电子科技大学人文社科高等研究院
The Advanced Institute of Humanities and Social Sciences

2025 Symposium on Quantum Philosophy,
AI-HSS, UESTC, Chengdu, China, 12-14 December 2025

Info-Computation and Observer-Dependence in Quantum

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Affiliations

School of Innovation, Design and Engineering

Division of Computer Science and Software Engineering

Research groups:
Artificial Intelligence and Intelligent Systems
Ubiquitous Computing

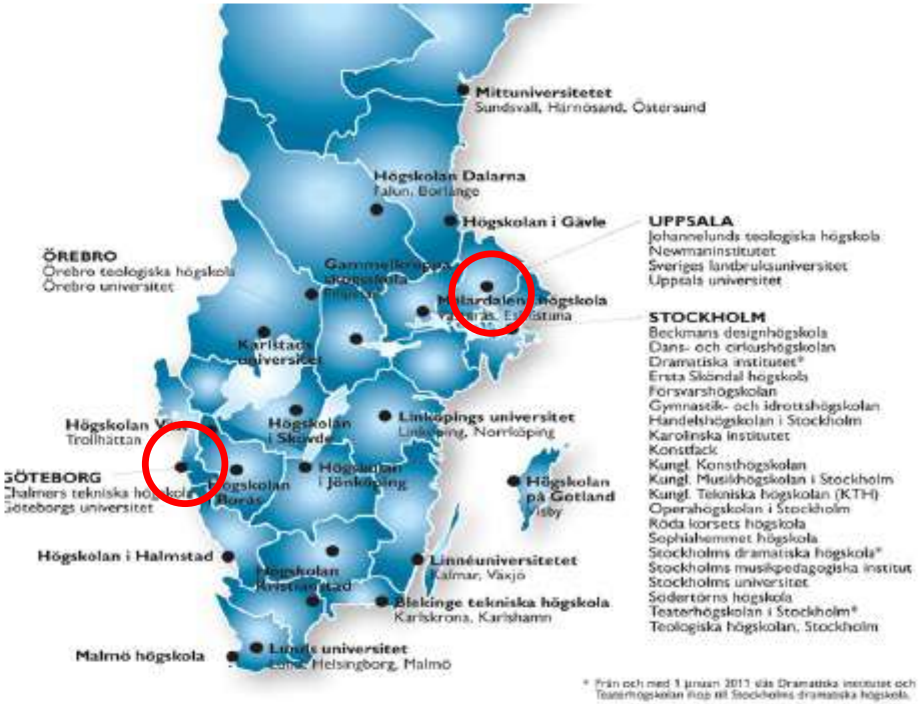
AI & Society-AI@MDU Research Fellow

Department of Computer Science and Engineering

Computer Science and Software Engineering Division

Research groups:
Interaction Design and Software Engineering
Critical Robotics

Sweden



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Högskolan Dalarna
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ÖREBRO
Örebro teologiska högskola
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Beckmans designhögskola
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Ersta Sköndal högskola
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Kungl. Musikhögskolan i Stockholm
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Stockholms dramatiska högskola*
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Teaterhögskolan i Stockholm*
Teologiska högskolan, Stockholm
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Kalmar, Växjö
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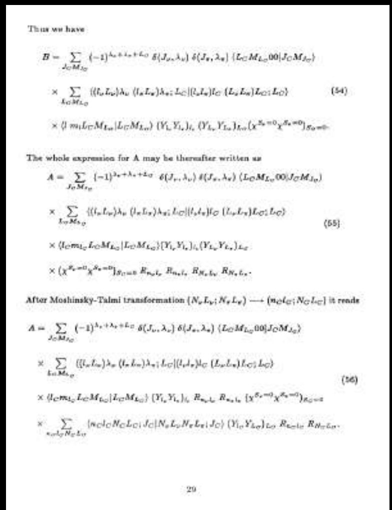
Karlskrona, Karlshamn
Malmö högskola
Helsingborg, Malmö

MY RESEARCH BACKGROUND


Thus we have

The whole expression for A may be thereafter written as

After Moshinsky-Talmi transformation it reads

29

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

PhD in Computing, 2006
Mälardalen University

Current: Morphological Computing and Cognition

AI Ethics, Digital Ethics, Digital Humanism

Gordana Dodig-Crnkovic, 2025

Theory as product of cognition
Humberto Maturana & Francisco Varela

'Everything said is said **by an observer to an observer** who could be him/herself " (Maturana and Varela, 1980; p. 8)

Through self-observation, we interact with our own descriptions and can describe ourselves describing ourselves in an endless recursive process.

