroinformatics

All above problems depend on the adequate models of computation and they depend on the computational architecture.

*Observe the difference between S O LV I N G and M A N A G I N G a problem!

Construction of knowledge from data by computation

We construct knowledge from the data as pieces of information we get directly from the world via interrelation and combination of information from memory or indirectly via other people (either exchanging information personally or from the stored information found in diverse kinds of documents.)

See Dodig-Crnkovic, Constructivist Research and Info-Computational Knowledge Generation,

http://www.mrtc.mdh.se/~gdc/work/MBR09ConstructiveResearch.pdf

Cognition as morphological info-computation

Cognition for an agent is process of acquiring knowledge and understanding through thought, experience, and the senses and physical interactions with the environment and other cognitive agents.

The term cognition (Latin: cognoscere, "to know", "to conceptualize" or "to recognize") refers to a faculty for the processing of information, applying knowledge, and changing preferences. Cognition, or cognitive processes, can be natural or artificial, conscious or unconscious. (Wikipedia)

Knowledge as natural processes

Naturalized epistemology (Feldman, Kornblith, Stich) is, in general, an idea that knowledge may be studied as a natural phenomenon -- that the subject matter of epistemology is not our concept of knowledge, but the knowledge itself.

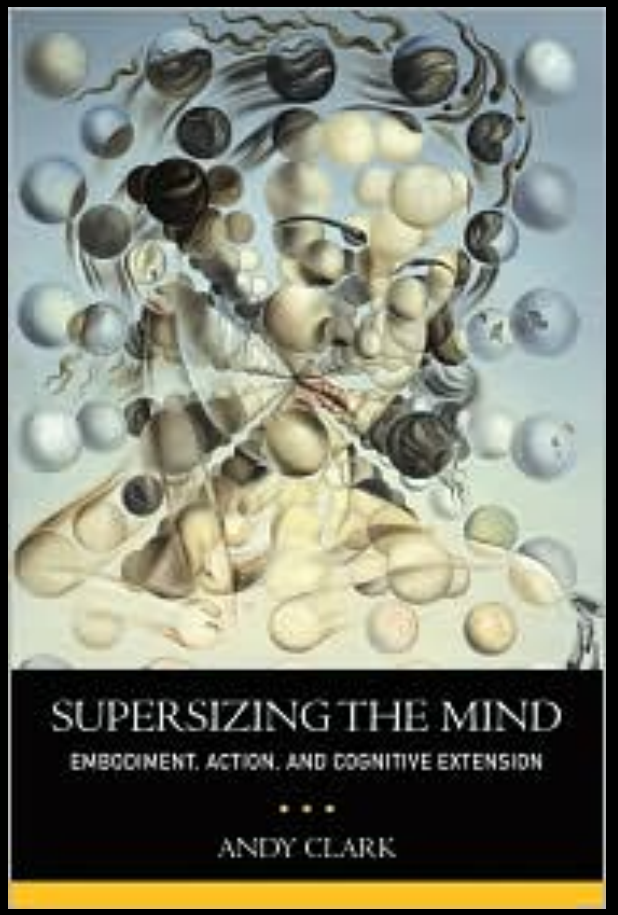
“The stimulation of his sensory receptors is all the evidence anybody has had to go on, ultimately, in arriving at his picture of the world. Why not just see how this construction really proceeds? Why not settle for psychology? “("Epistemology Naturalized", Quine 1969; emphasis mine)

I will re-phrase the question to be: Why not settle for computing?

Epistemology is the branch of philosophy that studies the nature, methods, limitations, and validity of knowledge and belief.

