May 13, YCCSA Summer Seminar Series – University of York – online

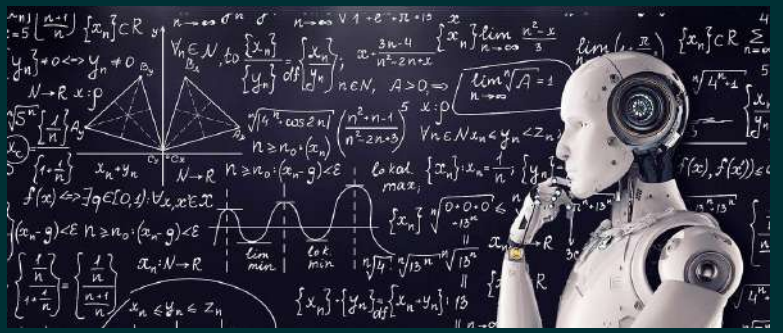
Natural Morphological Computation as Foundation of Learning to Learn in Humans, Other Living Organisms, and Intelligent Machines

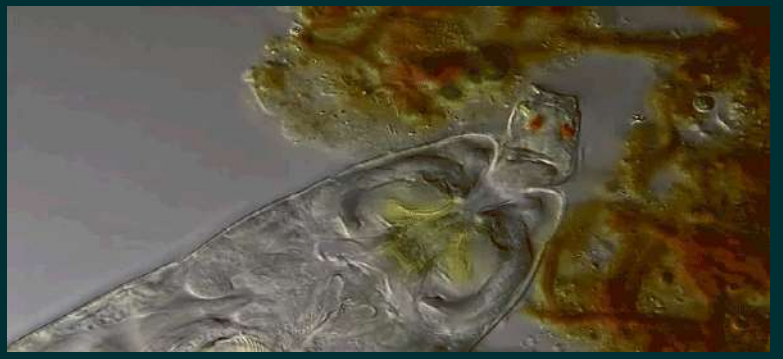
Gordana Dodig Crnkovic

Professor of Computer Science
Chalmers Technical University | University of Gothenburg
& Mälardalen University, Sweden

http://gordana.se/

https://www.mdh.se/en/malardalen-university/staff?id=gdc01
https://www.chalmers.se/en/staff/Pages/gordana-dodig-crnkovic.aspx
http://www.es.mdh.se/staff/37-Gordana_Dodig_Crnkovic





https://img.huffingtonpost.com/asset/5baec821240000310096862c.gif?ops=scalefit_600_noupscale

Speaking about what cannot be said (yet)

"Whereof one cannot speak, thereof one must be silent."
(Basic proposition 7)

Wittgenstein, Ludwig. Tractatus Logico-Philosophicus (TLP), 1922, C. K. Ogden (trans.), London: Routledge & Kegan Paul. Originally published as "Logisch-Philosophische Abhandlung", in Annalen der Naturphilosophische, XIV (3/4), 1921.

We should insist instead that philosophy consists in the effort to say what cannot be said, in particular whatever cannot be said directly, in a single sentence or a few sentences, but only in a context.

In this sense it has to be said that the concept of philosophy is itself the contradictory effort to say, through mediation and contextualization, what cannot be said *hic et nunc*; to that extent philosophy contains an inner contradiction, that is, it is inwardly dialectical in itself.

Adorno, Theodor W. *Lectures on Negative Dialectics*, ed. by Rolf Tiedemann, trans. Rodney Livingstone (Cambridge, UK; Malden, MA: Polity Press, 2008), Lecture 7: 'Attempted Breakouts' (30 November 1965), p. 74.

Speaking about what cannot be said, mapping the territory

"I invite readers not on a visit to an archaeological museum, but rather on an adventure in science in making"

Ilya Prigogine. The End of Certainty: Time, Chaos and New Laws of Nature, 1997

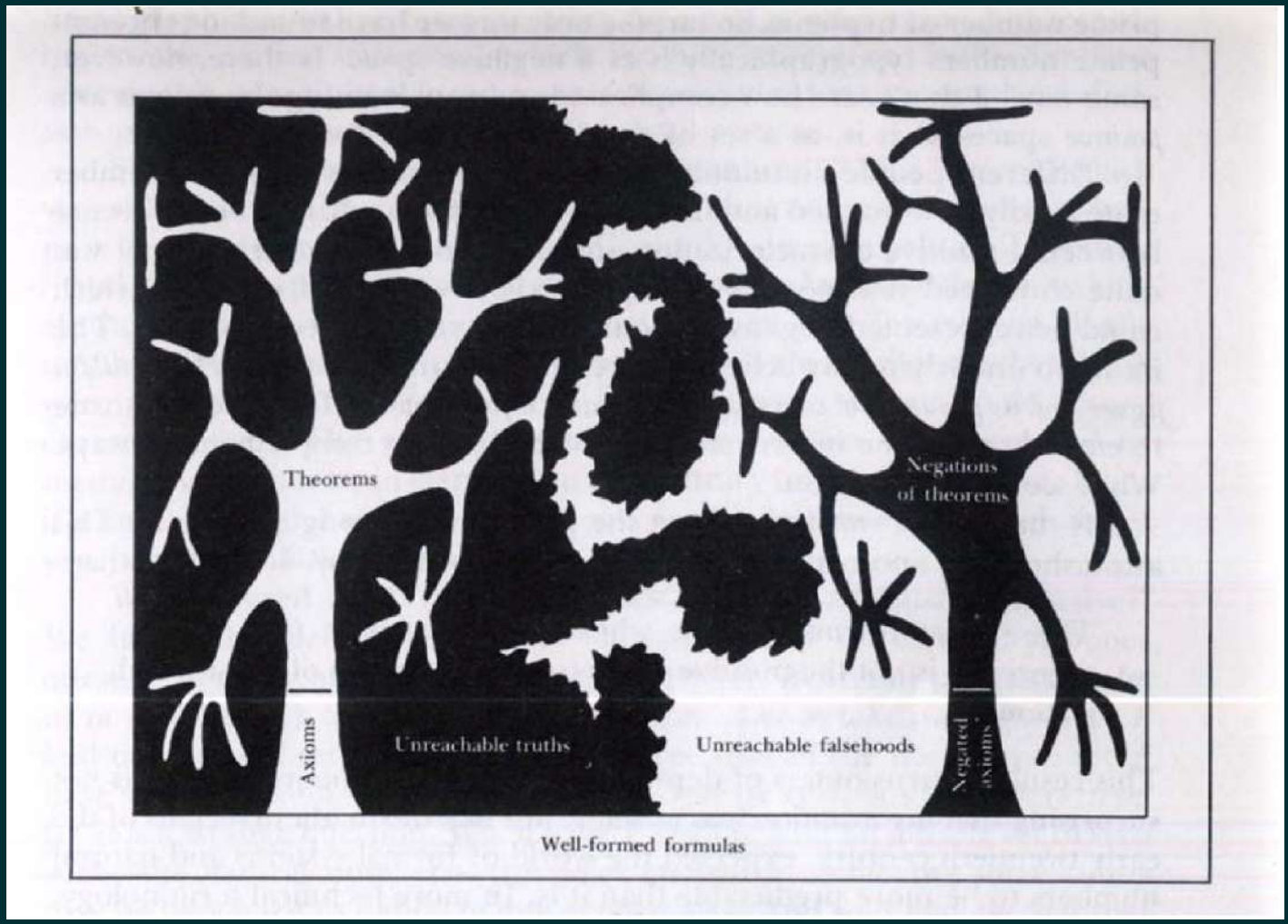
"Biology and computer science—life and computation—are related. I am confident that at their interface great discoveries await those who seek them."

Leonard Adleman. Computing with DNA. Scientific American, Aug. 1998

"In these times brimming with excitement, our task is nothing less than to discover a new, broader, notion of computation, and to understand the world around us in terms of information processing."

Lila Kari, Grzegorz Rozenberg, The Many Facets of Natural Computing. Communications of the ACM, October, Vol. 51 No. 10, Pages 72-83. 2008

Gödel: Thruths Impossible to Express within Formal System



Hofstadter, Douglas R., 1945. Gödel, Escher, Bach: An Eternal Golden Braid. New York. Basic Books, 1999.

Recognizing Themes from Gödel, Esher, Bach

- Meaning and Form in Mathematics (Computing!)
- Consistency, Completeness and Geometry
- Recursive Structures and Processes
- Location of Meaning
- Levels of Description
- Minds and Thougts & Brain and Thoughts
- Formally Undecidable propositions & Jumping Out of the System
- Artificial Intelligence
- Strange Loops or Tangled Hierarchies

Recognizing Themes from Gödel, Esher, Bach & Emergence of New Themes

- Gödel, Esher, Bach is fundamentally about STRUCTURES
- TIME aspect is coming as a big theme both in computing and in cognitive science
- RESOURCE-awareness is coming big, where resources are limited and often scarce – TIME, SPACE, ENERGY
- DISTRIBUTED INFORMATION PROCESSING, PARALLELISM
- LEVELS OF ORGANIZATION, NOT ONLY DESCRIPTION
- MATERIALS with not only gemetry but also physical properties (electrical, chemical) take prominent role in domain-specific natural/unconventional computing

Learning from Nature and Testing Models on Practical Solutions – a Two-way Process

Learning from nature is a two-way process as discussed in literature*. Computing is learning from neuroscience, while neuroscience is quickly adopting new computational/information processing models.

The question is, what can the inspiration from computational nature** at this stage of the development contribute to further development of deep learning and how much models and experiments in machine learning can motivate, justify and lead research in neuroscience and cognitive science and to practical applications of artificial intelligence.

* G. Rozenberg and L. Kari, "The many facets of natural computing," Commun. ACM, vol. 51, pp. 72–83, 2008.
**G. Rozenberg, T. Bäck, and J. N. Kok, Eds., Handbook of Natural Computing. Berlin Heidelberg: Springer, 2012.

Beyond Conventional Computing/Calculating:

Natural Computing/Physical Computing/Morphological Computing/Unconventional Computing

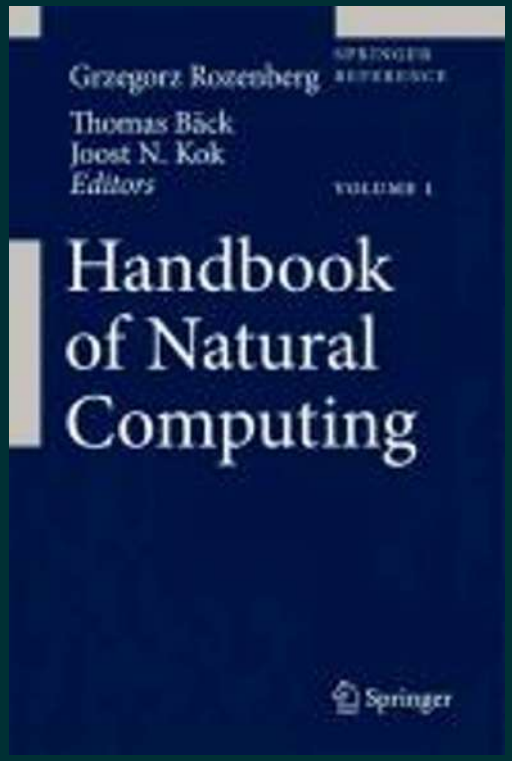
The progress of computing depends on the development of hardware and software. This includes algorithms, programming languages, compilers and interpreters, operating systems, virtual machines, etc. Yet Computability Theory is still based on the Turing Machine Model of computation.

One of the ideals of computing ever since the time of Turing is *intelligent computing*, which would imply machine capable of not only executing predefined mechanical procedure, but even intelligent problem solving.

Thus the goal is a computer able to simulate behaviour of human *mathematician*, capable of intelligent insight.

A development of cognitive computing aims towards human-level abilities to process/organize/understand information.

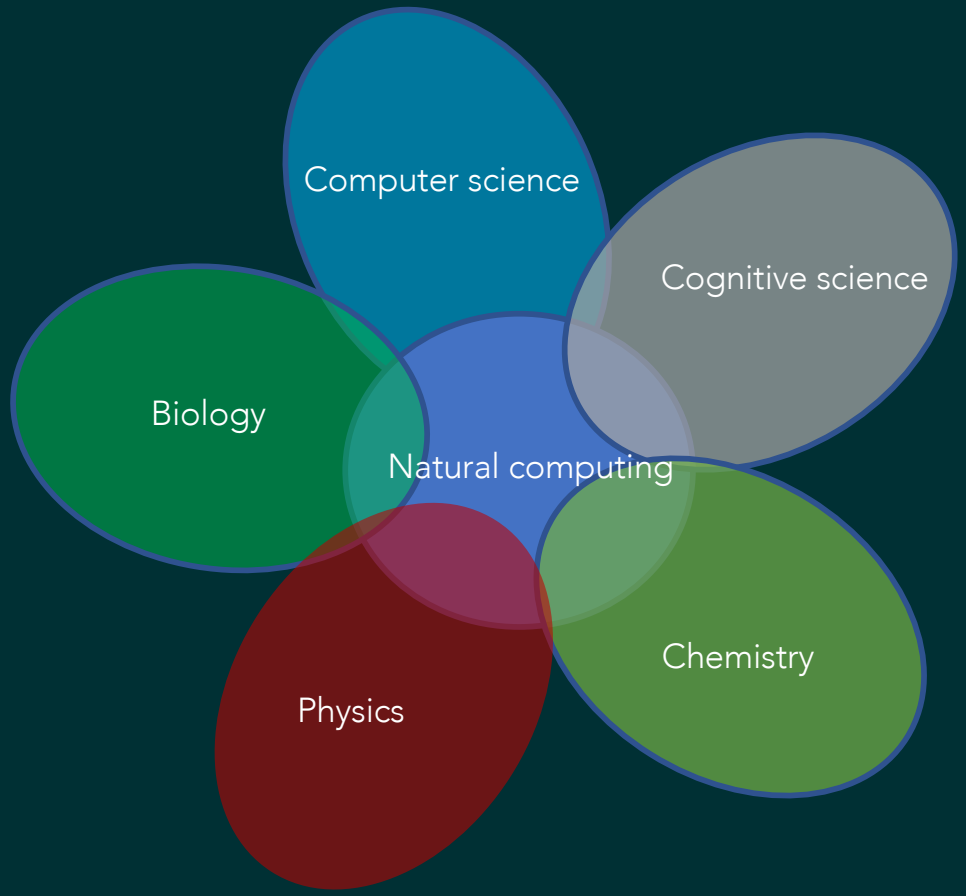
Beyond Conventional Computing: Natural Computing



Natural computing is "the field of research that investigates both human-designed computing inspired by nature and computing taking place in nature." Handbook of Natural Computing

It includes, among others, areas of cellular automata and neural computation, evolutionary computation, molecular computation, quantum computation, nature-inspired algorithms and alternative models of computation.

Transdisciplinary-Interdisciplinary-Multidisciplinary Character of Natural Computing



"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.´"

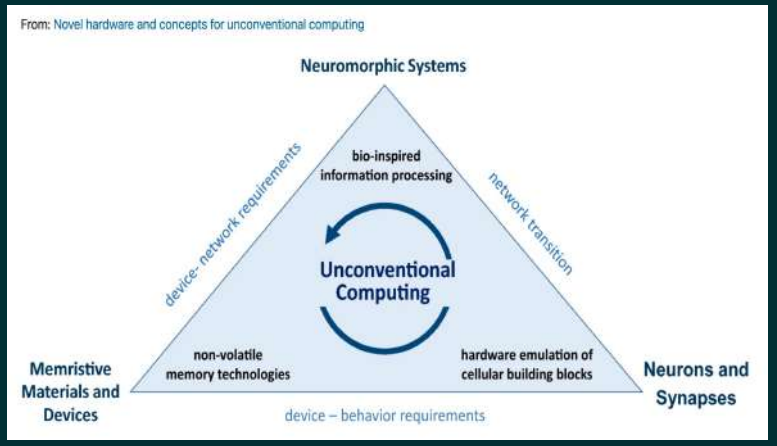
Dharmendra S. Modha, Rajagopal Ananthanarayanan, Steven K. Esser, Anthony Ndirango, Anthony J. Sherbondy, Raghavendra Singh Cognitive Computing (2011) Communications of the ACM, August, Vol. 54 No. 8, pp. 62 -71 http://cacm.acm.org/magazines/2011/8/114944-cognitive-computing/fulltext

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

Unconventional Computing

"Unconventional computing is a cross-breed of computer science, physics, mathematics, chemistry, electronic engineering, biology, materials science and nanotechnology. The aims are to uncover and exploit principles and mechanisms of information processing in, and functional properties of, physical, chemical and living systems, with the goal to develop efficient algorithms, design optimal architectures and manufacture working prototypes of future and emergent computing devices."

Unconventional Computing, Andrew Adamatzky
A Volume in the Encyclopedia ofComplexity and Systems Science,Second Edition, 2018.



Novel hardware and concepts for unconventional computing.
Martin Ziegler. Scientific RepoRtSl (2020) 10:11843
https://www.nature.com/articles/s41598-020-68834-1.pdf

"Unconventional computing is about breaking boundaries in thinking, acting and computing. Typical topics of this non-typical field include, but are not limited to physics of computation, non-classical logics, new complexity measures, novel hardware, mechanical, chemical and quantum computing. Unconventional computing encourages a new style of thinking while practical applications are obtained from uncovering and exploiting principles and mechanisms of information processing in and functional properties of, physical, chemical and living systems."

Andrew Adamatzky, Selim Akl, Mark Burgin, Cristian S. Calude, José Félix Costa, Mohammad Mahdi Dehshibi, Yukio-Pegio Gunji, Zoran Konkoli, Bruce MacLennan, Bruno Marchal, Maurice Margenstern, Genaro J. Martínez, Richard Mayne, Kenichi Morita, Andrew Schumann, Yaroslav D. Sergeyev, Georgios Ch. Sirakoulis, Susan Stepney, Karl Svozil, Hector Zenil,

East-West paths to unconventional computing, Progress in Biophysics and Molecular Biology, Volume 131, 2017, pp. 469-493,

https://en.wikipedia.org/wiki/Unconventional_computing

Knowledge and Cognition (Disembodied)

In the beginning, 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 (disembodied) cognition is directly connected with old computationalism – symbol manipulation view of mind.

GOFAI and Expectation of “Substrate Independence”

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 machines.

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).

Cognition and Intelligence

Studies in simpler living organizations, from the simplest ones like viruses (which are limit case of life and act like molecular machines), to unicellular organisms like bacteria and up to humans, show clear connection between the physical embodiment and cognition or intelligence.

In new computational approaches to cognition and intelligence body is integral part of cognitive 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.

Overcoming “The Bias Of Mathematicians” (Cooper)

Embodiment is invalidating the `machine as data' and universality paradigm.

The organic linking of mechanics and emergent outcomes provides a clearer model of supervenience of mentality on brain functionality, and a connection between different levels of effectivity.