Maturana, Humberto, and Francisco Varela (1980) *Autopoiesis and Cognition: The Realization of the Living.* Boston Studies in the Philosophy of Science [Cohen, Robert S., and Marx W. Wartofsky (eds.)], Vol. 42, Dordecht: D. Reidel Publishing Co.

My perspective: Info-computational approach.

Connecting information, computation, and cognition. Agency-based hierarchies of levels

1. Information constitutes a structure consisting of differences in one system that cause differences in another system. In other words, information is <observer>-relative.
2. Computation is information processing (dynamics of information). It is a physical process of morphological change in the informational structure which is the physical implementation of information, as there is no information without physical implementation (Landauer).
3. Both information and computation appear on a succession of levels of organization/abstraction/ resolution/granularity of matter/energy in space/time.

Information, computation, cognition. Agency-based hierarchies of levels

4. Of all autonomous agents (entities capable of acting on their own behalf) only living agents have the ability to actively make choices so as to increase the probability of their own continuing existence /<survival>. This ability of living agents to act autonomously on their own behalf* is based on the use of energy and information from the environment.
5. Cognition consists of all (info-computational) processes necessary to keep a living agent's organizational integrity on all different levels of its existence. Cognition = info-computation
6. Cognition is equivalent to the (process of) life.* Its complexity increases with evolution. This complexification is a result of morphological computation.

* The original idea about cognition in living organisms: Maturana & Varela, Stewart

* Agency in the sense of S. Kauffman and T, Deacon

* Active inference, K. Friston

Information, computation, cognition.
Agency-based hierarchies of levels

7. Cognition is **embodied** and **distributed** information processing.
   It is a result of information processing in networks of agents.
8. Basal cognition exists already at the level of a single cell.*

*Levin unifies natural and artifactual cognition into a continuum of possible cognitive architectures

Levin M (2022) Technological Approach to Mind Everywhere: An Experimentally-Grounded Framework for Understanding Diverse Bodies and Minds. Front. Syst. Neurosci. 16:768201. doi: 10.3389/fnsys.2022.768201

See also biosemiotics approaches to cell behavior:
Emmeche, Claus, and Kalevi Kull (2011) "Towards a Semiotic Biology" (2011) Imperial College Press. doi:10.1142/P771.

Information as a fabric of reality for a cognizing agent
(cell, tissue, organ, organism, groups of organisms, ecologies)

"Information is the difference that makes a difference."*
Gregory Bateson

It is the difference in the world that makes the difference for an agent. Here the world includes agents themselves too.

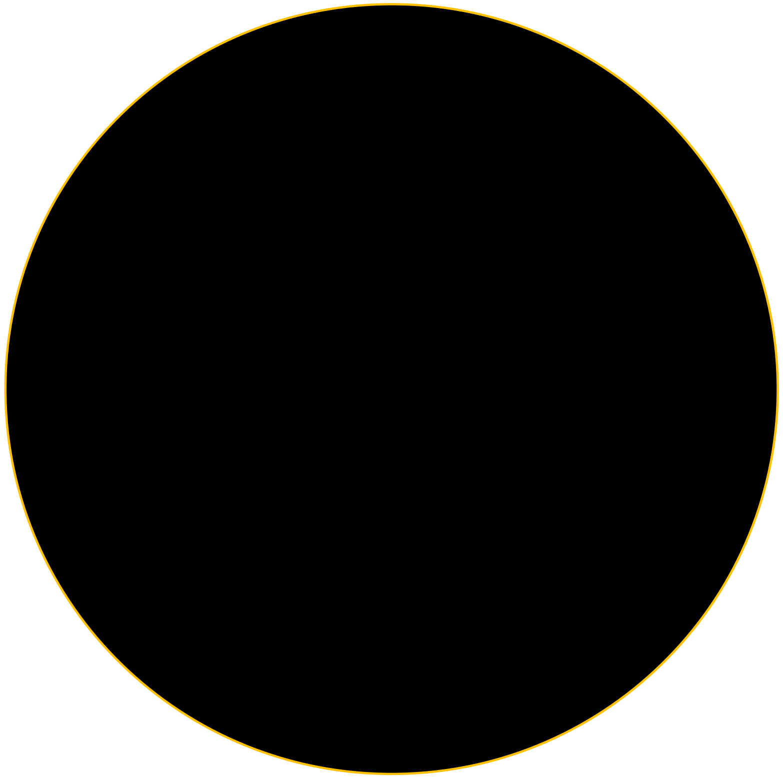
"Information expresses the fact that a system is in a certain configuration that is correlated to the configuration of another system. Any physical system may contain information about another physical system."
Carl Hewitt

Bateson, G. (1972). *Steps to an Ecology of Mind*: Collected Essays in Anthropology, Psychiatry, Evolution, and Epistemology pp. 448–466). University Of Chicago Press.