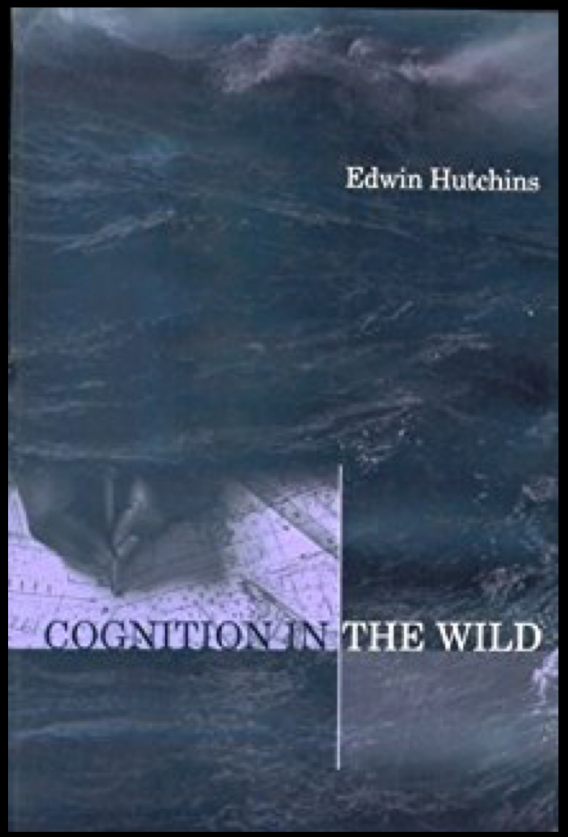
The extended mind

Andy Clark and David Chalmers proposed the idea of mind delegating cognitive* functions to the environment - in which objects within the environment function as a part of the mind
http://consc.net/papers/extended.html



Distributed cognition

Based on extended mind – environment supports cognition processes performed by brain and body, with further processing of information capabilities.



Hutchins, Edwin (1995). Cognition in the Wild. MIT Press. ISBN 0-262-58146-9.
Hutchins, E. (1995) "How a cockpit remembers its speeds". Cognitive Science, 19, 265-288.

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

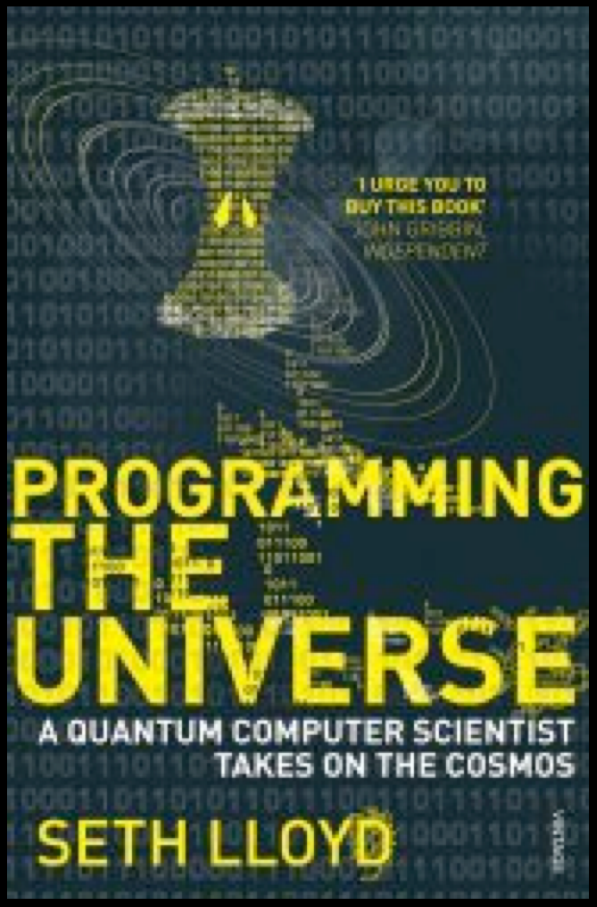
http://cacm.acm.org/magazines/2011/8/114944-cognitive-computing/fulltext