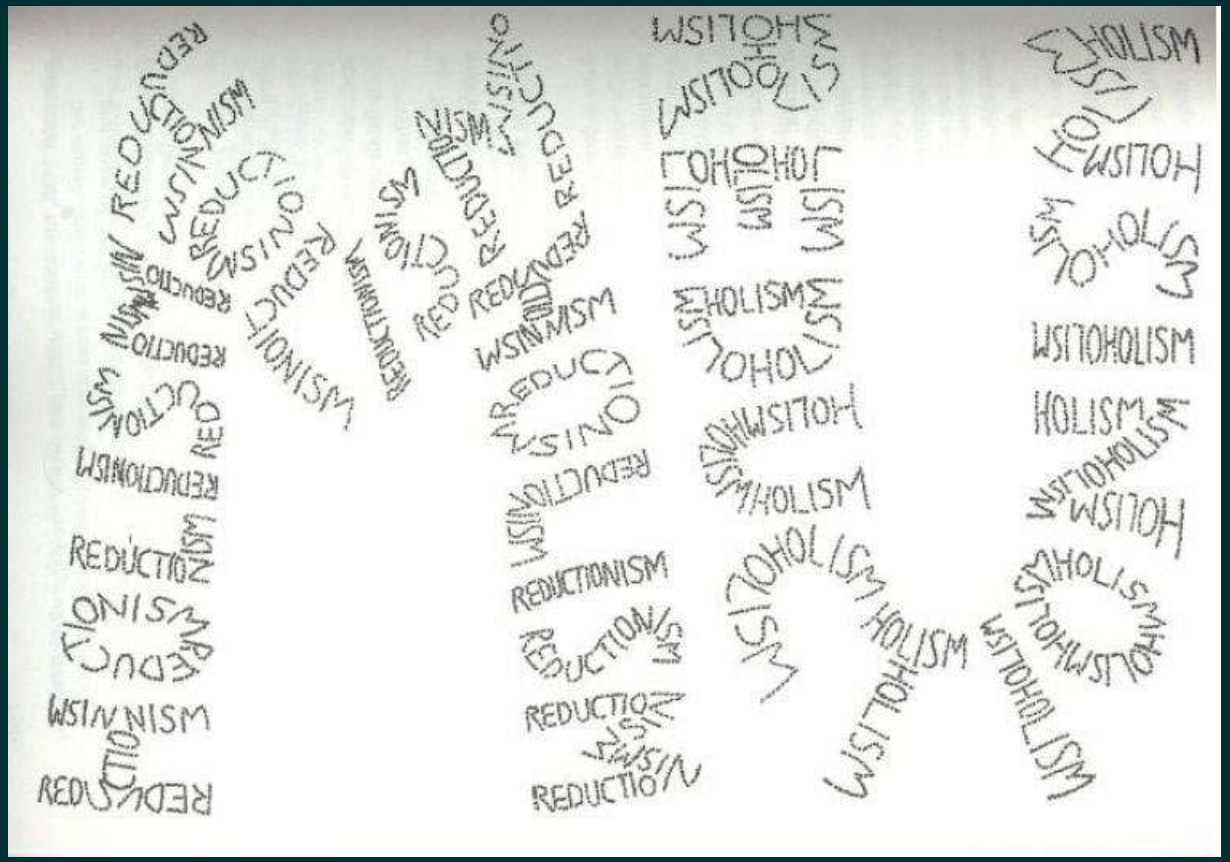
A reaffirmation of experiment and evolving hardware, for both AI and extended computing generally.

The validating of a route to creation of new information through interaction and emergence.

S. B. Cooper, “Turing’s Titanic Machine?,” Communications of the ACM, vol. 55, no. 3, pp. 74–83, 2012

Symbolic vs. Sub-symbolic Computation

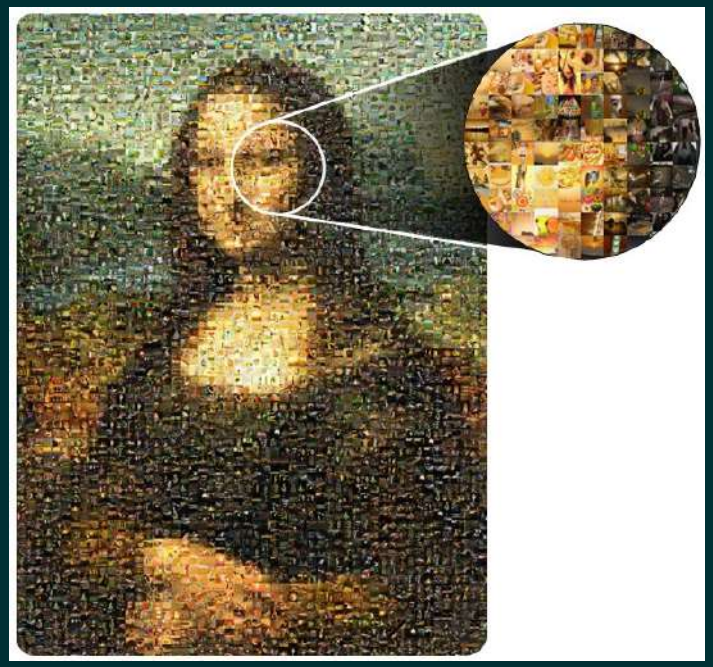
Embodied cognition was sometimes considered as an argument against computational theory of cognition. However, not computation models are abstract and substrate-independent. Natural/Unconventional computation is explicitly physical.



Hofstadter in the dialogue "Prelude…Ant fugue" in "Gödel, Escher, Bach".

Hofstadter, Douglas R. Gödel, Escher, Bach: An Eternal Golden Braid. Basic Books, 1999.

Turing Machines and a Modelling of Complex Systems

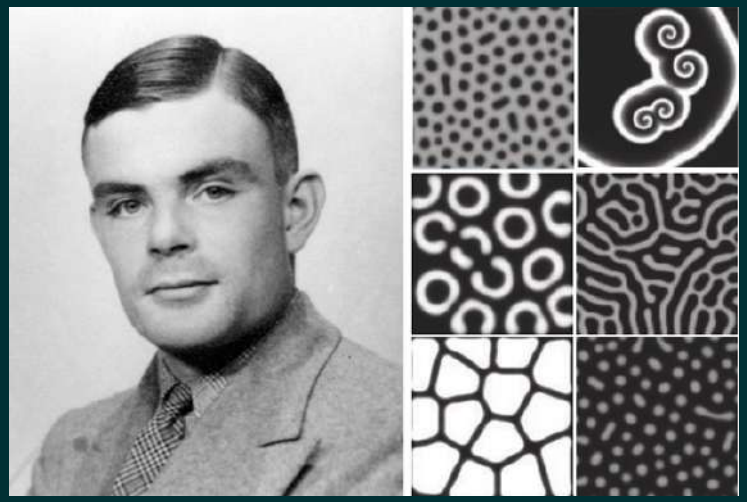


After: Leonardo, Mona Lisa

Arcimboldo: Librarian

Simplified, one can say: anything can be used to model anything else – for some cognizing agent.
The question is only how adequate the model is for a given agent in a given context.

Turing Beyond Turing Machine Model



2012 we celebrated 100th Turing birthday

Alan Turing was:

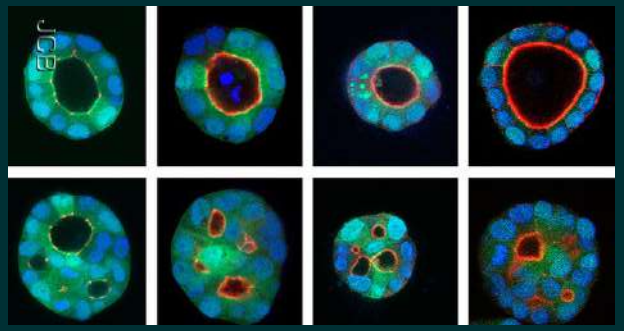
Mathematician

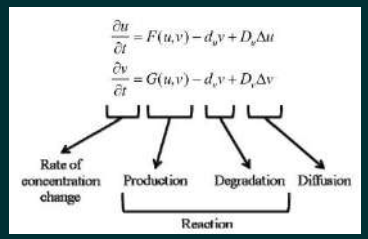
Originator of the "Logical Machine" (TM) computability theory

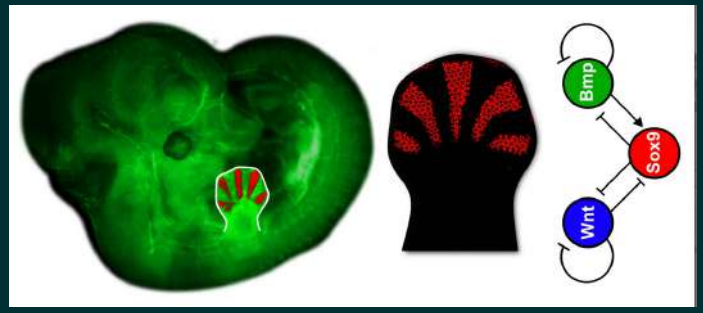
Codebreaker

Natural philosopher

Visionary man before his time







Researchers confirm that a mathematical theory first proposed by Alan Turing in 1952 can explain the formation of fingers
https://www.crg.eu/en/news/crg-researchers-confirm-mathematical-theory-first-proposed-alan-turing-1952-can-explain-formation-fingers

http://www.cs.usfca.edu/www.AlanTuring.net/turing_archive/index.html Jack Copeland and Diane Proudfoot
http://www.turing.org.uk/turing The Alan Turing Home Page, Andrew Hodges

System 1 and System 2 “Thinking” – Knowledge and Learning – Connecting Abstract with Physical Computing

In humans, two basic cognitive systems have been recognized,
System 1 (reflexive, non-conscious, automatic, intuitive information processing, which is fast) and
System 2 (reflective, conscious, reasoning and decision making, which is slow) (Kahneman 2011; Tjøstheim et al. 2020)

As deep learning models are inspired by the human brain information processing, recent advances in understanding of natural cognitive systems can contribute both to better explanatory models and to future developments of constructive engineered cognitive architectures.

Deep learning level corresponds to Kahneman’s fast, intuitive System 1 (Kahneman 2011), and current developments in AI are continuing towards even more ambitious goals of modelling System 2 (symbolic reasoning) (Russin, O’Reilly, and Bengio 2020).

Cognition and Intelligence – Embodied, Embedded, Enacted

Traditionally, in philosophy, psychology and cognitive science **only humans were seen as cognitive and intelligent agents**. Cognition and Intelligence were based on abstract symbol manipulation.

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

Equally important is new understanding of cognitive (sensory-based) and intelligent (problem-solving) processes that regulate the state of each living cell. Cognition is characteristics of all life.

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.

* We are learning about the importance of glia cells for information processing in the brain

Cognition and Intelligence

Inspired by the models of "minimal cognition" computational and robotic cognitive systems are developed with certain degree of cognition and intelligence (in comparison to human). Certain functions of artificial intelligence 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.

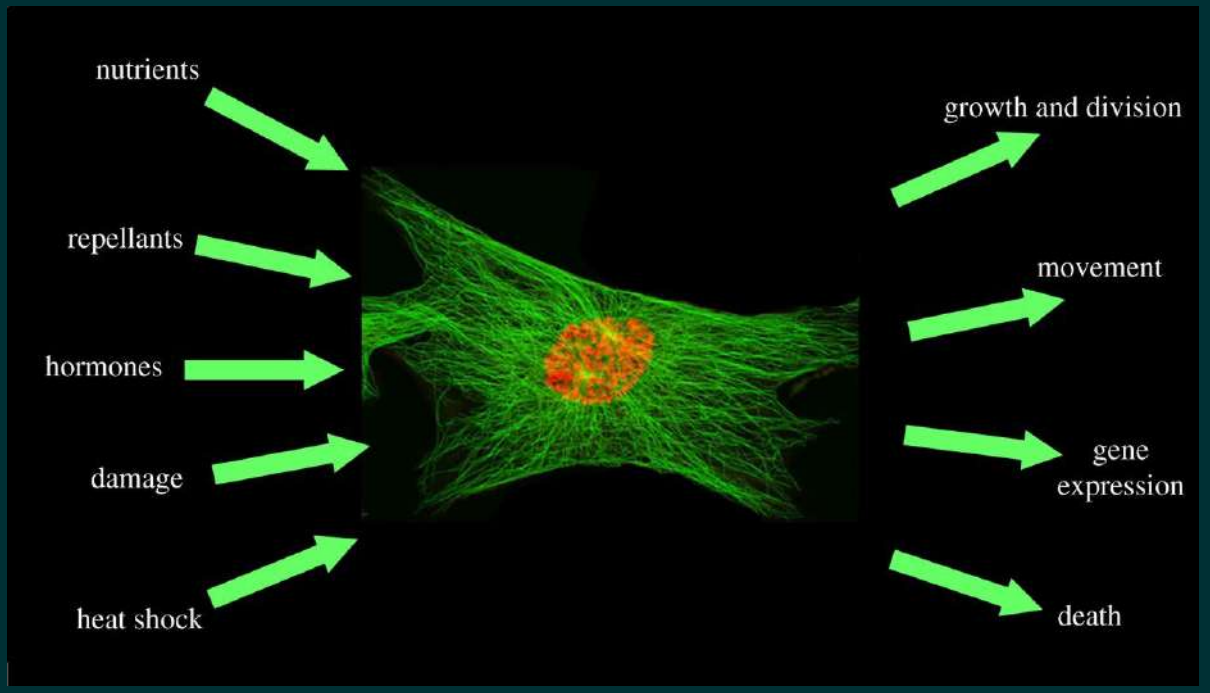
Intelligence is a capacity closely connected with cognition:

Cognition = Process of "continual being in the world" of an agent. It is based on learning/adaptation.
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. Part of it is anticipation.

*Human intelligence is often considered to be a multidimensional capability that includes both classical Problem-solving and Decision-making (logical-mathematical reasoning), Existential (ability to survive), Visual-Spatial, Bodily-kinesthetic, Naturalist, Linguistic, Interpersonal (social), and Intra-personal (inner insight) intelligence. Those can in a broader sense be seen as optimizations of different goal-directed behaviors.

Natural Cognition & Intelligence.
Basic Level of Cells Processing Information



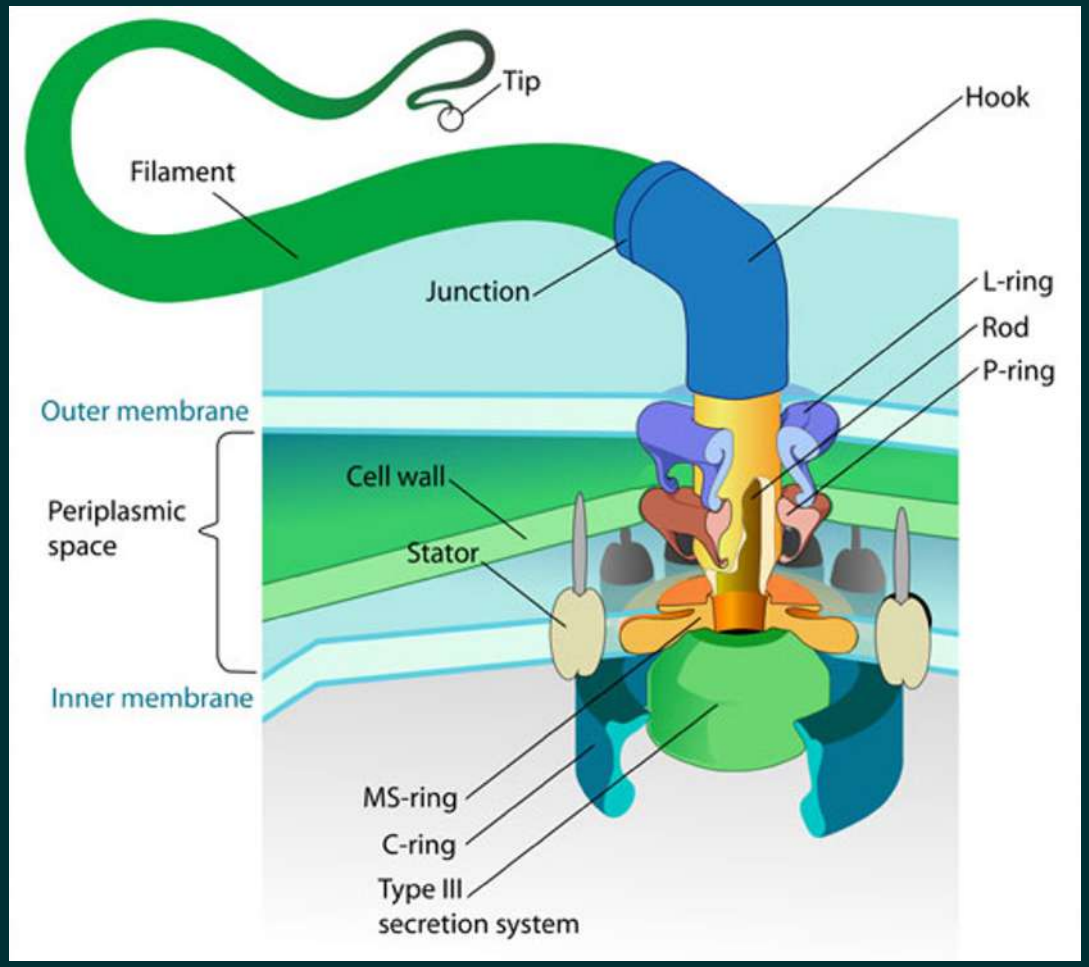
http://rsfs.royalsocietypublishing.org/content/4/3/20130070

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

"even the most primitive living organisms are minimally "cognitive"
J. Stewart (1996). Cognition = Life : Implications for higher-level cognition. Behavioural Processes 35: 311-326.

Some (Very Mechanistic) Details of a Molecular Machinery in Bacteria (Unicellular Organism)



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

Single-celled Lacrymaria olor Hunts Down Another Cell

Lacrymaria olor is a single-celled organism, its name means "tears of a swan". It has a “neck” and a “mouth”.

Lacrymaria olor beats the hair-like cilia around its 'head" and extends its neck up to 8 times its body length.

https://www.youtube.com/watch?v=sq6Y54mxjOg

https://www.cell.com/cms/10.1016/j.cub.2019.09.034/attachment/e5e40ae4-8751-4336-acc5-318c3897f558/mmc2.mp4

https://www.cell.com/current-biology/fulltext/S0960-9822(19)31196-0?_returnURL=https%3A%2F%2Flinkinghub.elsevier.com%2Fretrieve%2Fpii%2FS0960982219311960%3Fshowall%3Dtrue
Coupled Active Systems Encode an Emergent Hunting Behavior in the Unicellular Predator *Lacrymaria olor*

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

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

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.

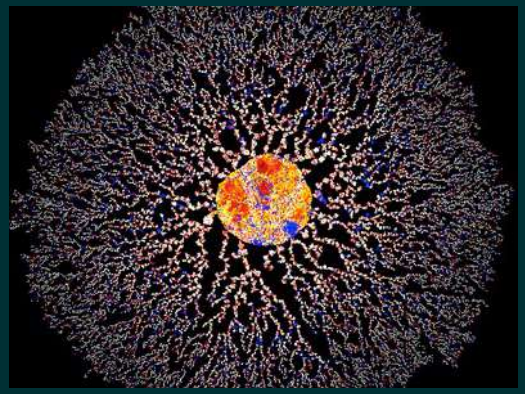
Plant behaviour and communication.
Karban, Richard (2008). " Ecology Letters. 11 (7): 727–739.
doi:10.1111/j.1461-0248.2008.01183.x.
PMID 18400016.