Hewitt, C. (2007). What Is Commitment? Physical, Organizational, and Social. In P. Noriega, J. Vazquez, Salceda, G. Boella, O. Boissier, & V. Dign (Eds.), Coordination, Organizations, Institutions, and Norms in Agent Systems II (pp. 293 –307). Berlin, Heidelberg: Springer Verlag.

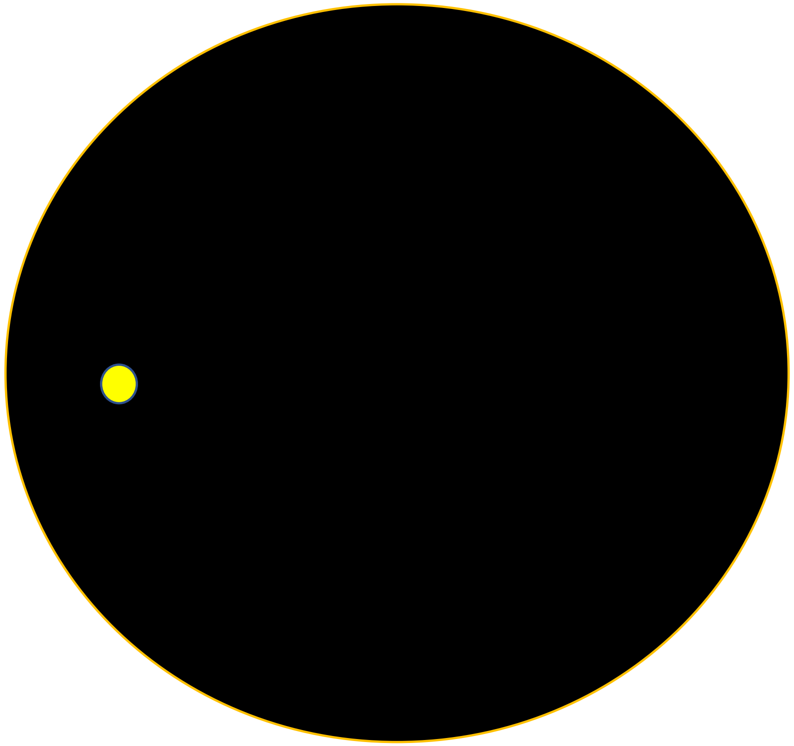
*Aaron Sloman has critical views on Bateson's formulation, in What did Bateson mean when he wrote "information" is "a difference that makes a difference"?
https://www.cs.bham.ac.uk/research/projects/cogaff/misc/information-difference.html