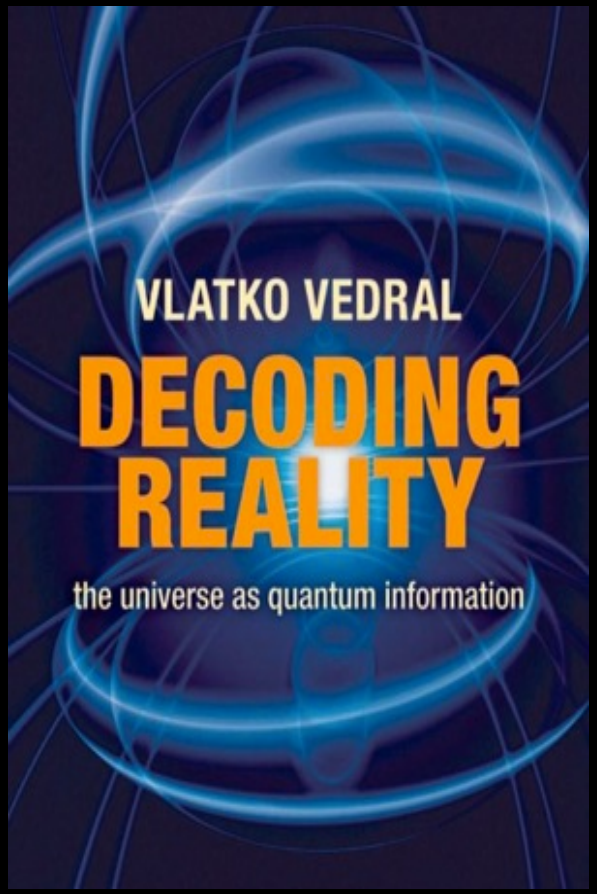
Communications of the ACM , Vol. 54 No. 8, Pages 62-71

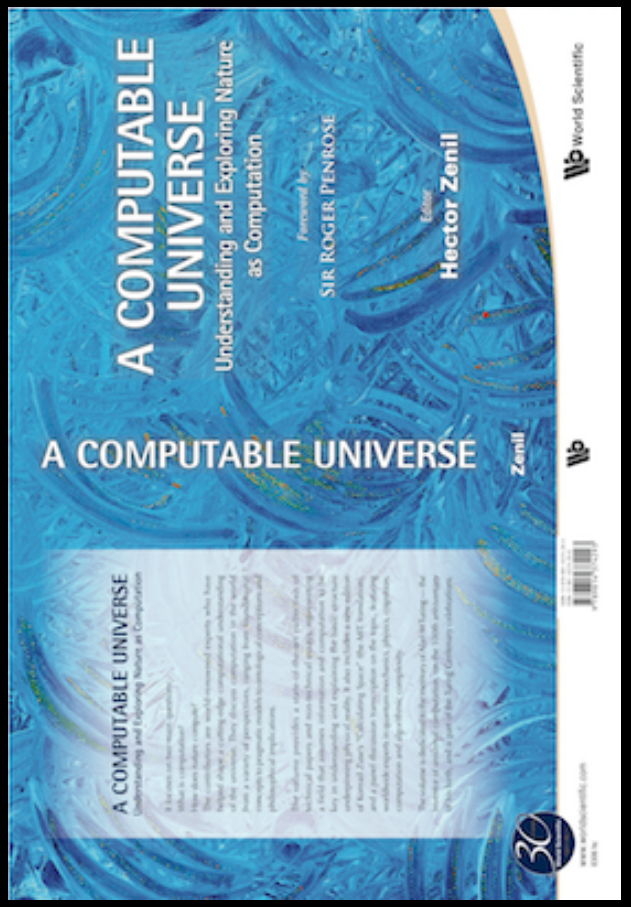
The quest for intelligent machines ultimately requires new breakthroughs in philosophy, neuroanatomy, neurophysiology, computational neuroscience, supercomputing, and computer architecture orchestrated in a coherent, unified assault on a challenge of unprecedented magnitude. The state of today's effort 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."