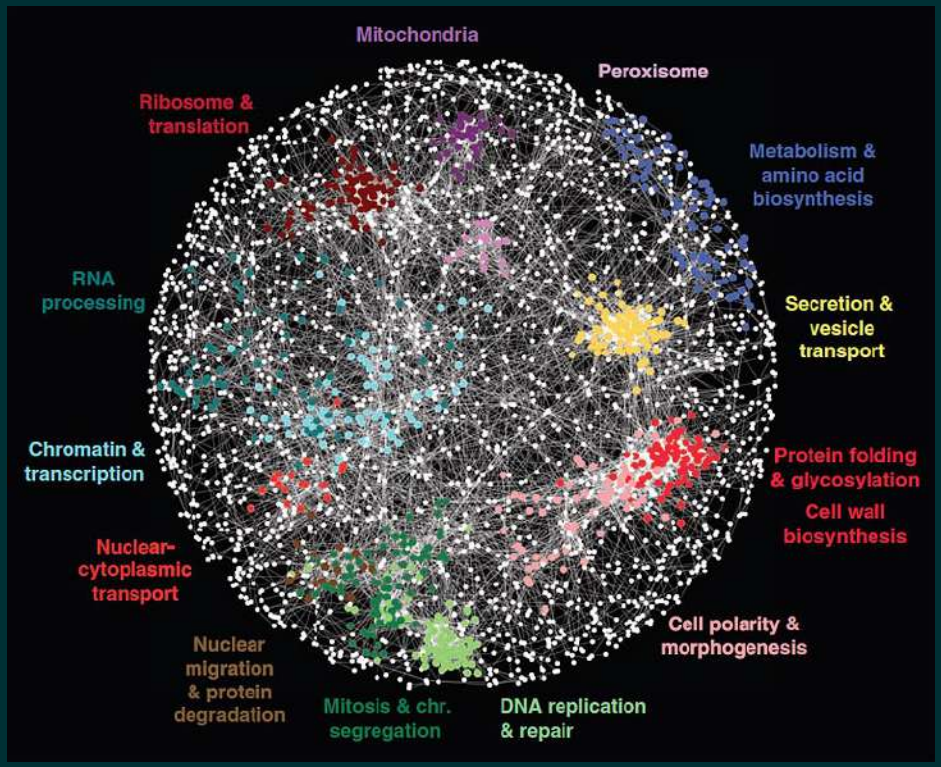
http://www.nature.com/nrm/journal/v2/n4/images/nrm0401_307a_f1.gif

Animal cognition

Rudimentary forms of language

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

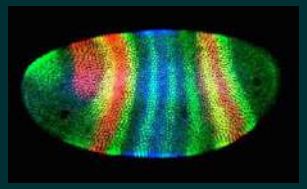




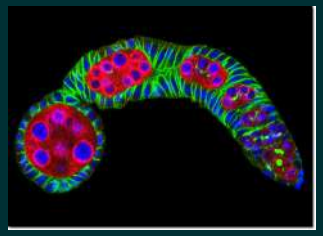
http://phys.org/news/2009-11-conquer-social-network-cells.html

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

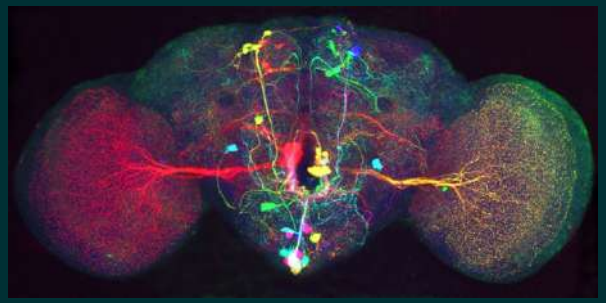
http://www.visualcomplexity.com/vc/images/122_big01.jpg Protein network



Fruit fly embrio



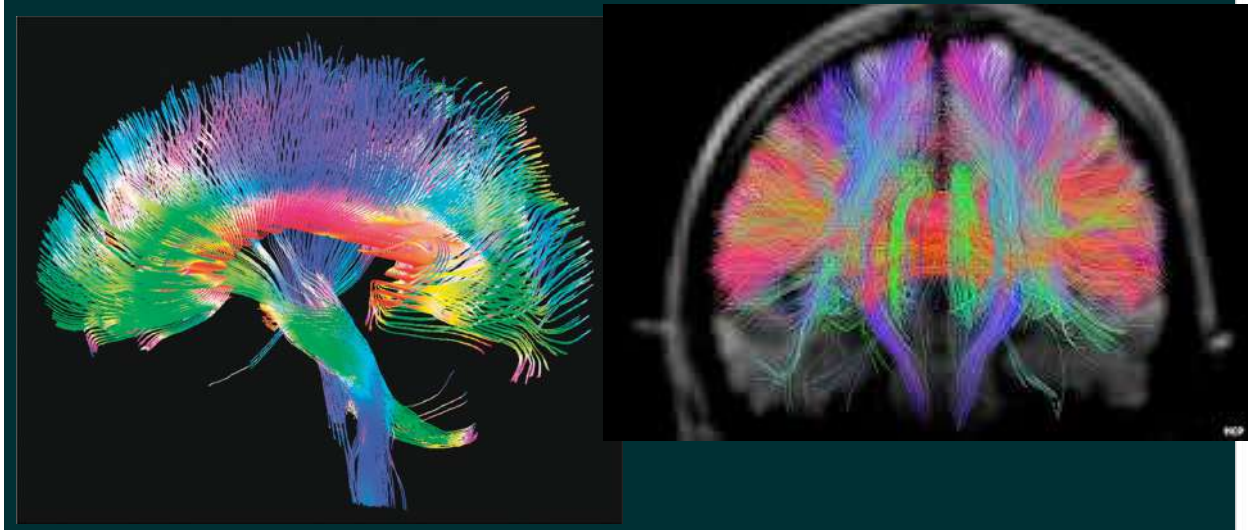
Fruit fly larva



Fruit fly brain neurons

Fruit fly head

Human Cognition
Structures and Processes

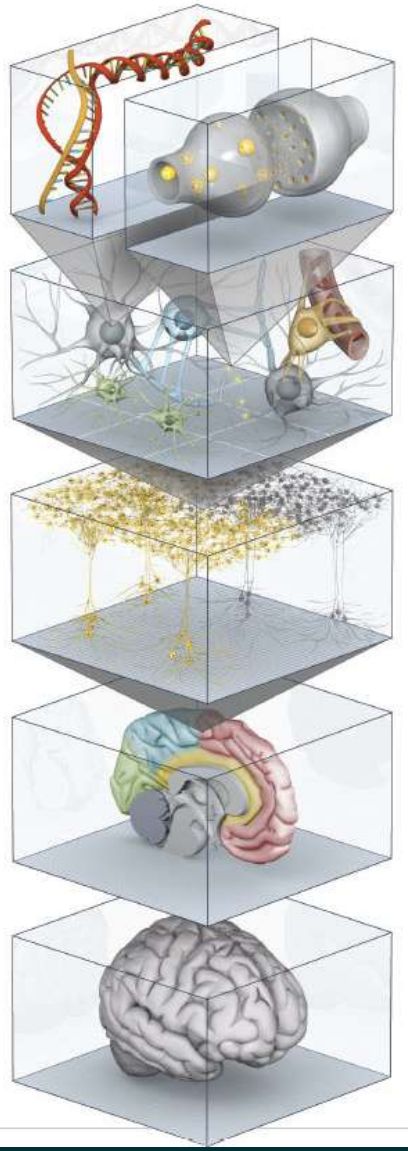


HUMAN CONNECTOME
http://outlook.wustl.edu/2013/jun/human-connectome-project

TEMPORAL ASPECTS ARE LEFT OUT!
https://passioncomm.com/wp-content/uploads/2016/07/Brain-light-up-GIF-Final.gif

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.

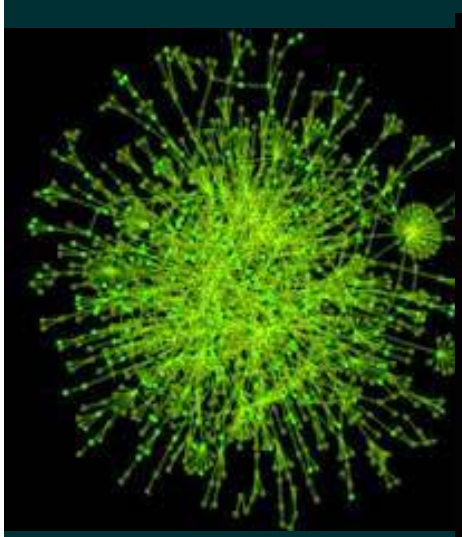
Circuits
A model of the neural connections between different brain areas and among neighboring cells may furnish clues to the origins of complex brain diseases such as autism and schizophrenia.

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.

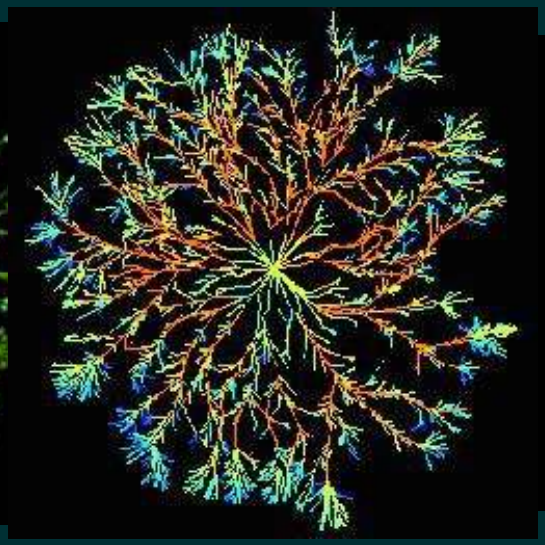
Whole Organ
An in silico brain might substitute for the actual organ. By removing the computer code for a "gene," the virtual system can, for instance, mimic the effects of a mutation, as scientists do today by "knocking out" a gene in mice. The tool would avoid the lengthy breeding process and could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

http://www.nature.com/scientificamerican/journal/v306/n6/pdf scientificamerican0612-50.pdf p. 29
THE HUMAN BRAIN PROJECT

Information Processing in Life Networks

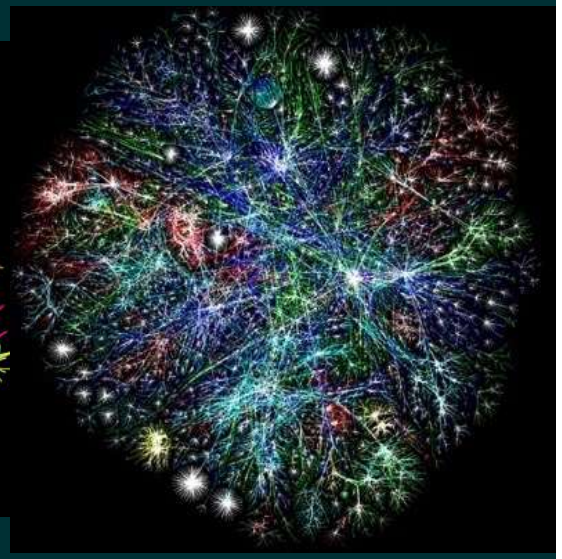


A map of protein–protein interactions in yeast cell



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

Cognition at Different Levels of Organization of Living Organism – From Cells up

Traditional anthropogenic approach to cognition – only humans are cognitive agents.

Biogenic approaches – cognition is ability of all living organisms. (Maturana & Varela, 1980; Maturana, 1970; Stewart, 1996), argued that *cognition and life are identical processes*.

"A cognitive system is a system whose organization defines a domain of interactions in which it can act with relevance to the maintenance of itself, and the process of cognition is the actual (inductive) acting or behaving in this domain. Living systems are cognitive systems and living as a process is a process of cognition. This statement is valid for all organisms, with and without a nervous system." (Maturana, 1970)

New abiotic approaches to cognition assume that it is possible to construct cognitive agents starting from abiotic.

Maturana Humberto, "Biology of Cognition," Defense Technical Information Center, Illinois, 1970.
Maturana, Humberto, and Francisco Varela. 1992. The Tree of Knowledge. Shambala.
Stewart, John. 1996. "Cognition = Life: Implications for Higher-Level Cognition." *Behavioral Processes* 35: 311-326.

Connecting Anthropogenic with Biogenic and Abiotic Cognition

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

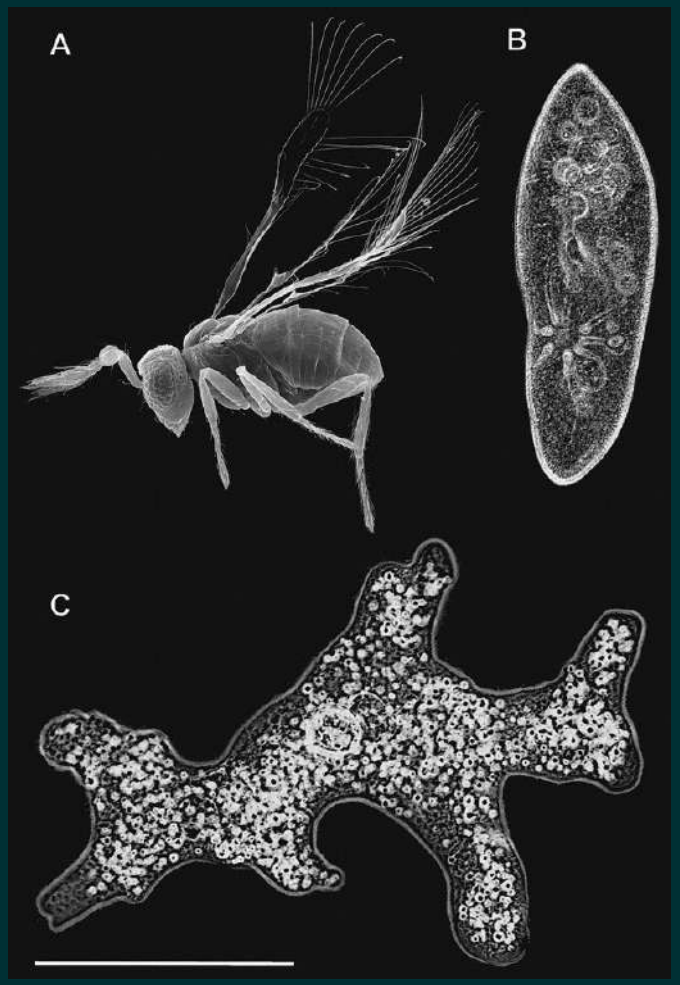
As in the all of biology, nothing makes sense except for in the light of evolution (Dobzhansky, 1973)

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

Wonders of Evolution – The Smallest Insect With Brain, Smaller Than an Amoeba



Size of the smallest wasp and two protozoans in comparison.
(A) Megaphragma mymaripenne.
(B) Paramecium caudatum.
(C) Amoeba proteus.

Scale bar for A–C is 200 μm.

B and C are made up of a single cell,
A the wasp complete with eyes, brain, wings, muscles, guts – is actually smaller.

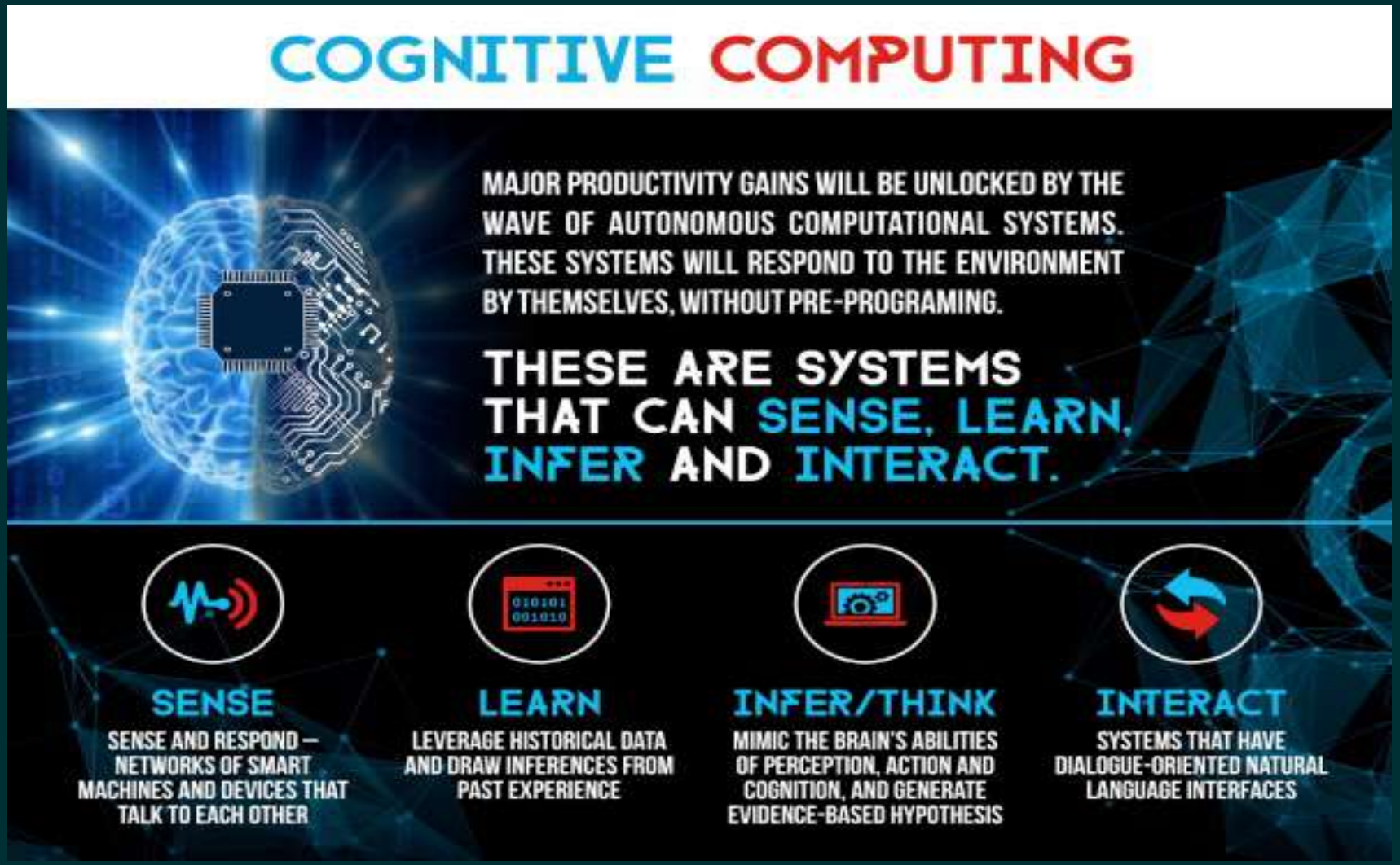
This wasp is the third smallest insect alive.

the smallest nervous systems of any insect, consisting of just 7,400 neurons.
Housefly has 340,000
Honeybee has 850,000.
95% of the wasps' neurons have no nucleus.

http://www.sciencedirect.com/science/article/pii/S1467803911000946 The smallest insects evolve anucleate neurons
Arthropod Structure & Development, Volume 41, Issue 1, January 2012, Pages 29–34