Information from data, an illustration



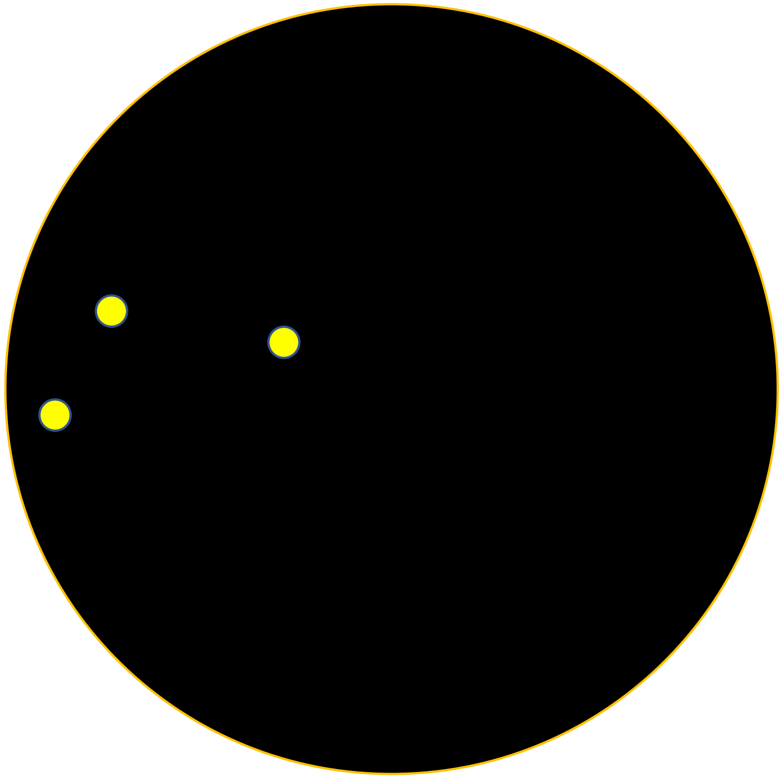
No differences for an agent

Information from data, an illustration



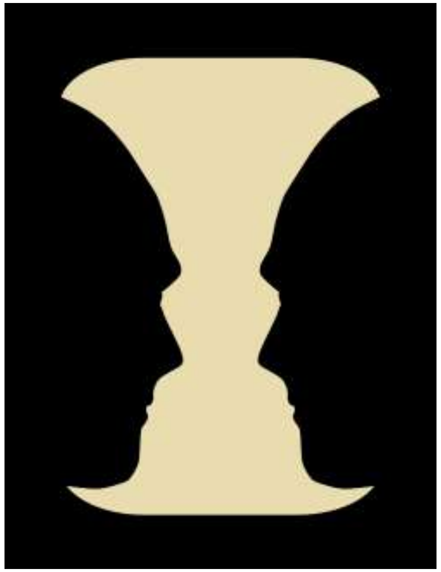
A difference that makes the difference
(For an agent who can see light)

Information from data, an illustration



A system of differences constitutes the fabric of reality for an agent.

Background vs. Foreground (Deacon's absentials)



Even here, the system of differences constitutes the object, which is the reality for an agent-
Switching between background/foreground distinctions .

Top-down causation in cognitive/living systems

Fig. 1. Internal (endogenous) vs. external (exogenous) top-down causation

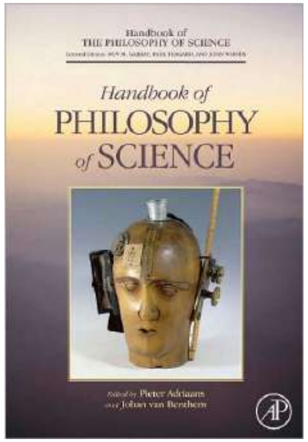
Presented perspective reframes life not merely as a reactive chemical system, but as an organized, memory-driven process oriented toward the future (anticipating).

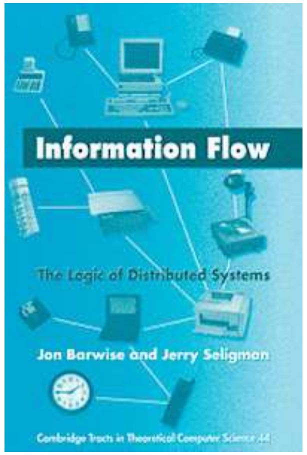
Dodig-Crnkovic, G. (2026) Anticipation, Memory, and Top-Down Causation in Living Systems, BioSystems, Volume 259, 105640, ISSN 0303-2647, https://doi.org/10.1016/j.biosystems.2025.105640.

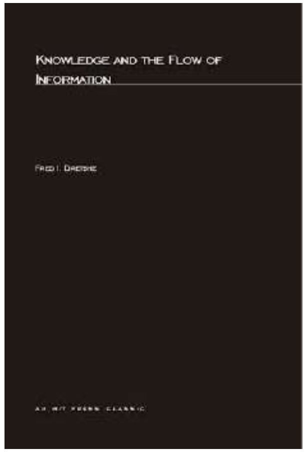
Observing science in making in studies of information and its processes (computation)

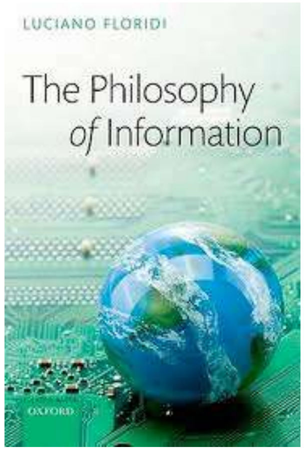
"I invite readers not on a visit to an archaeological museum, but rather on an adventure in science in making"