LITERATURE, FURTHER READING

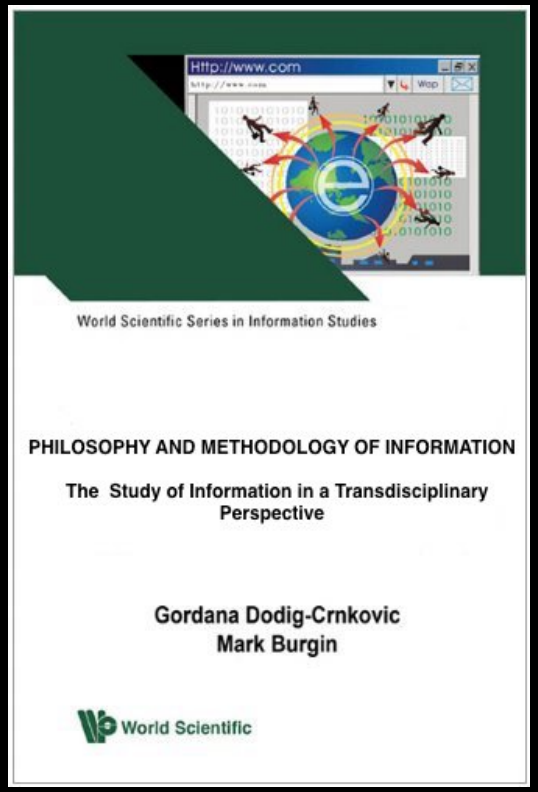
The Computing Universe



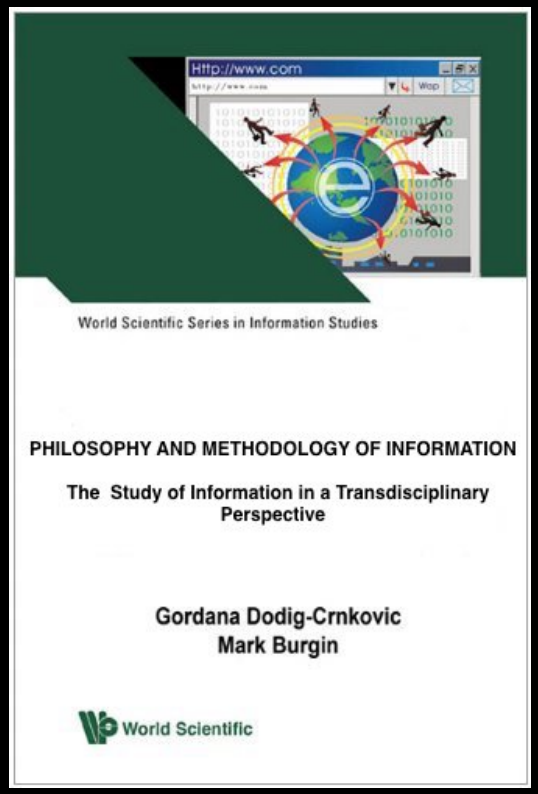




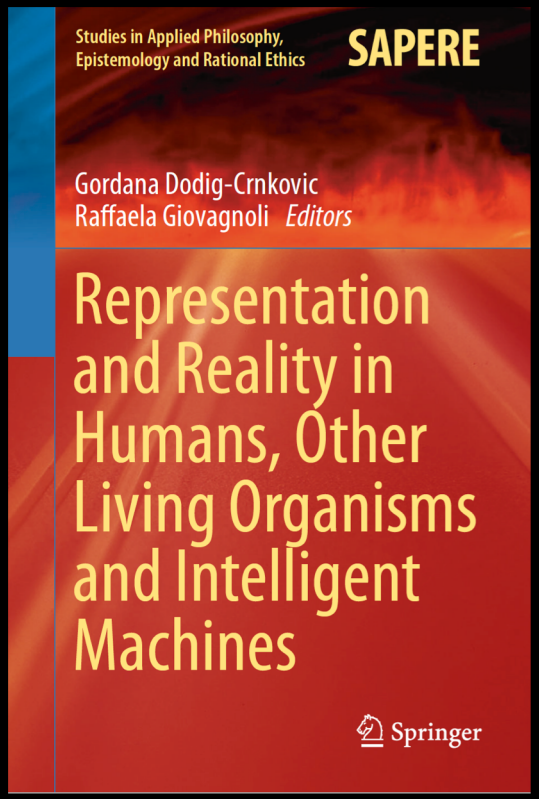
Nature, Information & Computation



Forthcoming: *PHILOSOPHY AND METHODOLOGY OF INFORMATION*
Dodig-Crnkovic G. and Burgin M.
World Scientific Series in Information Studies, May 2019