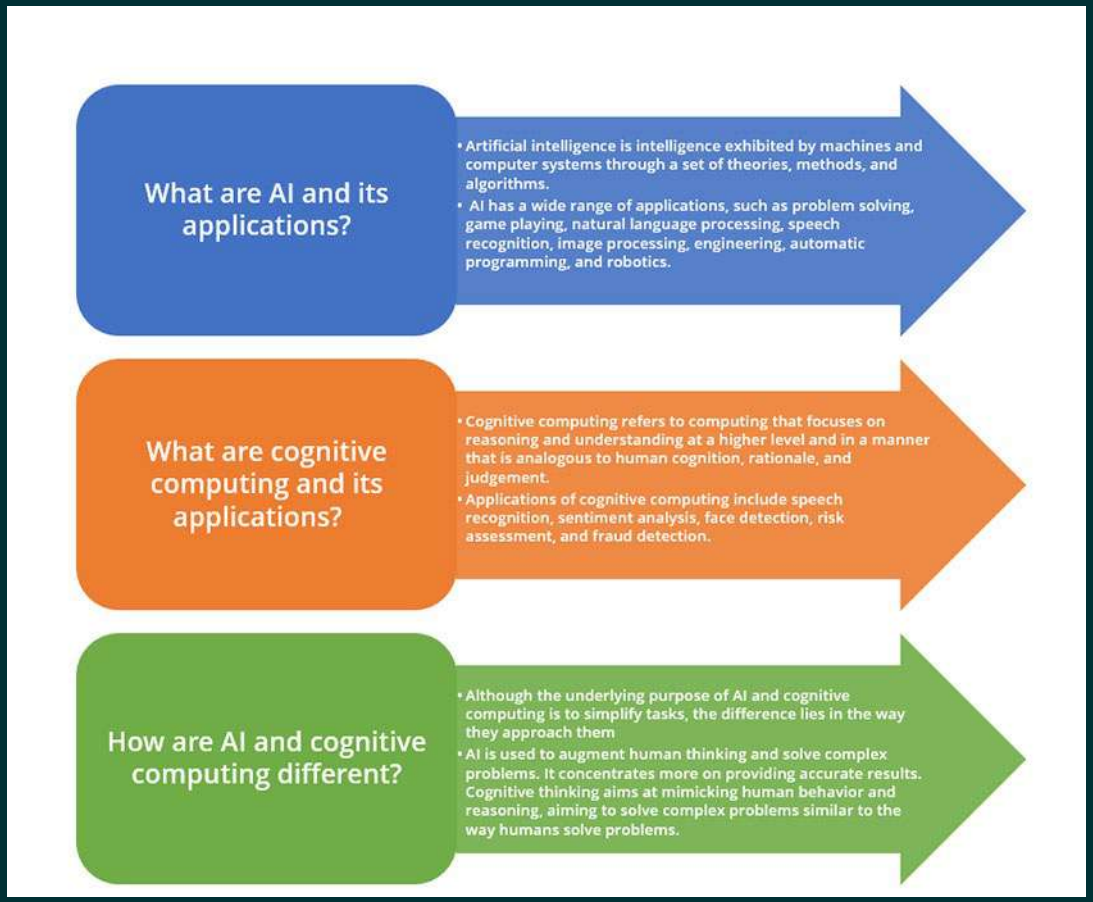
Machine Cognition

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



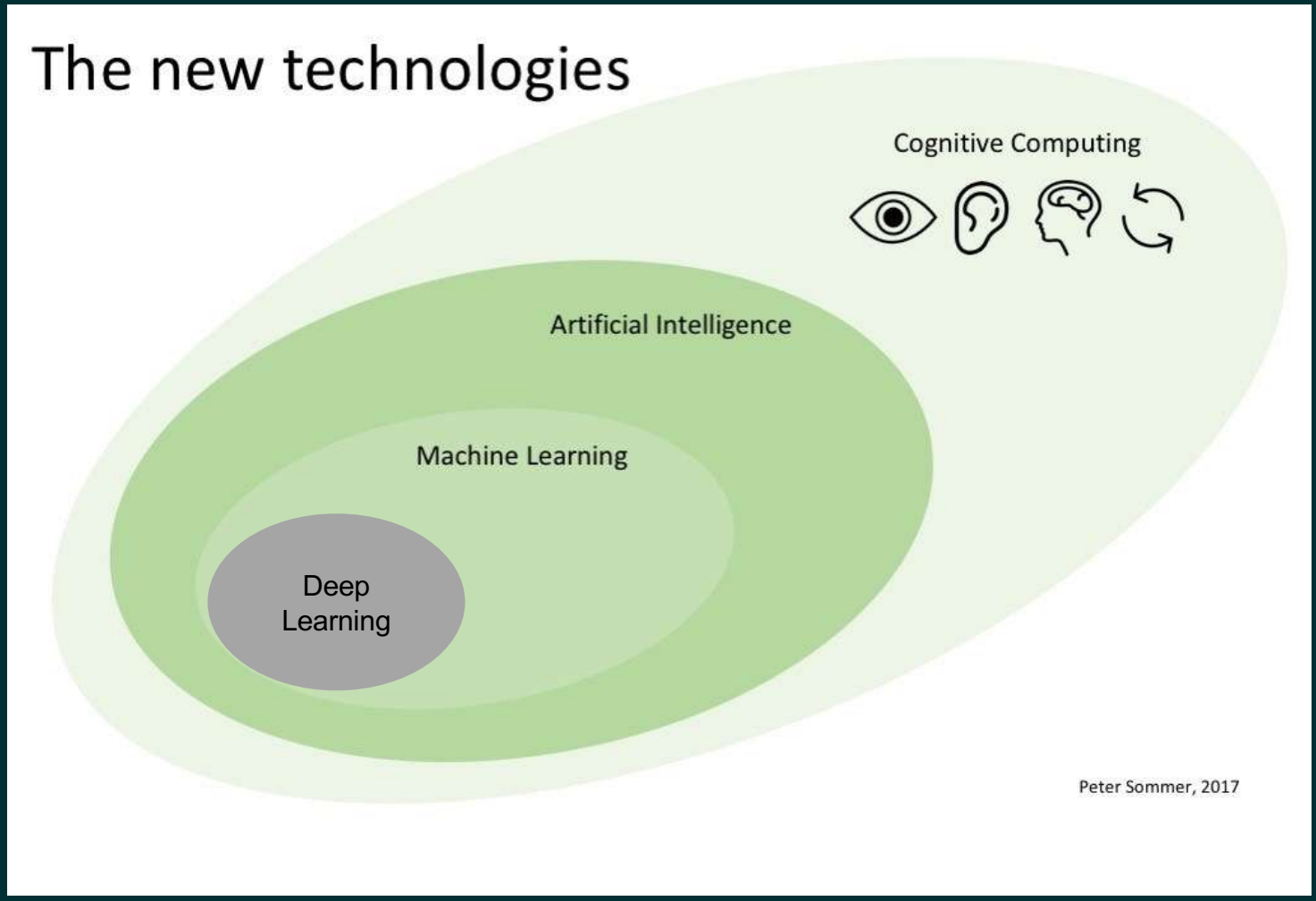
http://www.enterrasolutions.com/media/Wipro-Cognitive-Computing-2.png

Cognitive Computing vs. Artificial Intelligence



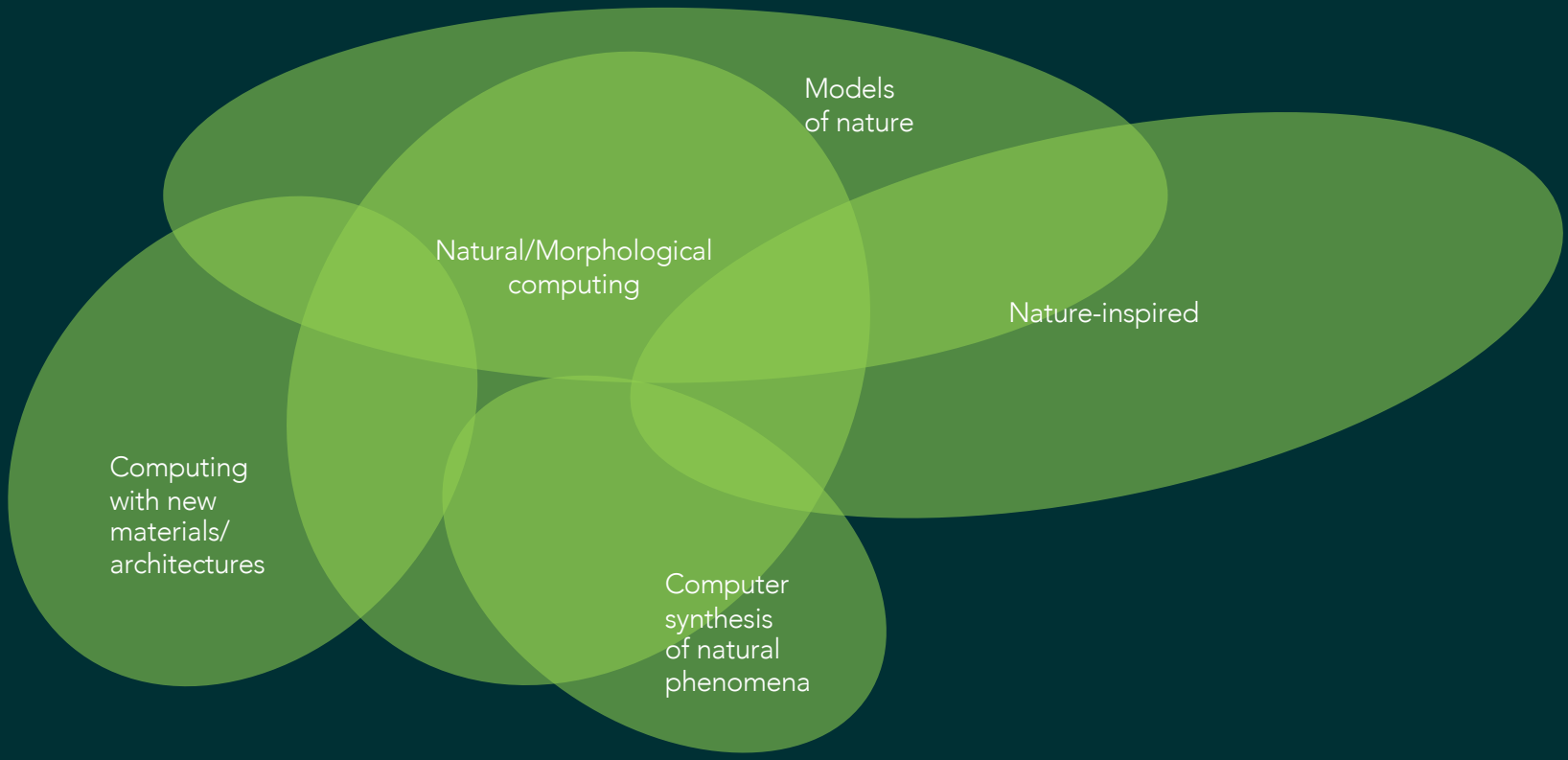
Observe that one assumes human-level intelligence and human-level cognition

Machine Learning, AI & Cognitive Computing



Intelligent Futures: Automation, AI and Cognitive Ecologies

Computing in Cognitive Systems, Connecting Data to Intelligent Agency



Computationalism Is Not What It Used To Be …

… that is the thesis that persons are Turing machines

Turing Machine is a model of computation equivalent to an algorithm, and it may be used for description of different processes in living organisms.

We need computational models for the basic characteristics of life, such as the ability to differentiate and synthesize information, make a choice, adapt, evolve and learn in an unpredictable world. That requires computational mechanisms and models which are not "certainly, exactly correct" and predefined as Turing machine, "probably approximately correct " (PAC)*.

* L. Valiant (2013) Probably Approximately Correct. Basic Books.

Computationalism Is Not What It Used To Be …

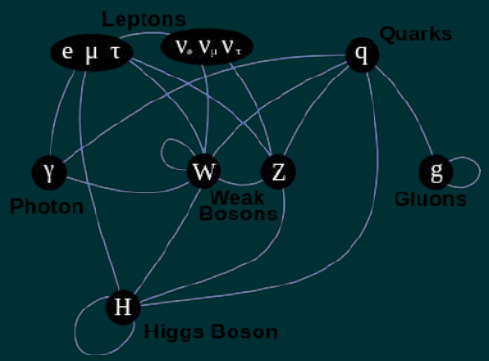
… that is the thesis that persons are Turing machines

Computational approaches that are capable of modelling adaptation, evolution and learning are found in the field of natural computation and computing nature.

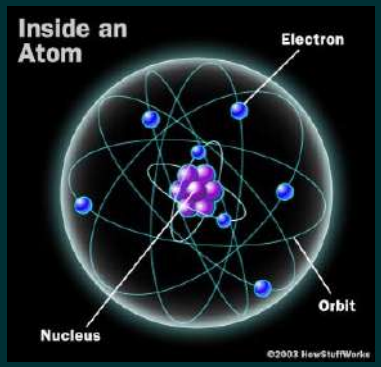
Cognitive computing and cognitive robotics are the attempts to construct abiotic systems exhibiting cognitive characteristics of biotic systems.

It is argued that cognition comes in degrees, thus it is meaningful to talk about cognitive capabilities of artifacts, even though those are not meant to assure continuing existence, which was the evolutionary role of cognition in biotic systems.

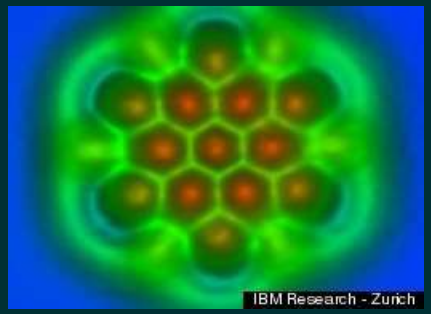
Computing Nature and Nature Inspired Computation



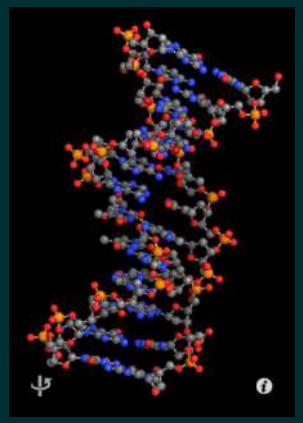
Subatomic particles



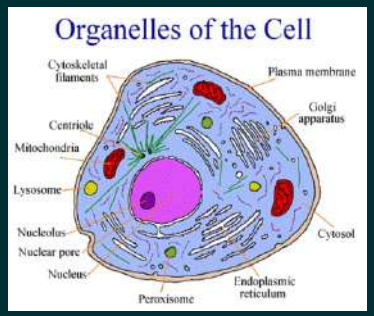
Atoms



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



DNA molecule



Unicellular organism

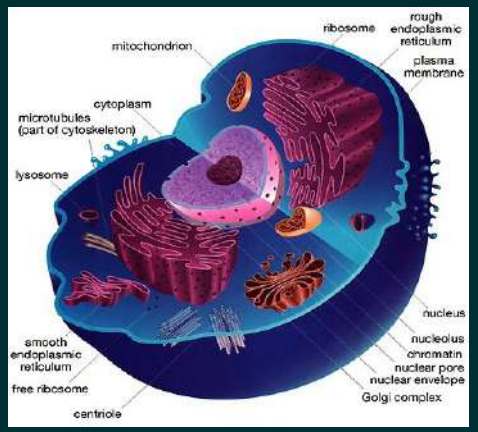
Bacterial colony a multi-cellular "organism"

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



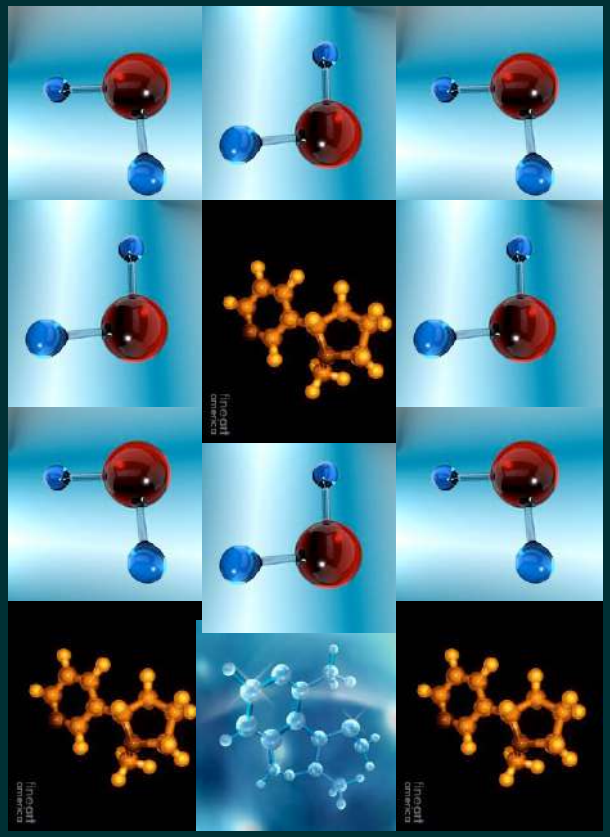
Complex biological systems must be modeled as self-referential, self-organizing "component-systems" (George Kampis) which are self-generating and whose behavior, though computational in a general sense, goes far beyond Turing machine model.

"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

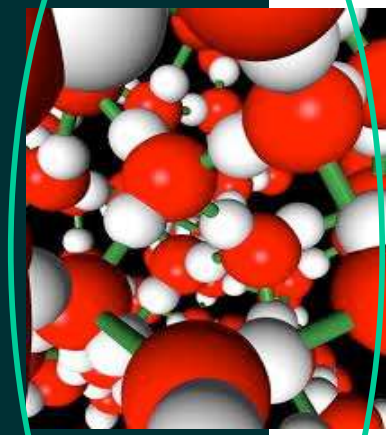
Kampis (1991) Self-Modifying Systems in Biology and Cognitive Science. A New Framework For Dynamics, Information, and Complexity, Pergamon Press

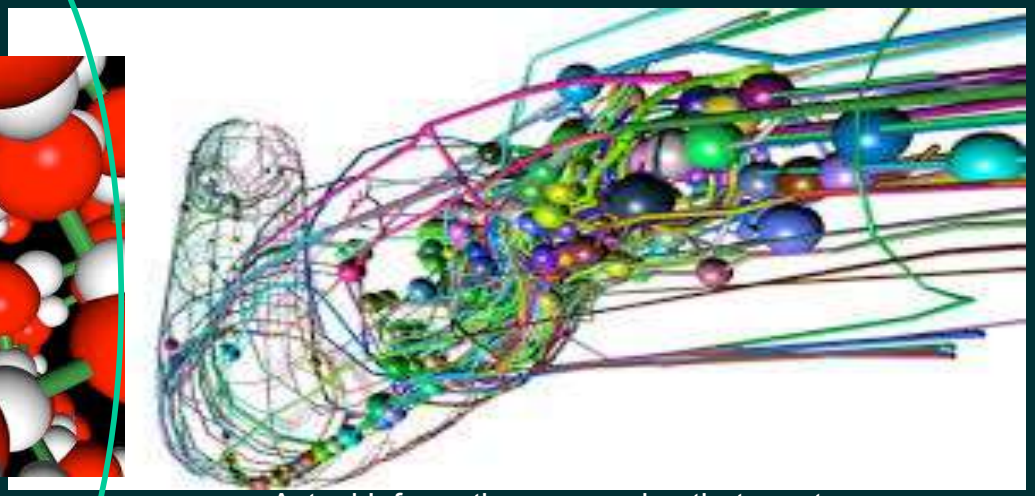
Dodig Crnkovic, G. (2011). Significance of Models of Computation from Turing Model to Natural Computation. *Minds and Machines*, (R. Turner and A. Eden guest eds.) Volume 21, Issue 2, p.301.

World as Information for an Agent



Potential information - outside world for C-elegans





Actual Information processing that creates reality for C-elegans

Cognition as interaction interface for C-elegans between potential information of the outside world and actual information of its inner world

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 i n h i b i t o r y while others are e x c i t a t o r y.

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

Reality for an Agent – An Observer-dependent Reality

Reality for an agent is an informational structure with which agent interacts. As systems able to act on their own behalf and make sense (use) of information, cognitive agents are of special interest with respect to <knowledge>* generation.

This relates to the idea of **participatory universe**, (Wheeler, 1990) "it from bit" as well as to **endophysics** or "physics from within" where an observer is being within the universe, unlike the "god-eye-perspective" from the outside of the universe. (Rössler, 1998)

*<knowledge> for a very simple agent can be the ability to optimize gains and minimize risks. (Popper, 1999) p. 61 ascribes the ability to know to all living: "*Obviously, in the biological and evolutionary sense in which I speak of knowledge, not only animals and men have expectations and therefore (unconscious) knowledge, but also plants; and, indeed, all organisms.*"

Info-computational Framework and Levels of Organization

The question of levels of organization/levels of abstraction for an agent is analyzed within the framework of **info-computational constructivism**, with natural phenomena modeled as **computational processes on informational structures.**

Info-computationalism is a synthesis of **informational structuralism** (nature is an informational structure for an agent) (Floridi, Sayre) and **natural computationalism/pancomputationalism** (nature computes its future states from its earlier states) (Zuse, Fredkin, Wolfram, Chaitin, Lloyd).

Two central books presenting the diversity of research on information and computation:

Adriaans P. and van Benthem J. eds. 2008. **Philosophy of Information** (Handbook of the Philosophy of Science) North Holland.

Rozenberg, G., T. Bäck, and J.N. Kok, eds. 2012. **Handbook of Natural Computing.** Berlin Heidelberg: Springer.

Living Agents – Basic Levels of Cognition –

Physical/Energetic Constraints

A living agent is an entity acting on its own behalf, with autopoietic properties that is capable of *undergoing at least one thermodynamic work cycle*. (Kauffman, 2000)

This definition differs from the common view that (living) *agency* requires beliefs and desires, unless we ascribe some primitive form of <belief> and <desire> even to a very simple living agents such as bacteria.