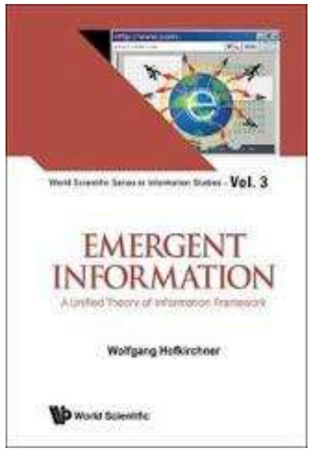
Ilya Prigogine (1997) *The End of Certainty: Time, Chaos and New Laws of Nature*











Information structures as a fabric of reality

Informational structural realism (Floridi, Sayre) argues that information (for an agent) constitutes the fabric of reality:

Reality for a cognizing agent consists of informational structures organized on different levels of abstraction/resolution.

Floridi, L. A defence of informational structural realism. Synthese 161, 219–253 (2008). https://doi.org/10.1007/s11229-007-9163-z

Sayre, K.M. *Cybernetics and the Philosophy of Mind*; Routledge & Kegan Paul: London, 1976

See also:

Van Benthem and Adriaans (2008) Philosophy of Information, In: Handbook of the philosophy of science series. http://www.illc.uva.nl/HPI

Ladyman J. and Ross D., with Spurrett D. and Collier J. (2007) Every Thing Must Go: Metaphysics Naturalized, Oxford UP

Relational approaches in physics, from "It from bit" to relational quantum mechanics and info-computation

"what we call reality arises in the last analysis from the posing of yes-no questions and the registering of equipment-evoked responses; in short, all things physical are information-theoretic in origin and this is a participatory universe."

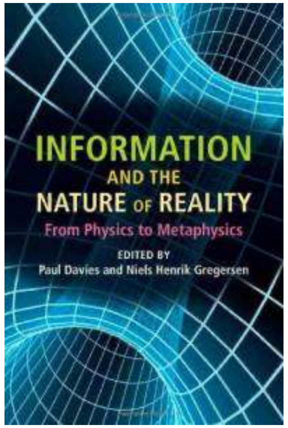
John Archibald Wheeler, "Information, Physics, Quantum: The Search For Links" Proc. 3rd Int. Symp. Foundations Of Quantum Mechanics, Tokyo, 1989, pp.354-368

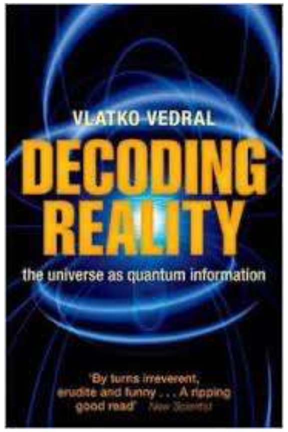
Related approaches:

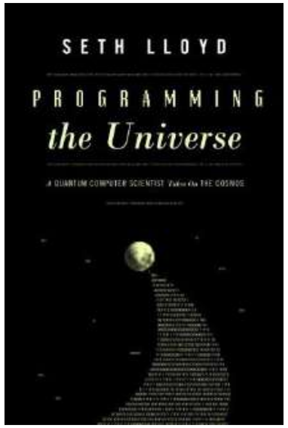
Stephen Wolfram, A Project to Find the Fundamental Theory of Physics
https://writings.stephenwolfram.com/2020/04/finally-we-may-have-a-path-to-the-fundamental-theory-of-physics-and-its-beautiful/

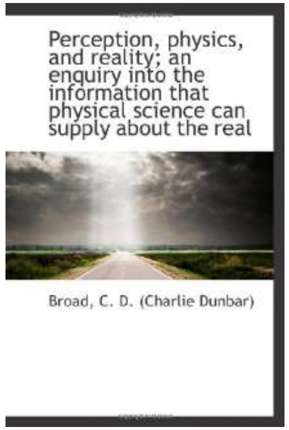
The above two assume discrete systems, the Rovelli, as well as info-computationalism does not!