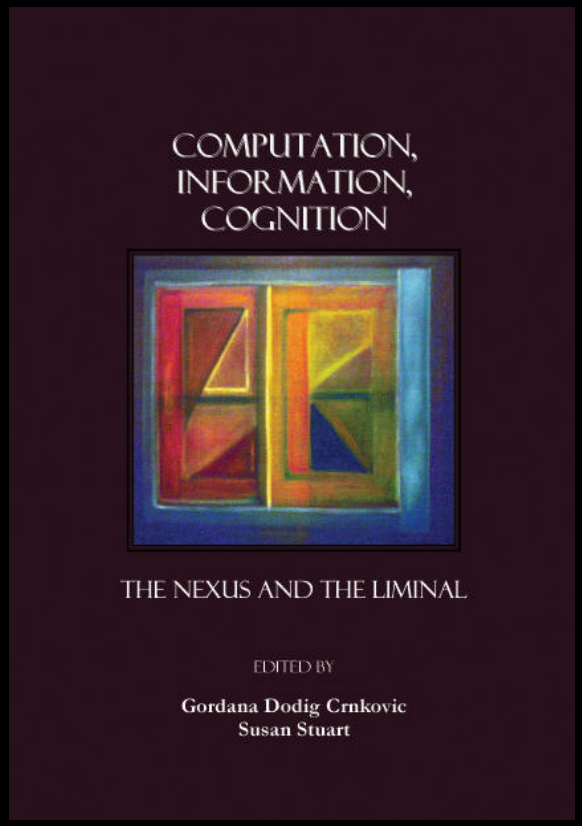


Forthcoming: I*NFORMATION IN THE WORLD*
Burgin M. and Dodig-Crnkovic M.
World Scientific Series in Information Studies, September 2019

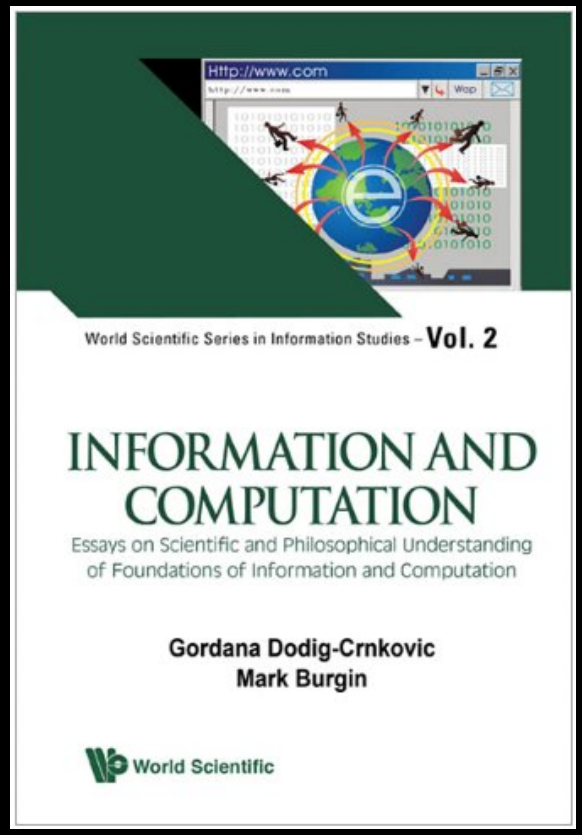


REPRESENTATION AND REALITY
Gordana Dodig Crnkovic and Raffaela Giovagnoli, Eds.
Springer, 2017