The fact is that bacteria act on some kind of <anticipation> and according to some <preferences> which might be automatic in a sense that they directly derive from the organism's morphology.

Even the simplest living beings act on their own behalf.

Living Agents – Basic Levels of Cognition

Although a detailed physical/energetic account of the agent's capacity to perform work cycles and so persist* in the world is central for understanding of life/cognition, as (Kauffman, 2000) (Deacon, 2007) have argued in detail, present argument is primarily focused on the info-computational aspects of life.

Given that there is no information without physical implementation (Landauer, 1991), computation as the dynamics of information is the execution of physical laws.

*Contragrade processes (that require energy and do not spontaneously appear in nature) become possible by connecting with the orthograde (spontaneous) processes which provide source of energy.

Living Agents – Basic Levels of Cognition

Kauffman's concept of agency (also adopted by Deacon) suggests the possibility that life can be derived from physics through self-organization. That is not the same as to claim that life can be reduced to physics that is obviously false. See also the work of Michael Levin.

In deriving life from physics, one may expect that both our understanding of life as well as physics will change.

Currently, we witness the emergence of information physics (Goyal, 2012) (Chiribella, G.; D'Ariano, G.M.; Perinotti, 2012) as a possible reformulation of physics that may bring physics and life/cognition closer to each other.

Levels of Organization of Life/Cognition

The origin of <cognition> in first living agents is not well researched, as the idea still prevails that only humans possess cognition and knowledge.

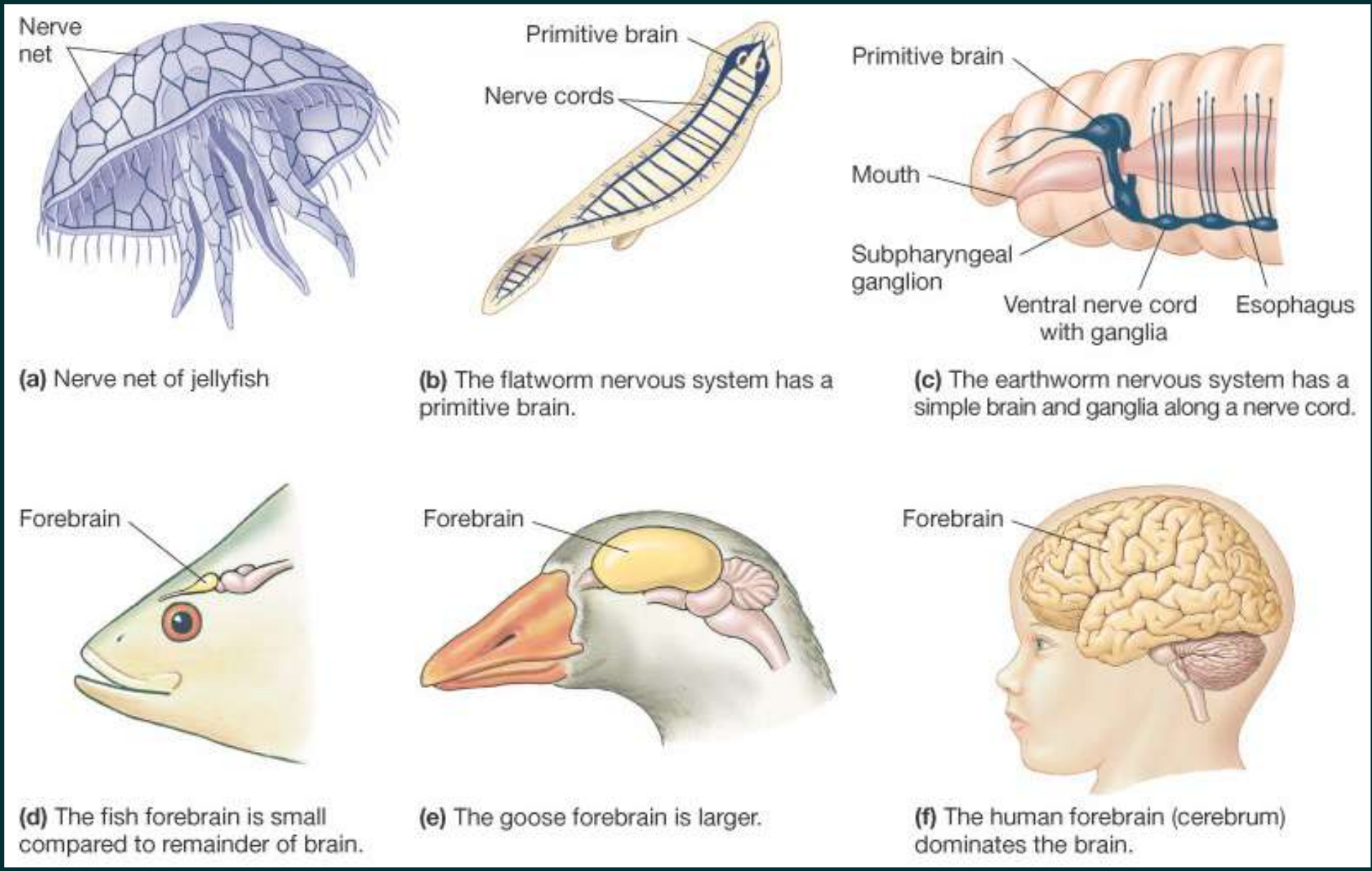
However, there are different types of <cognition> and we have good reasons to ascribe simpler kinds of <cognition> to other living beings.

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)

Plants can be said to possess **memory** (in their bodily structures) and **ability to learn** (adapt, change their morphology) and can be argued to possess **simple forms of cognition**.

Ben-Jacob, E. (2009). Learning from Bacteria about Natural Information Processing. *Annals of the New York Academy of Sciences*, *1178*, 78–90.

Evolution of the Nervous System



(a) Nerve net of jellyfish

(b) The flatworm nervous system has a primitive brain.

(c) The earthworm nervous system has a simple brain and ganglia along a nerve cord.

(d) The fish forebrain is small compared to remainder of brain.

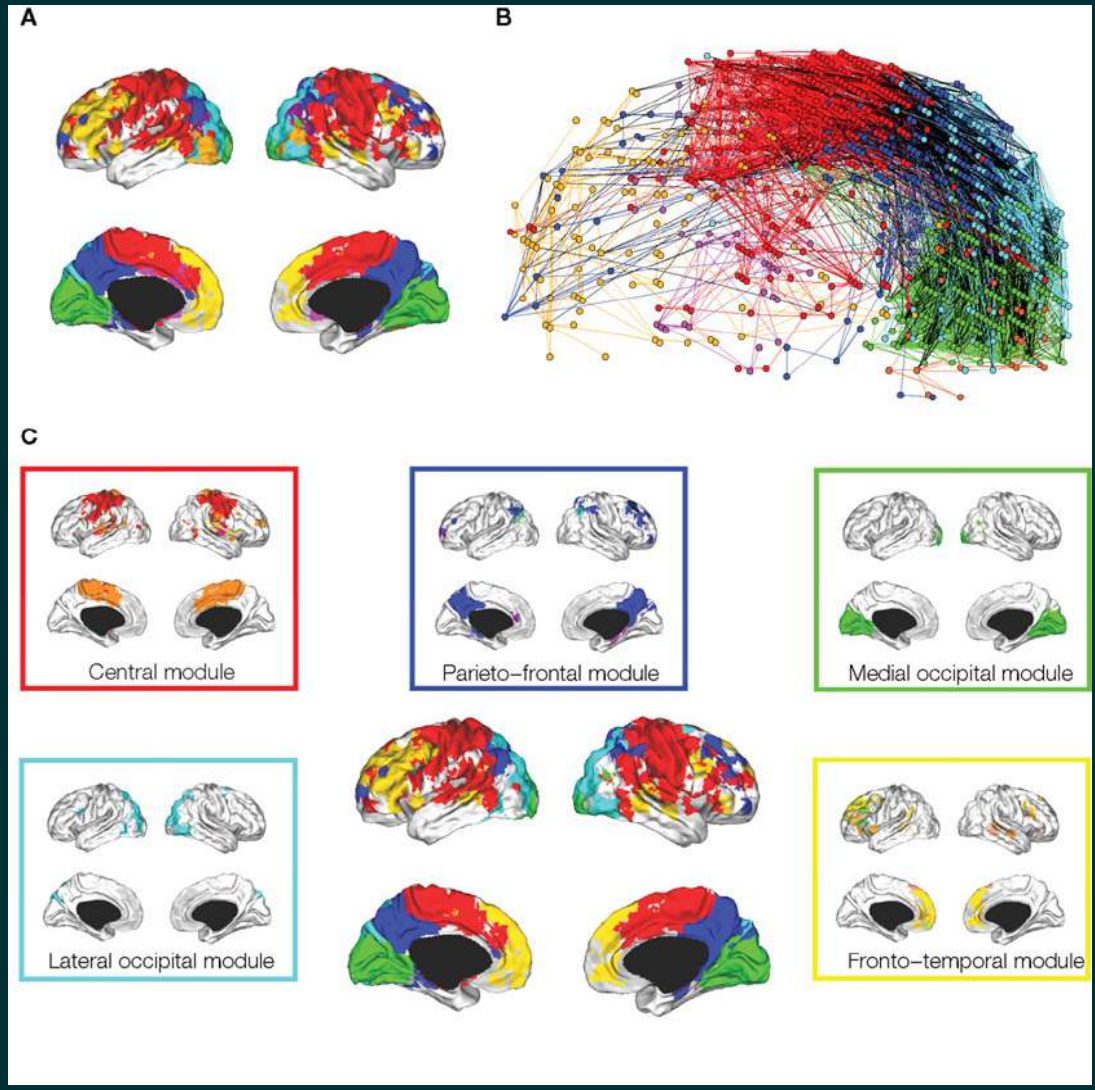
(e) The goose forebrain is larger.

(f) The human forebrain (cerebrum) dominates the brain.

Information Processing in the Brain

http://www.neuroinformatics2013.org
Neuroinformatics

Modular and hierarchically modular organization of brain networks
D. Meunie, R. Lambiotte and E. T. Bullmore
Frontiers of Neuroscience



http://www.frontiersin.org/neuroscience/10.3389/fnins.2010.00200/full
http://www.scienceprog.com/ecccerobot-embodied-cognition-in-a-compliantly-engineered-robot/

Learning and Evolution of "The Sensitive Soul" (subjective experiencing/consciousness) Ginsburg & Jablonka Proposal

What characterizes the evolutionary transition from organisms without consciousness to those with consciousness (with minimal **subjective experiencing, or, as Aristotle described it, "the sensitive soul")?**

[for Aristotle, having soul = being alive]

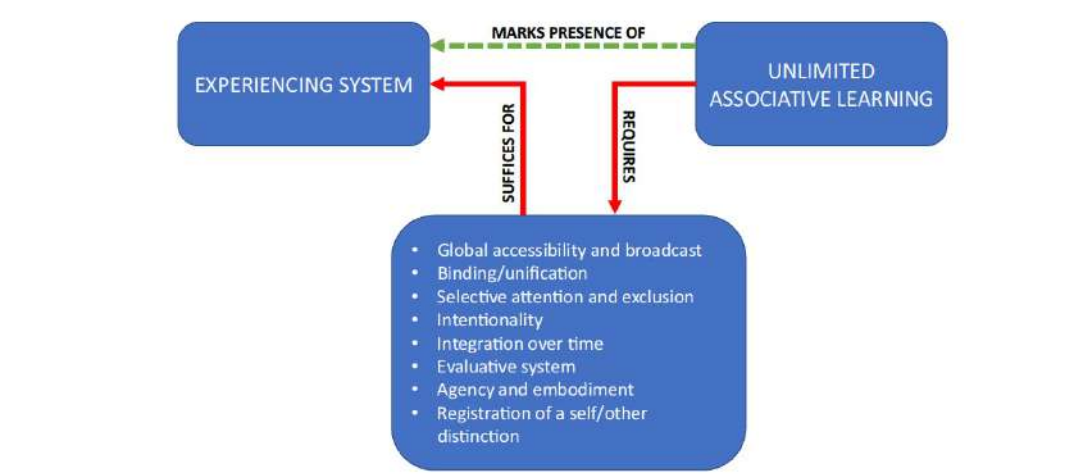


Fig. 3 Unlimited Associative Learning (UAL) as a transition marker for the origin of consciousness

Based on the historical, neurobiological, and philosophical grounds Ginsburg & Jablonka propose that the evolutionary marker of basic/minimal consciousness is **a complex form of associative learning, which they term "unlimited associative learning" (UAL).**

UAL enables an organism to find motivational value in a novel, compound, stimulus or action, and use it as the basis for future learning. Associative learning powered the Cambrian explosion and its massive variation of organisms.

In humans, symbolic language plays a role of marker for the evolutionary transition to human rationality, to Aristotle's "rational soul."

Ginsburg S. and Jablonka E. (2019) "The Evolution of the Sensitive Soul: Learning and the Origins ofConsciousness" The MIT Press & https://link.springer.com/content/pdf/10.1007/s10539-020-09772-0.pdf

Learning

Learning process is central for acquiring, maintaining, and managing knowledge, both theoretical (knowledge that) and practical (knowledge how).

We explore the relationships between the present advances in understanding of learning in the sciences of the artificial (deep learning, robotics), natural sciences (neuroscience, cognitive science, biology), and philosophy (philosophy of computing, philosophy of mind, natural philosophy).

The question is, what at this stage of the development the inspiration from nature, specifically its computational models such as info-computation through morphological computing, can contribute to machine learning and artificial intelligence.

Learning to Learn

Yoshua Bengio, (the 2018 ACM Turing Award, together with Geoffrey Hinton, and Yann LeCun) proposes to continue developing machine learning in the direction of unification between sub-symbolic and symbolic information processing* i.e., Kahneman's System 1 and System 2.

One contribution in the development is the understanding of the mechanisms of 'learning to learn', as a step towards deep learning with symbolic layer of computation/information processing in a framework linking connectionism with symbolism.

Given that natural systems possessing intelligence are cognitive systems, we describe the evolutionary arguments for the necessity of learning to learn for a system to reach human-level intelligence through evolution and development.

* https://www.youtube.com/watch?v=T3sxeTgT4qc Yoshua Bengio: From System 1 Deep Learning to System 2 Deep Learning (NeurIPS 2019)

AI, Deep Learning, System1 and System2 "Thinking" – Mapping the Territory

At present, AI in the form of machine learning is making impressive progress, especially the field of deep learning.

Deep learning algorithms have been inspired by nature, specifically by the human brain, in spite of our incomplete knowledge about brain function.
However, deep-learning intelligence is lacking distribution generalization, compositionality and common-sense reasoning.

The solution recently proposed by Yoshua Bengio* is based on agency, causality, attention and consciousness as mechanisms of learning and meta-learning (learning to learn).

They are used as the basis for deep learning to go beyond Kahneman's** System 1 (fast, unconscious task solving) to System 2 (slow, conscious, reasoning, planning etc.).

* Y. Bengio, "From System 1 Deep Learning to System 2 Deep Learning (NeurIPS 2019)," 2019.
** D. Kahneman, Thinking, Fast and Slow. New York: Farrar, Straus and Giroux, 2011

From System 1 to System 2 in Deep Learning

Step from System 1 to System 2 is proposed through two approaches, both using self-supervised learning.

One possibility is to learn by predicting missing parts in the actual input space of image, text, or audio.

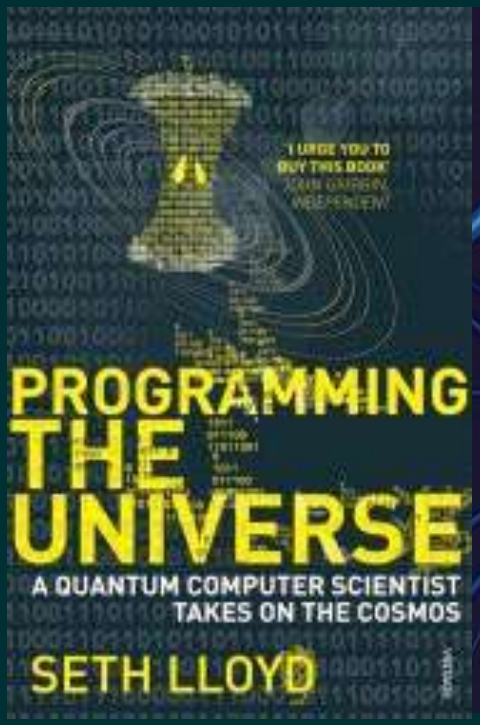
Another approach is to learn by predicting in an abstract space, similar to our brains. The predicting in abstract space is based on conscious task solving that learns representations derived from a high dimensional vector space using attention.

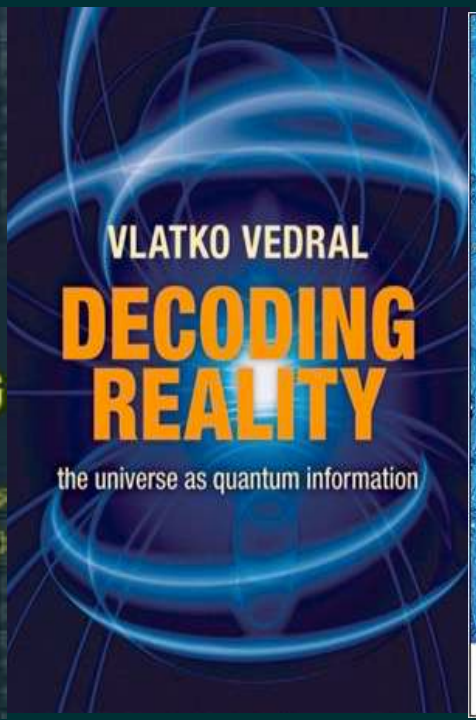
This low dimensional vector, when learned with the right training objective, could identify a few variables capturing causal relationships and could be used for reasoning, planning etc.

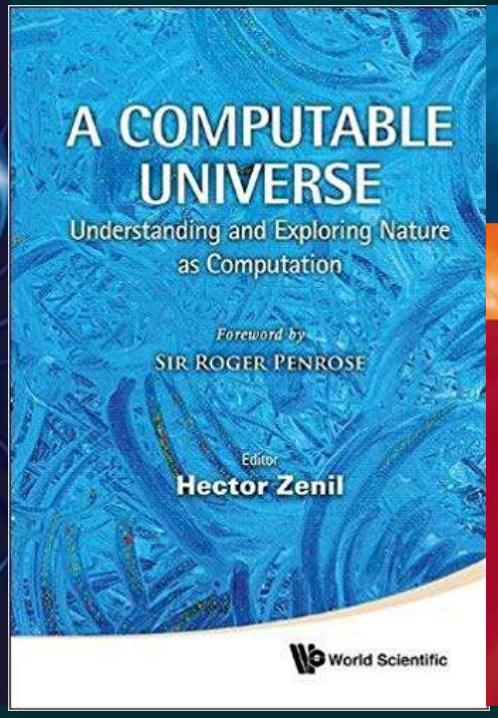
Y. Lecun, Y. Bengio, and G. Hinton, "Deep learning," Nature. 2015.
Y. Bengio, "From System 1 Deep Learning to System 2 Deep Learning (NeurIPS 2019)," 2019.
Y. Bengio, "Scaling up deep learning," 2014. KDD '14: Proceedings of the 20th ACM SIGKDD international conference on Knowledge discovery and data mining. Pages 1966 https://doi.org/10.1145/2623330.2630802
[Y. Bengio, "The Consciousness Prior," arXiv:1709.08568v2, 2019.