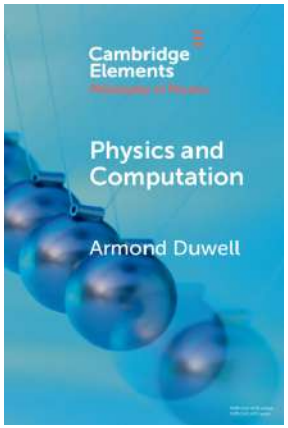
Carlo Rovelli, Relational Quantum Mechanics
https://plato.stanford.edu/entries/qm-relational/
https://www.scientificamerican.com/article/is-there-a-thing-or-a-relationship-betweenthings-at-the-bottom-of-things/

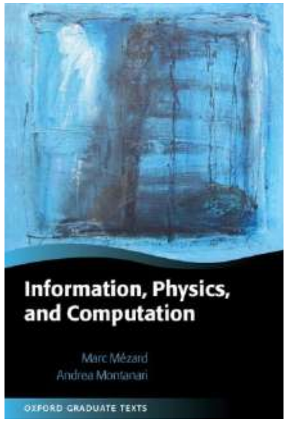

INFORMATION
AND THE
NATURE OF REALITY
From Physics to Metaphysics
EDITED BY
Paul Davies and Niels Henrik Gregersen

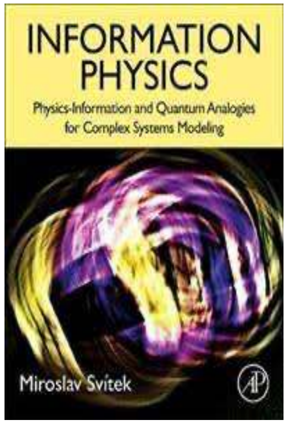

VLATKO VEDRAL
DECODING
REALITY
the universe as quantum information
'By turns irreverent, erudite and funny . . . A ripping good read'

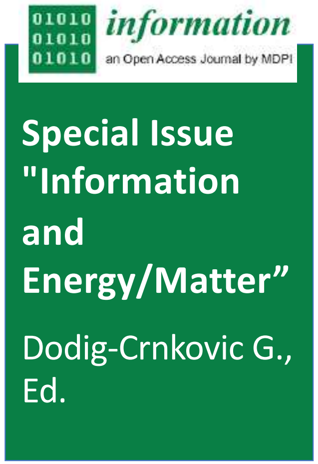

SETH LLOYD
PROGRAMMING
the Universe


Perception, physics, and reality; an enquiry into the information that physical science can supply about the real
Broad, C. D. (Charlie Dunbar)


Cambridge Elements
Physics and Computation
Armond Duwell


Information, Physics, and Computation
Marc Mézard
Andrea Montanari
OXFORD GRADUATE TEXTS


INFORMATION PHYSICS
Physics-Information and Quantum Analogies for Complex Systems Modeling
Miroslav Svítek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information
an Open Access Journal by MDPI
Special Issue "Information and Energy/Matter”
Dodig-Crnkovic G., Ed.

The relational definition of information

Combining classical definitions of Bateson:

" Information is a difference that makes a difference."
(Bateson, 1972)

and Hewitt:

"Information expresses the fact that a system is in a certain configuration that is correlated to the configuration of another system. Any physical system may contain information about another physical system."

(Hewitt, 2007),

we get:

Information is defined as the difference in one physical system that makes the difference in another physical system.

Structure vs. process

For all living agents, information is the fabric of reality.

But: the knowledge of structures is only half a story.

The other half are changes, processes – information dynamics.
In classical formulation: being and becoming.

Information processing will be taken as the most general definition of computation.

This definition of computation has a profound consequence – if computation is the dynamics of informational structures of the universe, the dynamics of the universe is a network of computational processes (natural computationalism).

Gordana Dodig-Crnkovic, Dynamics of Information as Natural Computation, Information 2011, 2(3), 460-477; Selected Papers from FIS 2010 Beijing, 2011.

Reality as an informational structure with computational dynamics: Info-computationalism

Information is defined as the difference in one physical system that makes the difference in another physical system.

This reflects the relational character of information and thus agent-dependency which calls for agent-based or actor models.

As a synthesis of informational structural realism and natural computationalism, I propose info-computational structuralism that builds on two basic concepts: information (as a structure) and computation (as a dynamics of an informational structure) (Dodig-Crnkovic, 2011).