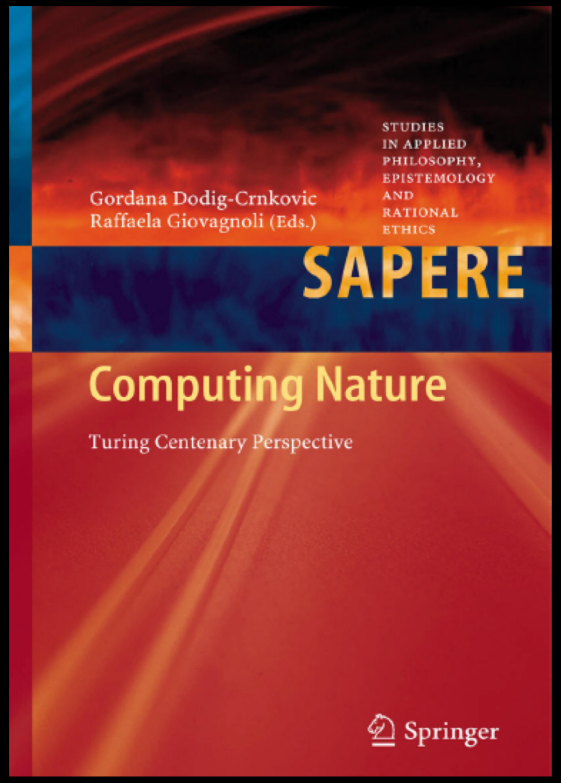
Computation, Information, Cognition



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

"TO DO" list – Open problems to be addressed

- "Building a Network of Interdisciplinary Institutions for Artificial Intelligence" (and Cognition) CÉDRIC VILLANI
- Understanding of fundamental properties of information as a structure, fabric of reality for an agent, and connecting it to other approaches to information
- Understanding of computation as a process (a hierarchical network of processes) over informational structures, and connect it with variety of existing models of computation such as Turing model and actor models of concurrent distributed computation and resource-aware computing
- Embracing evolutionary (morphogenetic) view of cognition and intelligence that come in degrees
- Learning from nature how to construct much better computational systems than those we have today – resilient, adaptive, "probably approximately correct") (Leslie Valiant)

"TO DO" list – Open problems to be addressed

- Learning to tackle complexity, emergence, multicriteria, multiplicity (plurality)
- Learning to address change, "fluid concepts and creative analogies" (Douglas Hofstadter) - dynamics
- This calls for different kinds of modeling, such as executable biology, new kinds of dynamic logic
- Interdisciplinary, Cross-disciplinary and Trans-disciplinary research is necessary
- At the bottom deep understanding of the ethics and values of this vision for science of intelligence.

References

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- Dodig-Crnkovic G., The Info-computational Nature of Morphological Computing, in Müller V. C. (ed.), Theory and Philosophy of Artificial Intelligence (SAPERE; Berlin: Springer), 2012. (Selected contributions from PT-AI conference @ACT) pp. 59-68.

- 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.

- CÉDRIC VILLANI (2018) For A Meaningful Artificial Intelligence

ADDITIONAL MATERIALS

Good Old-Fashioned Artificial Intelligence

GOFAI* ("Good Old-Fashioned Artificial Intelligence") i.e. symbolic AI built on human as model of intelligence (humans as symbolic species).

- Focus on language, both human and programming languages
- No interest in embodiment, embeddedness and enaction
- Denial of intelligence in any other living beings but humans
- Especially in the field of modern robotics awareness of intelligence coming in degrees & being dependent on the body of an agent
- AI is constructed as separate from the living world, even though human species is a result of evolution and cannot be understand without understanding its evolution

Evolution and Development of Cognition

Evolution and development can be understood as the processes of self-organisation of living agent's in the world and their reality construction.

Cognition in this framework is capacity possessed in different forms and degrees of complexity by every living organism and the same framework can be applied to artificial agents.

All physico-chemical processes in a cognizing agent depend on its morphology (form, structure and material).

Morphological computing is defined on a structure of nodes (agents) that exchange (communicate) information.

Computation as information (data) processing

Computation is generally defined as information (data) processing.

(See Burgin, M., Super-Recursive Algorithms, Springer Monographs in Computer Science, 2005)

The definition of computation is widely debated, and an entire issue of the journal **Minds and Machines** (1994, 4, 4) was devoted to the question **"What is Computation?"** Even: Theoretical Computer Science 317 (2004)

Burgin, M. and Dodig-Crnkovic, G., A Taxonomy of Computation and Information Architecture. ECSA 2015 ASDS Workshop. In Proceedings of the 2015 European Conference on Software Architecture Workshops (ECSAW '15). ACM, New York, NY, USA. DOI=10.1145/2797433.2797440

Cognition as restructuring of an agent through interaction with the environment

As a result of evolution, increasingly complex living organisms arise that are able to survive and adapt to their environment. It means they are able to register inputs (data) from the environment, to structure those into information, and in more developed organisms into knowledge.

The evolutionary advantage of using structured, component-based approaches is improving response-time and efficiency of cognitive processes of an organism.

Intelligent Information Processing:
Blurring the boundary between perception and memory

The constant stream of data from our sensory inputs gets checked against memorized data and corrected for missing parts based on memorized data. For the interpretation of input data memory is used. In that way perception and memory are connected.

http://www.scientificamerican.com/article.cfm?id=perception-and-memory

http://www.sciencedaily.com