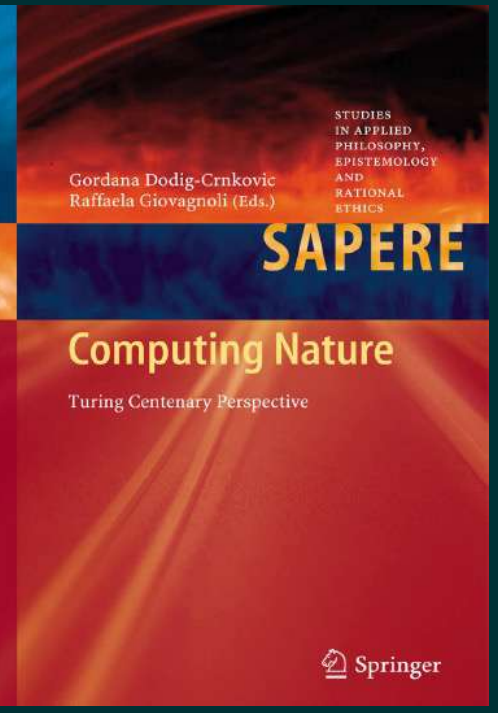
Literature, Further Reading – Mapping Territory Through Various Disciplines

Computing Universe

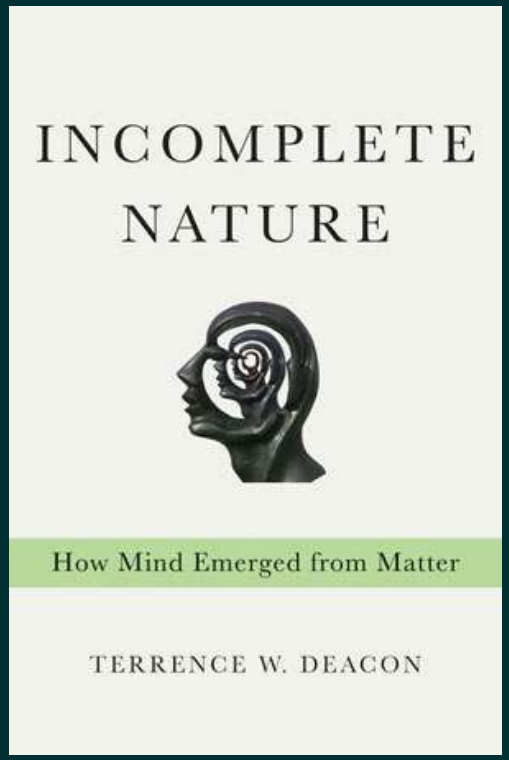


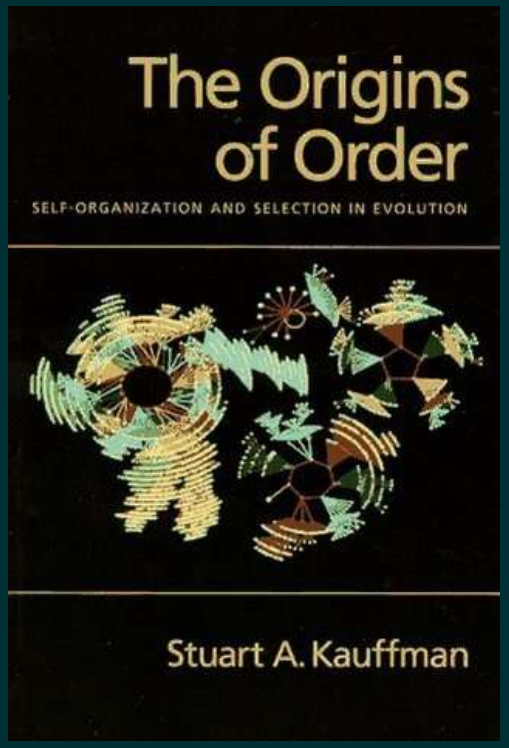


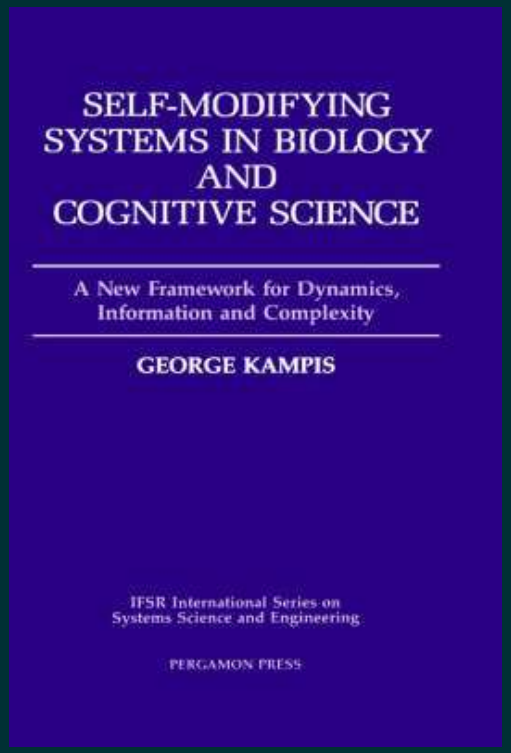




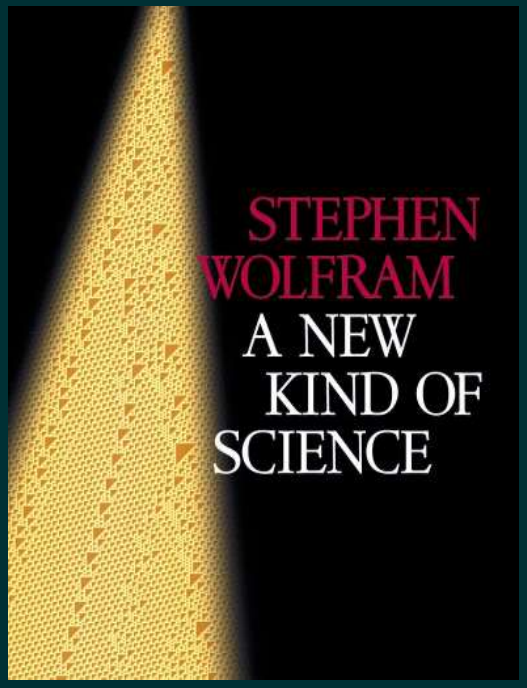
Self-organizing Nature

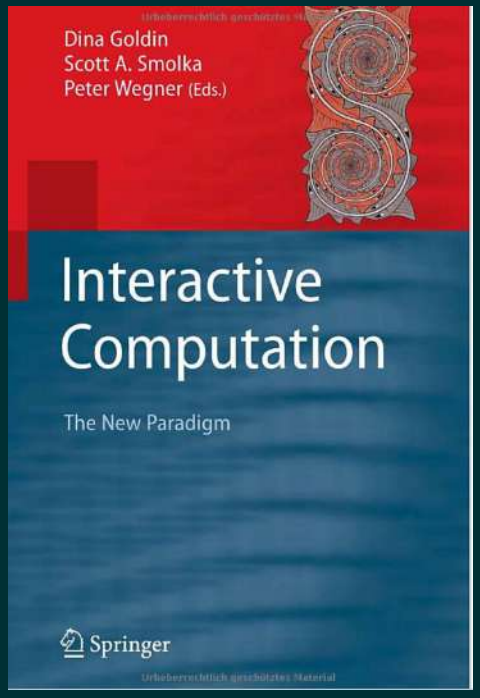


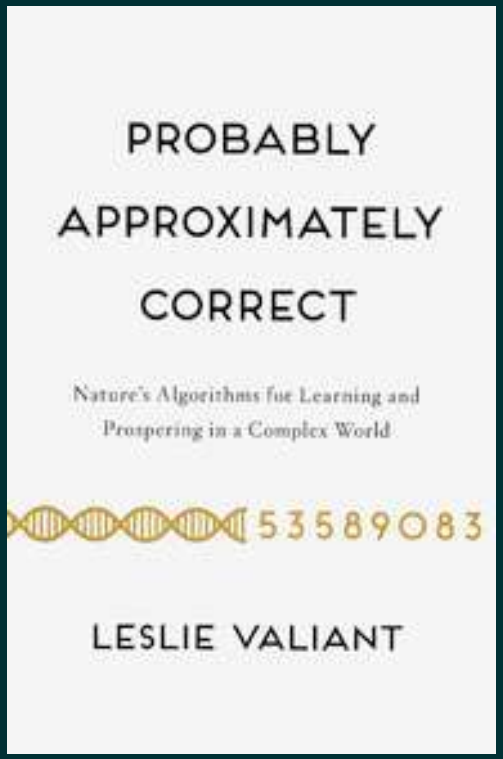




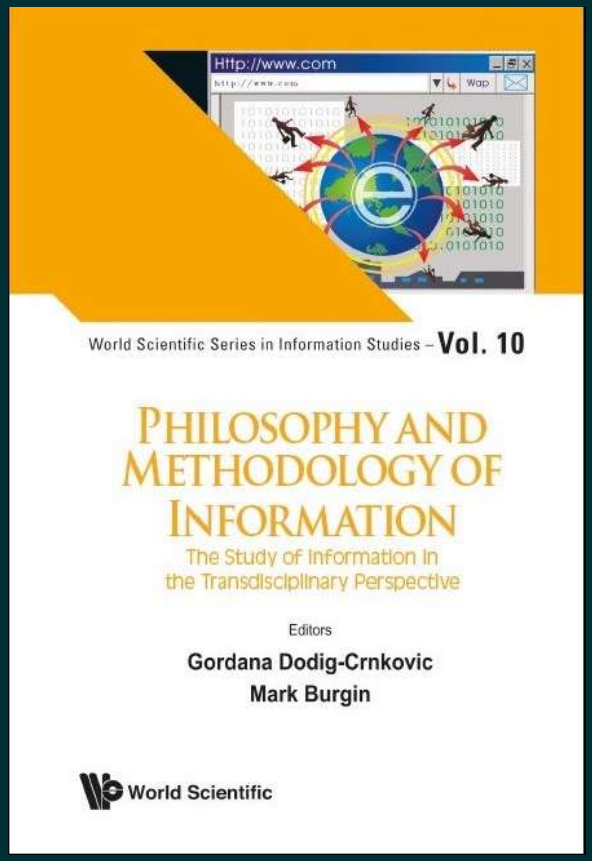
Computational Frameworks







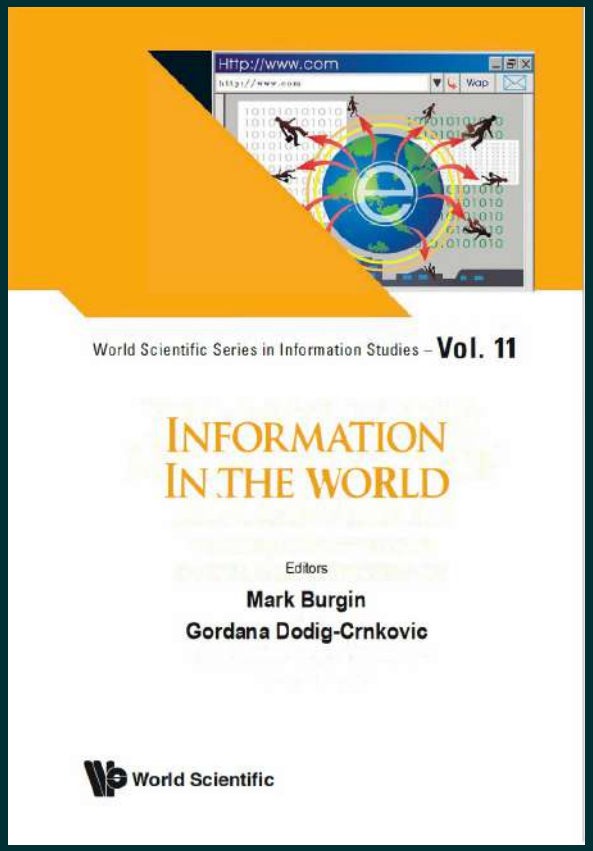
Nature, Information & Computation



PHILOSOPHY AND METHODOLOGY OF INFORMATION

Dodig-Crnkovic G. and Burgin M.

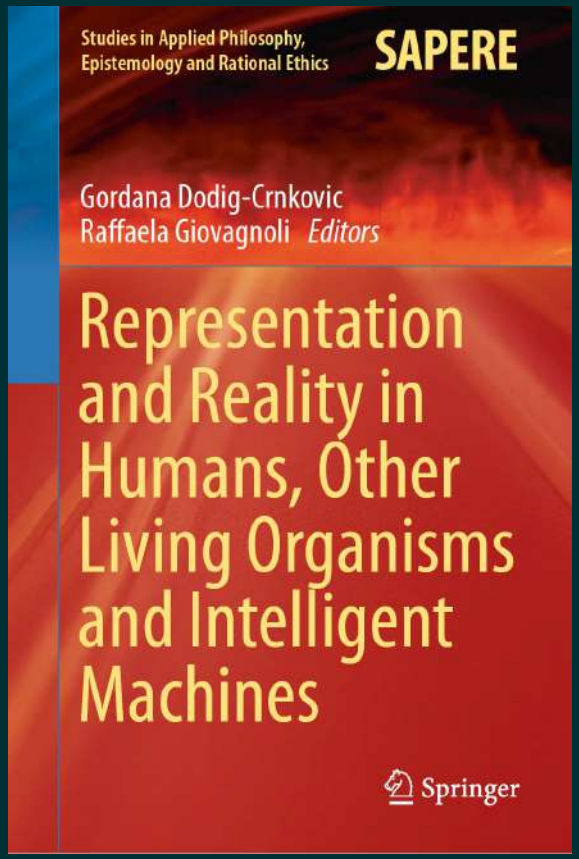
World Scientific, 2019



INFORMATION IN THE WORLD

Burgin M. and Dodig-Crnkovic M.

World Scientific, 2020

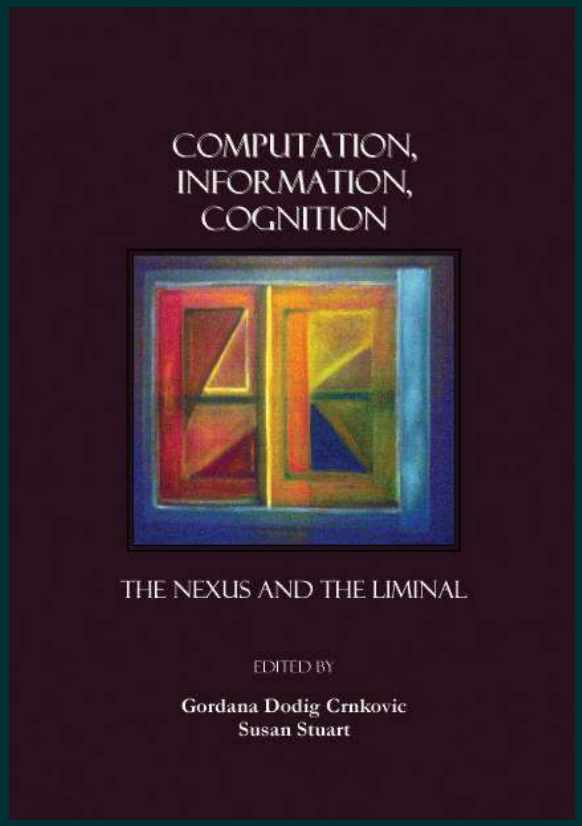


REPRESENTATION AND REALITY

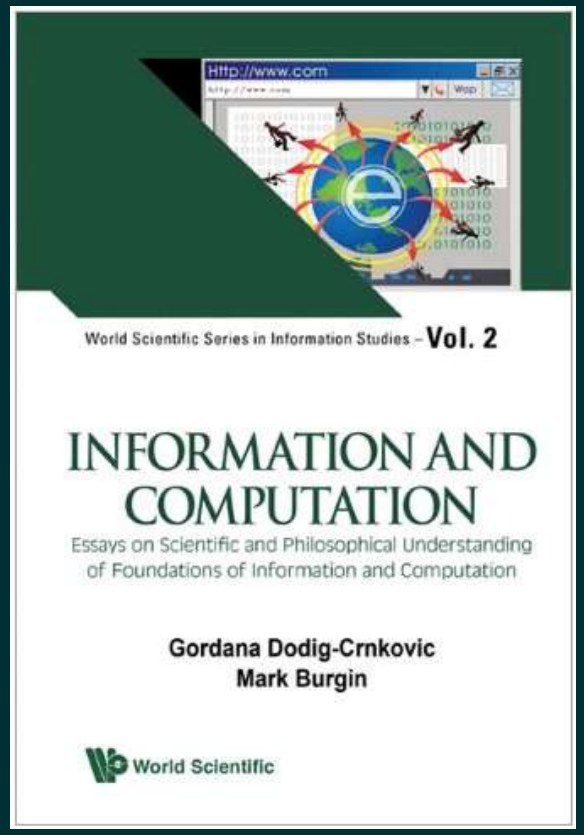
Dodig Crnkovic G. and Giovagnoli, R.

Springer, 2017

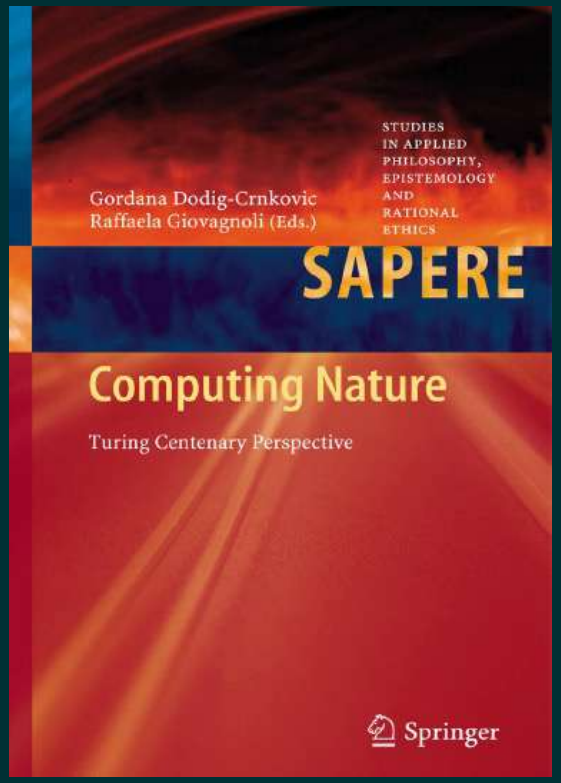
Computation, Information, Cognition



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

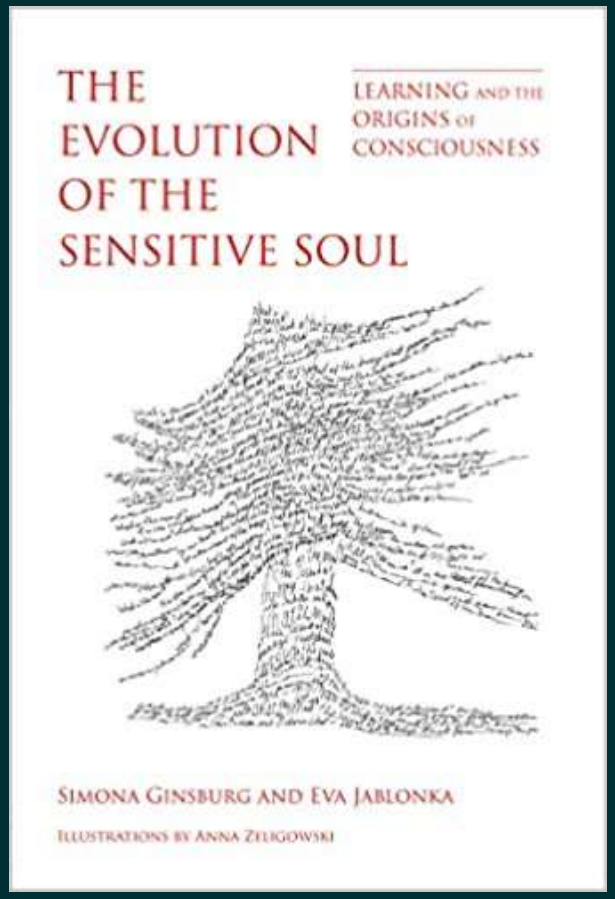


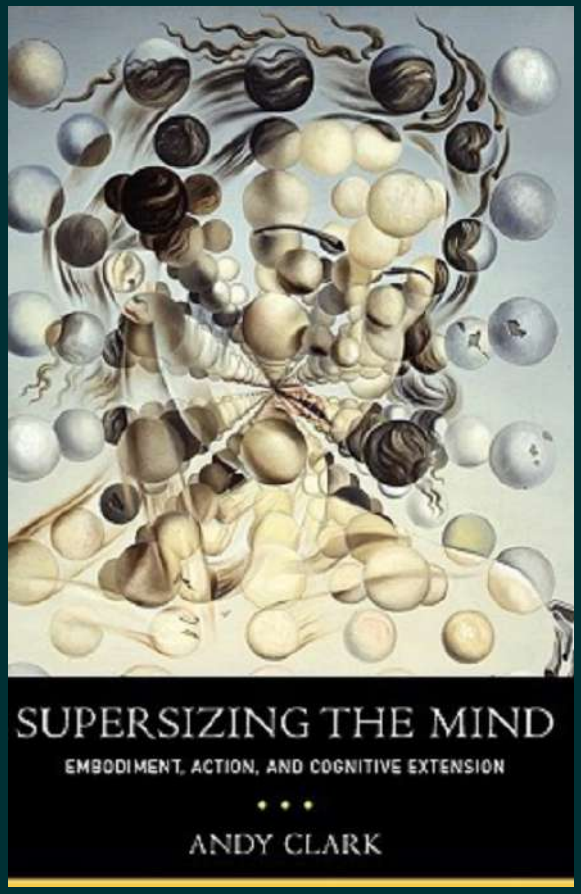
Information and Computation
Gordana Dodig Crnkovic and
Mark Burgin, Edts.
World Scientific, 2011