(Dodig-Crnkovic & Giovagnoli, 2013) Information and computation are two basic and inseparable elements necessary for naturalizing <cognition>. (Dodig-Crnkovic, 2009)

Natural computation – computing nature

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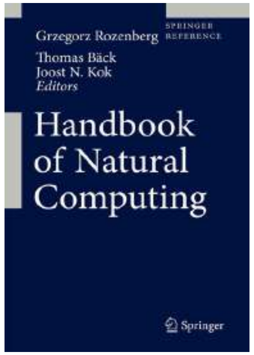
(Dodig-Crnkovic & Giovagnoli, 2013) Information and computation are two basic and inseparable elements necessary for naturalizing <cognition>. (Dodig-Crnkovic, 2009)

Computing Nature and Nature Inspired Computation



In 1623, Galileo in his book *The Assayer - Il Saggiatore*, claimed that the language of nature's book is mathematics and that the way to understand nature is through mathematics. Generalizing "mathematics" to "computation" we may agree with Galileo – the great book of nature is an e-book!

Natural computation includes computation that occurs in nature or is inspired by nature. Computing

Inspired by nature:

Evolutionary computation
Neural networks
Artificial immune systems
Swarm intelligence

Simulation and emulation of nature:

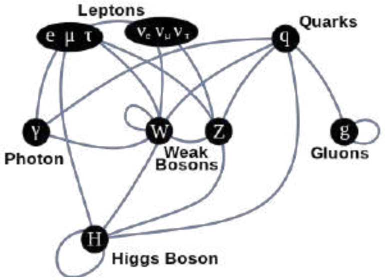
Fractal geometry
Artificial life

Computing with natural materials:

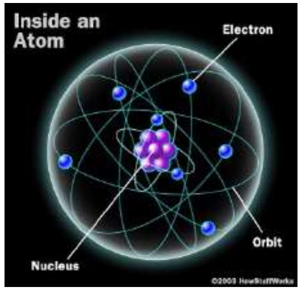
Quantum computing
DNA computing

Journals: Natural Computing and IEEE Transactions on Evolutionary Computation.

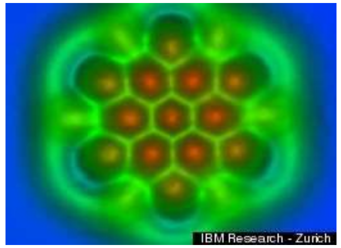
Computing nature and nature inspired computation



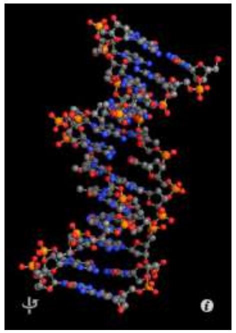
Subatomic particles



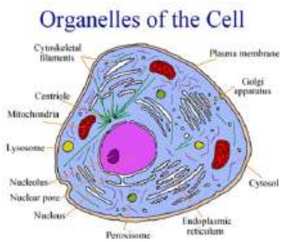
Atoms



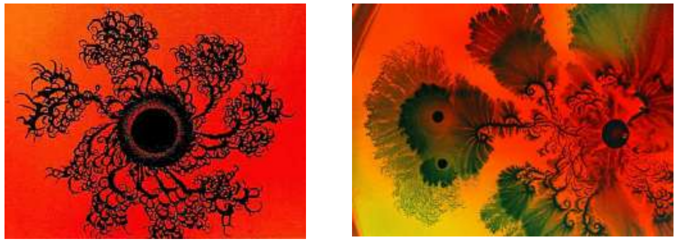
This image, by IBM scientists using an atomic force microscope, shows a nanographene molecule with carbon-carbon bonds



DNA molecule



Unicellular organism



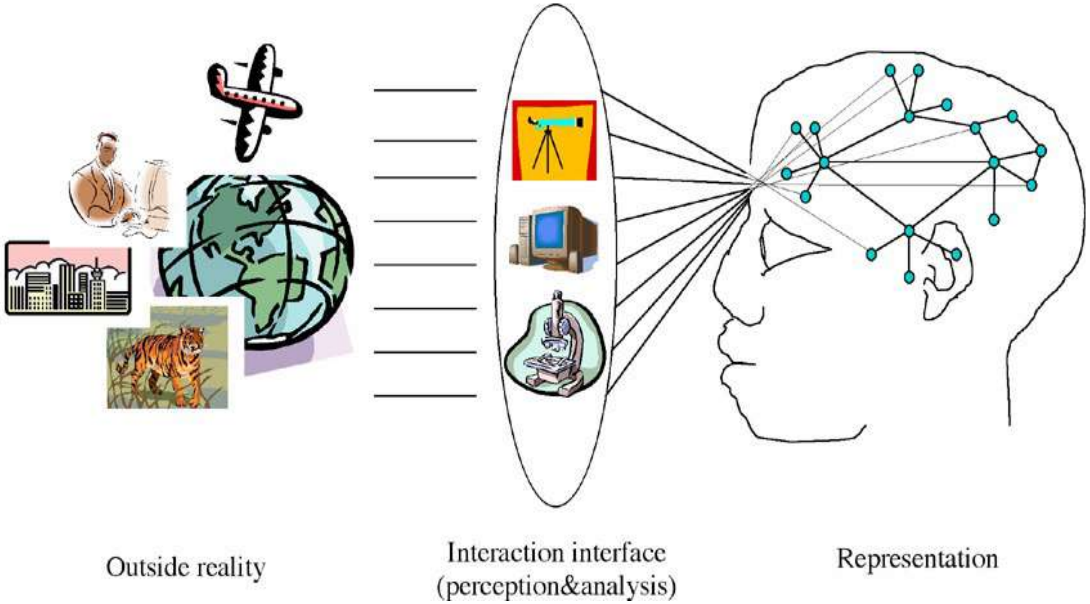
Bacterial colony a multi-cellular "organism"