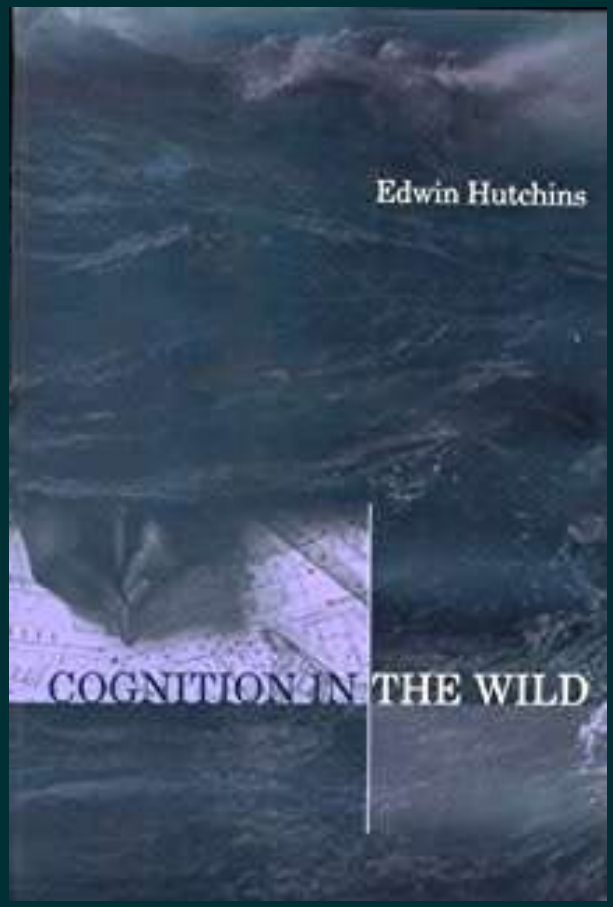


Computing Nature
Gordana Dodig Crnkovic and
Raffaela Giovagnoli, Edts.
Springer, 2013

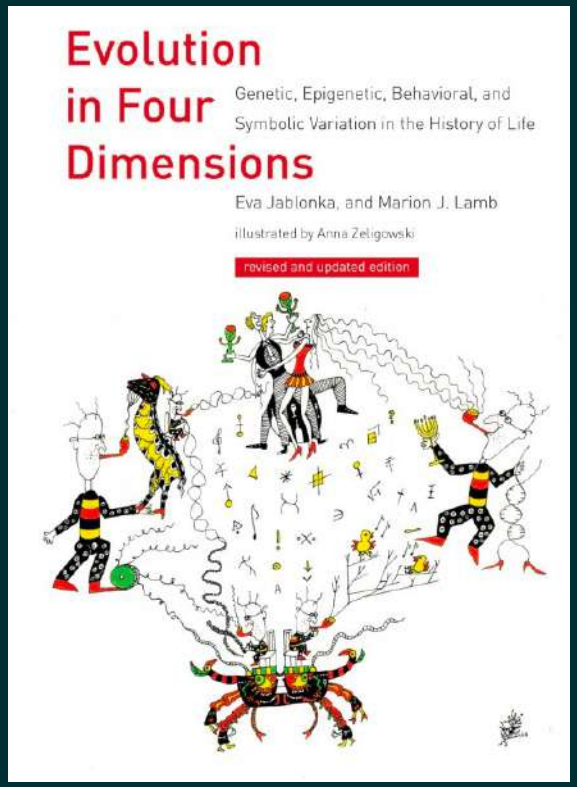
The Extended Mind in Nature

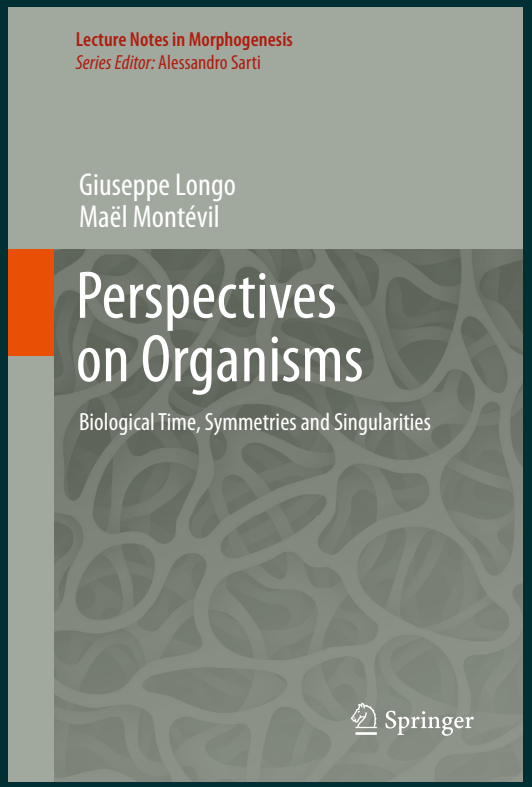


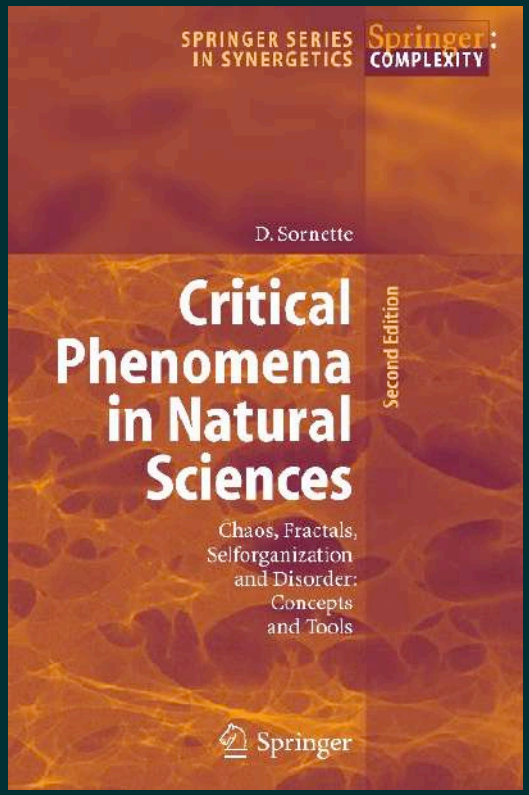




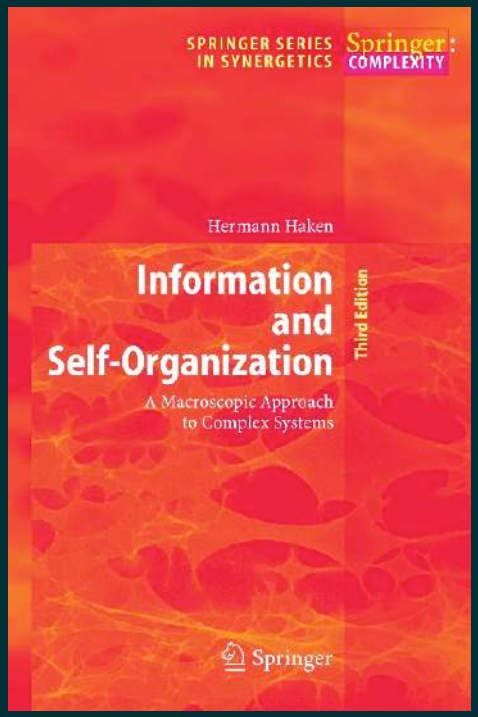
Evolution and The Extended Mind in Nature

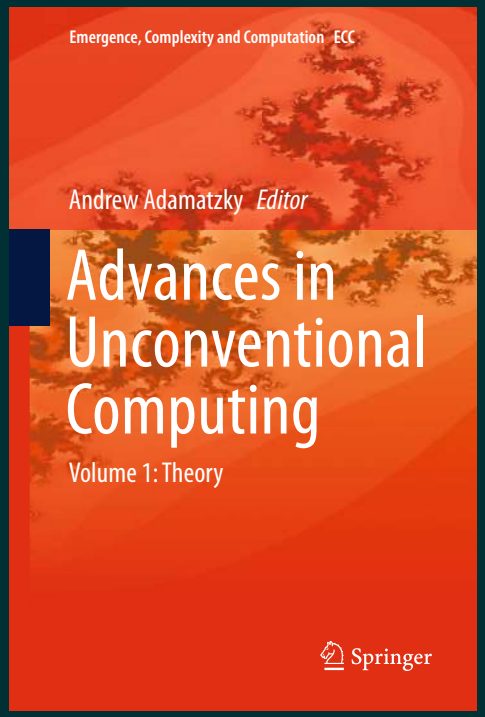


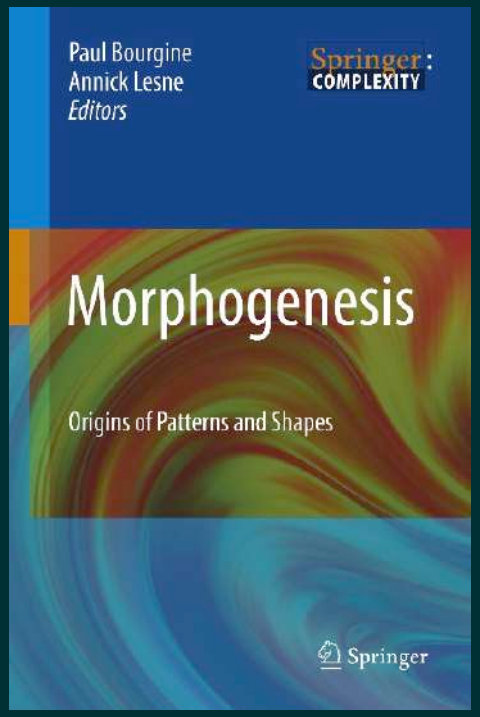




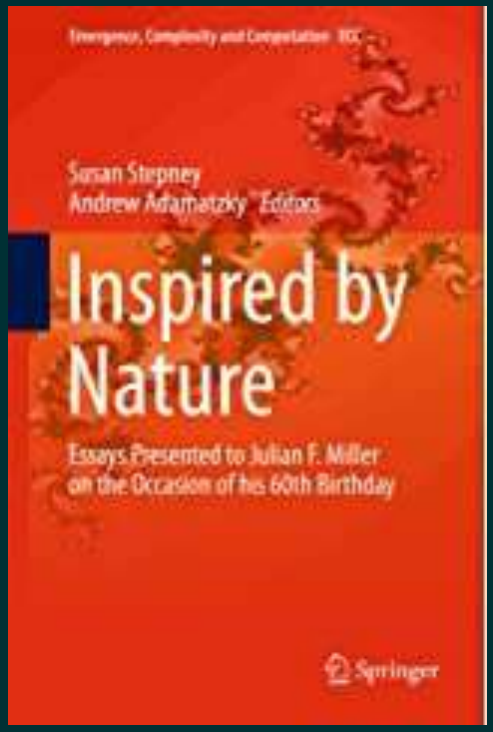
Natural/Unconventional/Morphological Computing

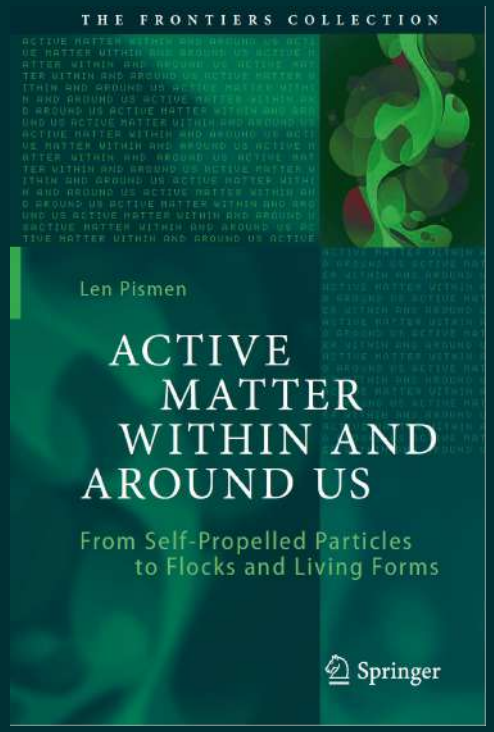


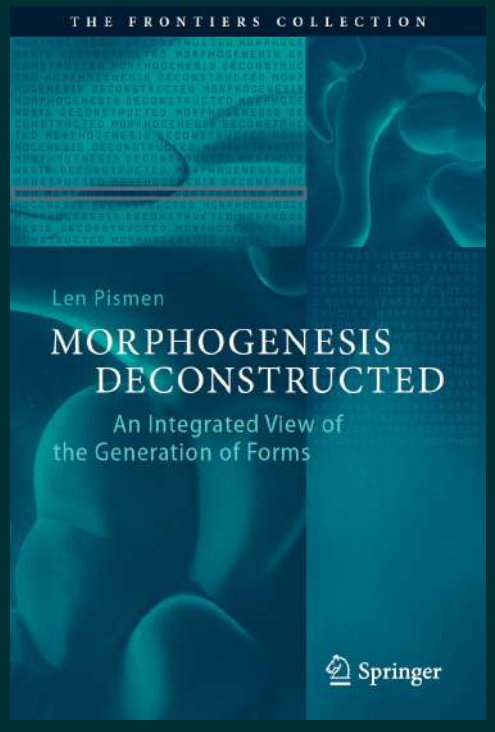


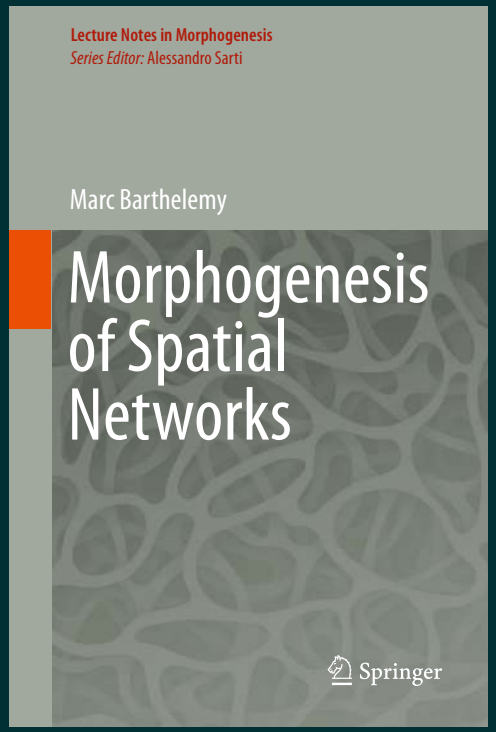


Natural/Unconventional/Morphological Computing

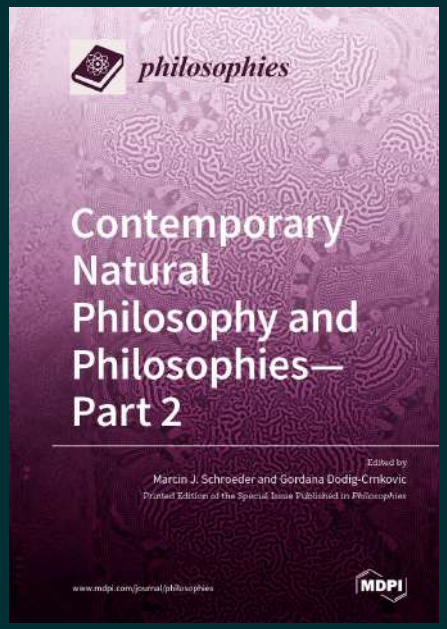


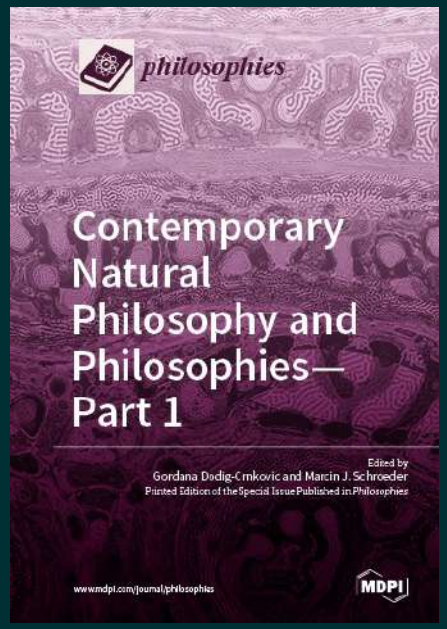






Contemporary Natural Philosophy – Special Issues and Book Series





Open call for submissions for Part 3:

Deadline August 31 2021
Journal Philosophies

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

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

ISBN 978-3-03943-535-7 (Hbk);
ISBN 978-3-03943-536-4 (PDF)
Download PDF

Dodig Crnkovic, G. and Marcin Schroeder (2019)
CONTEMPORARY NATURAL PHILOSOPHY AND PHILOSOPHIES - PART 1

ISBN 978-3-03897-822-0 (Pbk);
ISBN 978-3-03897-823-7 (PDF)
Download PDF

Upcoming Summit IS4SI 2021

IWNC Announcement and Call for Submissions of Extended Abstracts

The series of International Workshops on Natural Computing initiated in 2006 grew up from the original interest in molecular computing. However, within the years following this original initiative the topic of natural computing became one of main directions of study in several disciplines. Natural processes or even entire life started to be considered a form of information processing with characteristics of computing. On the other hand, information processing in natural systems became a source of inspiration for innovation in computer science, artificial intelligence and engineering. Moreover, computer simulation became a common tool for the study of nature.

The plan for the Workshop was cancelled in 2020 due to the outbreak of the new coronavirus. Since it is difficult to predict the future conditions the Workshop is planned in the online format along with the cluster of other conferences of the 2021 IS4SI Summit. This will be a unique opportunity to engage in the interaction and discussion with participants of multiple conferences of the Summit.

Following this general trend of mutual interactions of disciplines, the 13th International Workshop on Natural Computing continues already established tradition of the IWNC series to devote its sessions to the recent and future developments in research, practice, philosophical reflection and creative activity within the crossroads of nature, computing, information science, cognitive science, study of life and culture.

The 13th International Workshop on Natural Computing will be associated with the symposium on Morphological, Natural, Analog and Other Unconventional Forms of Computing for Cognition and Intelligence, which has its own tradition within the Summits of IS4SI.

The intention of the 13th International Workshop on Natural Computing is to bring together a very wide range of perspectives from philosophical to scientific ones, to visions of artists. There will be an opportunity to present original and creative contributions without any restriction by disciplinary divisions or the level of advancement of research. Contributions from the beginning of the academic or intellectual career are as welcome as those from its peak.

CONFIRMED INVITED SPEAKERS:

Andrew Adamatzky (Unconventional Computing Laboratory, UWE, Bristol, UK)
Yukio-Pegio Gunji (Waseda University, Tokyo, Japan)
Genaro Juarez Martinez (Computer Science Laboratory, IPN, Mexico)

ORGANIZING COMMITTEE

Marcin J. Schroeder (Tohoku University, Japan) mjs@gl.aiu.ac.jp
Masami Hagiya (Tokyo University, Japan) hagiya@is.s.u-tokyo.ac.jp
Yasuhiro Suzuki (Nagoya University, Japan) ysuzuki@nagoya-u.jp
Gordana Dodig-Crnkovic (Chalmers University, Sweden) gordana.dodig-crnkovic@chalmers.se

CALL FOR CONTRIBUTIONS (ABSTRACTS)

We invite submission of extended abstracts for intended presentations at the workshop. **Extended abstracts should be in English and they should be sufficiently extensive to describe clearly the content of presented work. Their expected volume is within 300-500 words.** There is no required format of extended abstracts, except that they should include the title of the presentation, the names of authors with their affiliations and e-mail address of the corresponding author. All extended abstracts will be published on the IS4SI website prior to the Summit. This way the participants of all conferences within the Summit will be able to select presentations of special interest and to attend not only those belonging to this conference, but also presentations belonging to other conferences of the Summit. The subject matter of presentations

https://summit-2021.is4si.org

13th International Workshop on
Natural Computing - IWNC 2021

In conjunction with the 4th International Workshop on
Morphological Computing - MORCOM 2021

AI, (Deep) Learning from System1 to System2 Information Processing (Computation)

At present, AI in the form of machine learning is making impressive progress, especially the field of deep learning.

Deep learning (DL) algorithms have been inspired by nature, specifically by the human brain, and its neural networks.
However, deep-learning intelligence is lacking distribution generalization, compositionality and common-sense reasoning.

The solution proposed by Yoshua Bengio* is based on agency, causality, attention and consciousness as mechanisms of learning and meta-learning (learning to learn).

They are used as the basis for deep learning to go beyond Kahneman's** System 1 (fast, unconscious task solving of current DL) to System 2 (slow, conscious, reasoning, planning etc.) for the future machine learning.

* Y. Bengio, "From System 1 Deep Learning to System 2 Deep Learning (NeurIPS 2019)," 2019.
** D. Kahneman, Thinking, Fast and Slow. New York: Farrar, Straus and Giroux, 2011

AI, (Deep) Learning from System1 to System2 Information Processing (Computation)

Continuing learning from nature, we explored different aspects and mechanisms of natural cognition and intelligence. 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

Summary
Learning as Information Processing (Computation)

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.
4. INTELLIGENCE = PROBLEM SOLVING ABILITY for both living organisms and artifacts. Its basic precondition is ability to learn and thus anticipate.
5. All cognizing systems (organisms and artifacts) are essentially dependent on information input from the surrounding
5. Biological cognition and intelligence can only be understood in the context of evolution*
6. Evolution in the info-computational nature is the result of natural/morphological computation on succession of levels of organization (scales)
7. Interdisciplinary, Cross-disciplinary and Trans-disciplinary research is necessary in order to understand cognition and intelligence at diverse scales
8. New Natural Philosophy can provide common background.

* 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)

Open Questions

- How close to natural (biological) systems do we have to be to get artifactual intelligent agents with "minimal" consciousness*?
- The role of embodiment (including timing) for learning and learning to learn
- Understanding of fundamental properties of information as a structure, fabric of reality for a cognizing, intelligent agent, and understanding of computation as a process (a hierarchical network of processes) over informational structures.
- Relate to existing models of computation such as Turing model and actor models of concurrent distributed computation and resource-aware computing
- New kinds of models, such as executable biology, new kinds of dynamic logics suitable for intelligent adaptive systems

Following authors argue against "minimal cognition" and consider cognition as a binary state, yes or no.

Lyon, Pamela, Fred Keijzer, Detlev Arendt, and Michael Levin. 2021. "Reframing Cognition: Getting down to Biological Basics." *Phil. Trans. R. Soc. B* 376: 20190750.

Lyon, Pamela, and Franz Kuchling. 2021. "Valuing What Happens: A Biogenic Approach to Valence and (Potentially) Affect." *Phil. Trans. R. Soc. B* 376: 2019075220190752.

References

- Russin, Jacob, Randall C. O'Reilly, and Yoshua Bengio. 2020. "Deep Learning Needs a Prefrontal Cortex." Workshop "Bridging AI and Cognitive Science" (ICLR 2020).
- Kahneman, Daniel. 2011. Thinking, Fast and Slow. Macmillan.
- Tjøstheim, Trond A., Andreas Stephens, Andrey Anikin, and Arthur Schwaninger. 2020. "The Cognitive Philosophy of Communication." Philosophies. https://doi.org/10.3390/philosophies5040039.
- Dodig-Crnkovic, G., Information, Computation, Cognition. Agency-Based Hierarchies of Levels. (author's draft). FUNDAMENTAL ISSUES OF ARTIFICIAL INTELLIGENCE, Müller V. C. (ed.), Synthese Library 377, pp 139-159. Springer International Publishing Switzerland 2016, DOI 10.1007/978-3-319-26485-1_10
- 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.
- Dodig-Crnkovic G., Physical Computation as Dynamics of Form that Glues Everything Together. Information 2012, 3, 204-218; doi:10.3390/info3020204

References

- Levin, Michael. 2019. "The Computational Boundary of a 'Self': Developmental Bioelectricity Drives Multicellularity and Scale-Free Cognition." Frontiers in Psychology 10: 2688.
- Levin, Michael, Fred Keijzer, Pamela Lyon, and Detlev Arendt. 2021. "Uncovering Cognitivesimilarities and Differences, Conservation Andinnovation." Phil. Trans. R. Soc. B 376: 20200458.
- Lyon, Pamela. 2005. "The Biogenic Approach to Cognition." Cognitive Processing 7: 11–29.
- Lyon, Pamela,. 2015. "The Cognitive Cell: Bacterial Behaviour Reconsidered." Frontiers in Microbiology 6: 264.
- Lyon, Pamela, Fred Keijzer, Detlev Arendt, and Michael Levin. 2021. "Reframing Cognition: Getting down to Biological Basics." *Phil. Trans. R. Soc. B* 376: 20190750.
- Lyon, Pamela, and Franz Kuchling. 2021. "Valuing What Happens: A Biogenic Approach to Valence and (Potentially) Affect." *Phil. Trans. R. Soc. B* 376: 2019075220190752.

References

- https://www.crg.eu/en/news/crg-researchers-confirm-mathematical-theory-first-proposed-alan-turing-1952-can-explain-formation-fingers CRG NEWS: Turing model of morphogenesis confirmed

- Ehresmann, Andrée C. (2012) "MENS, an Info-Computational Model for (Neuro-)cognitive Systems Capable of Creativity." Entropy 14, no. 9: 1703-1716. https://www.mdpi.com/1099-4300/14/9/1703

- Dodig-Crnkovic G., Physical Computation as Dynamics of Form that Glues Everything Together, Information (doi:10.3390/info3020204) Special Issue on Information: Its Different Modes and Its Relation to Meaning, R. Logan Ed., 2012 3(2), 204-218

- CÉDRIC VILLANI (2018) For A Meaningful Artificial Intelligence https://www.aiforhumanity.fr/pdfs/MissionVillani_Report_ENG-VF.pdf

- Eva Jablonka and Marion J. Lamb (2019) Evolution in Four Dimensions, Revised Edition. Genetic, Epigenetic, Behavioral, and Symbolic Variation in the History of Life. The MIT Press

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

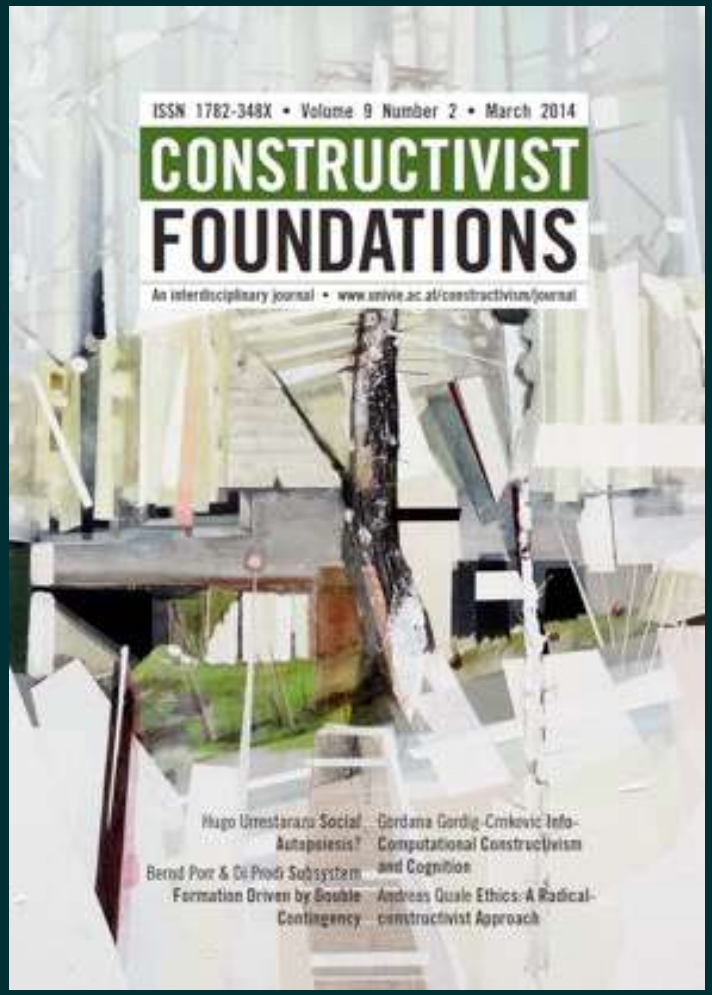
Morphological Computing and Cognitive Agency
@Gothenburg summit of International Society for the Study of Information, is4si
http://is4si-2017.org/
Co-organized with: Robert Lowe, Alexander Almér

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

ADDITIONAL MATERIALS

A mathematical model for Info-computationalism
A. C. Ehresmann

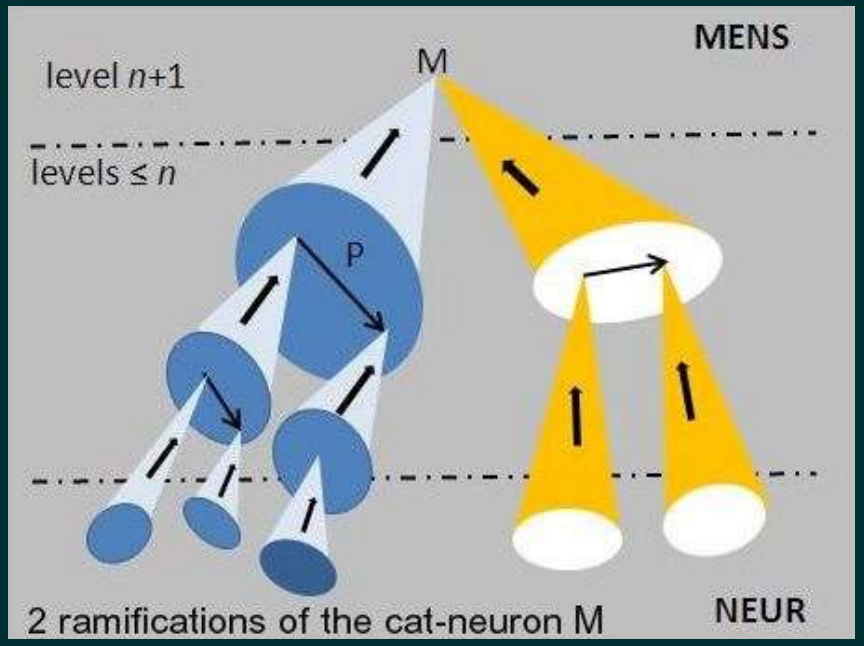


Open peer commentary on the article "Info-computational Constructivism and Cognition" by Gordana Dodig-Crnkovic.

Ehresmann proposes a mathematical approach to the framework developed by Dodig-Crnkovic. Based on the Property of natural computation, called the multiplicity principle development of increasingly complex cognitive processes and knowledge is described.
"Local dynamics are classically computable, a consequence of the MP is that the global dynamics is not, thus raising the problem of developing more elaborate computation models."

http://www.idt.mdh.se/~gdc/work/Constructivist%20Foundations%209%282%29.pdf

An Info-Computational Model for (Neuro-)cognitive Systems Capable of Creativity - Andrée C. Ehresmann



Ehresmann's model is based on a Dynamic Category Theory, accounting for the functioning of the neural, cognitive and mental systems at different levels of description and across different timescales.

Andrée C. Ehresmann http://www.mdpi.com/1099-4300/14/9/1703

Knowledge as Network of Natural Processes

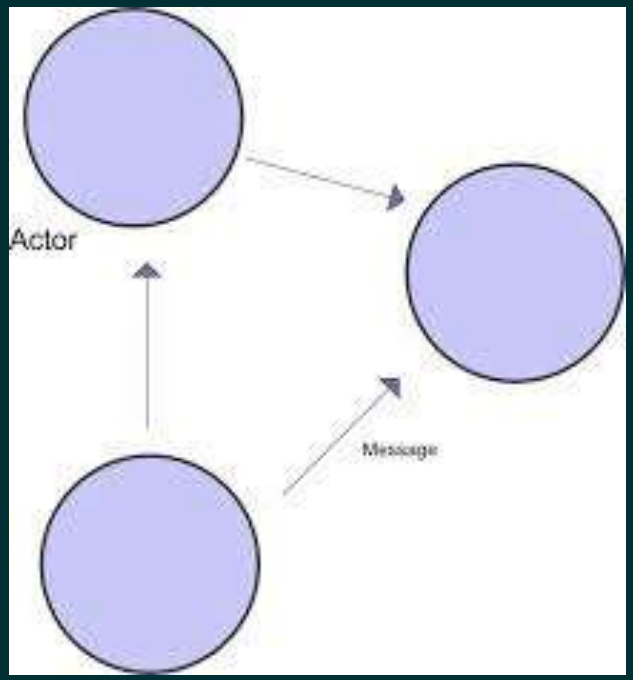
Naturalized epistemology* (Feldman, Kornblith, Stich) is, in general, an idea that knowledge may be studied as a natural phenomenon -- that the subject matter of epistemology is not our concept of knowledge, but the knowledge itself.

“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)

We can 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.

Actor Model Of Computation Suitable To Support The Relational Concept Of Information and Networked Agent Models - 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

Actors are the universal primitives of concurrent distributed digital computation. In response to a message that it receives, an Actor can make local <decisions>, create more Actors, send more messages, and designate how to respond to the next message received.

For Hewitt, Actors become Agents only when they are able to process expressions for commitments including the following: *Contracts, Announcements, Beliefs, Goals, Intentions, Plans, Policies, Procedures, Requests, Queries*.

In other words, Hewitt's Agents are human-like or if we broadly interpret the above capacities, life-like Actors.

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.

Natural Computing – Morphological Computing – Nonconventional Computing

Morphology studies shape, structure, pattern and material.

Structure and material are related. In the description of physical systems – material on one level of abstraction is a structure on the level below, (e.g. atom is a structure of protons, neutrons and electrons).

Morphology is described by data/information which describe a structure.

Dynamical processes on informational structure are morphological computation.

Morphological computing is a specific approach to natural computing which models nature in terms of structures and processes on those structures.

Nonconventional computing stands for all models and applications of computing that differs from the conventional ones. Natural computing, unconventional computing, cognitive computing are examples.

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 Model and M a n a g e* Computationally

- Cognitive behavior of living organisms
- Natural Intelligence/Intelligence in Nature
- Computational neuroscience & neuroinformatics
- Artificial (general) intelligence
- Cognitive robotics
- Intelligent cities
- Intelligent homes
- Big data
- Internet of everything
- Semantic web
- …

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

*Observe the difference between S O L V 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.)

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)

https://link.springer.com/chapter/10.1007/978-3-642-15223-8_20 Dodig-Crnkovic, Constructivist Research and Info-Computational Knowledge Generation

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 robotics rising 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 agents in the world, and their constant reality construction/adaptation.

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.

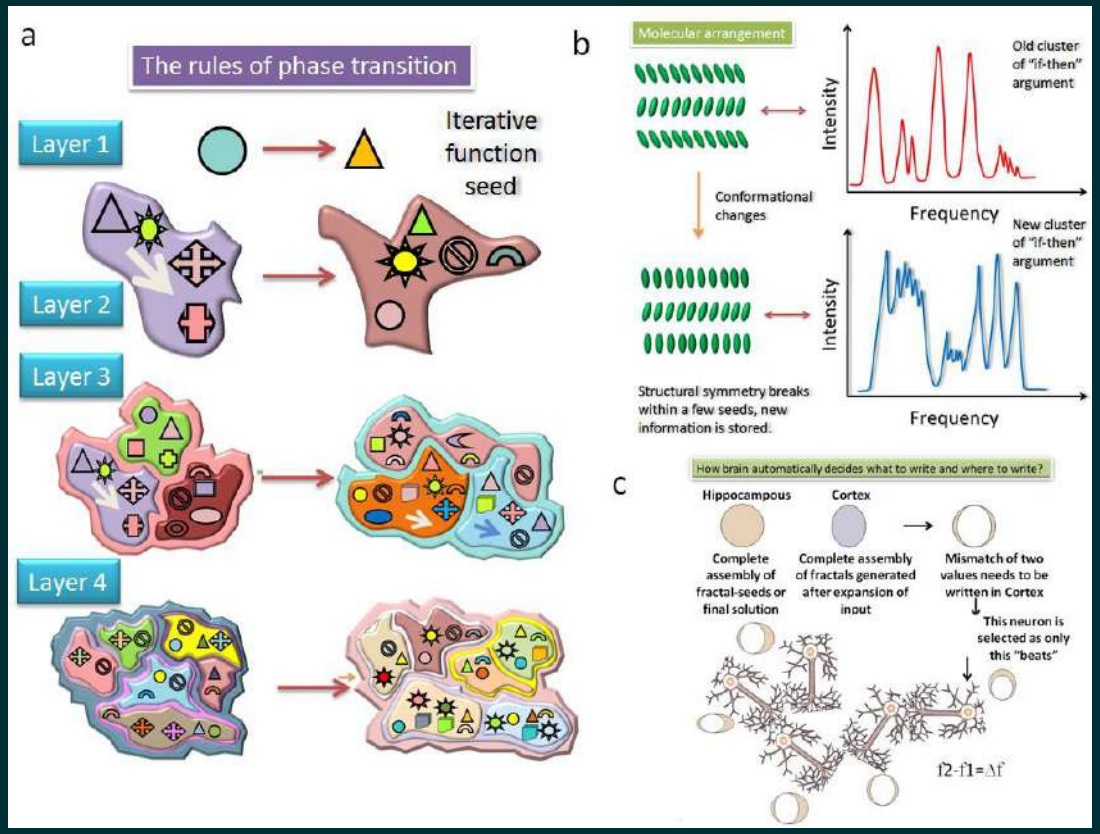
The evolutionary advantage of using structured, component-based approaches is improving response-time and efficiency of cognitive processes of an organism.

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

Design and Construction of a Brain-like Computer



"A New Class of Frequency-Fractal Computing Using Wireless Communication in a Supramolecular Organic, Inorganic System "

Subrata Ghosh, Krishna Aswani, Surabhi Singh, Satyajit Sahu, Daisuke Fujita and Anirban Bandyopadhyay

Information **2014**, *5*, 28-100; doi:10.3390/info5010028

http://www.mdpi.com/2078-2489/5/1/28