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

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)

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

Cognition: Agency/Interaction-based hierarchies of levels. The world as information for an agent

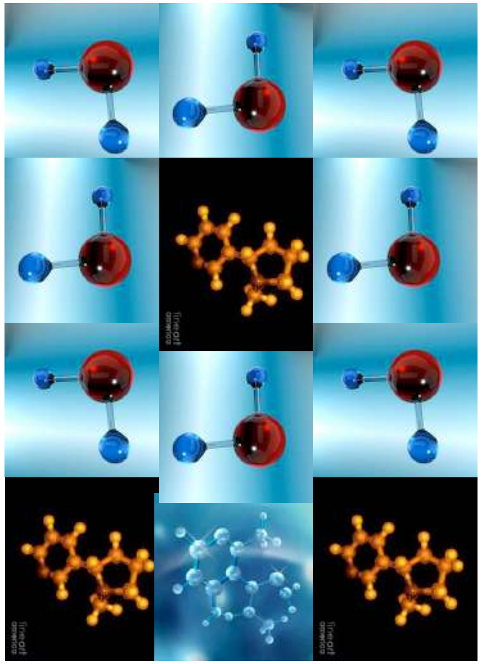


Potential information | Cognition | Actual information for an agent

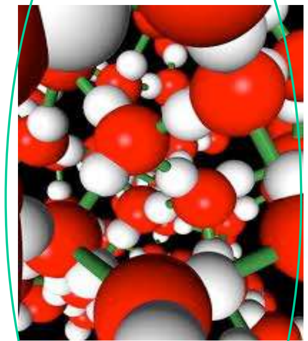
From: http://www.alexeikurakin.org

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

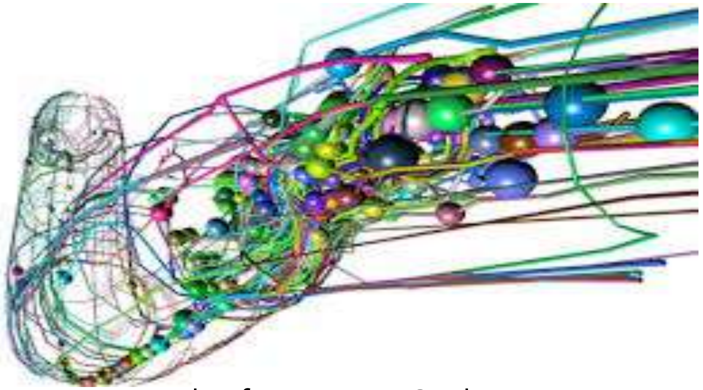
Agency/Interaction-based hierarchies of levels. The world as information for an agent



Potential information
Outside reality for C-elegans



Interaction interface for C-elegans
Cognition



Actual Information C-elegans

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

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

The reality for an agent: info-computation-based observer-dependent reality

The reality for an agent is an informational structure with which the agent interacts. As systems capable of acting on their own behalf and making 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.*"

The meaning of information (for a cognitive agent)

Meaning demystified.

Meaning as use.
All living organisms use information, from single cells to organisms, societies and ecologies.
For all of them, meaning is use.
"Umwelt" Jakob von Uexküll and Thomas Sebeok

In Ludwig Wittgenstein "meaning is use" means words don't have inherent meanings but derive their significance from how they function within specific "language games" and social contexts, acting like tools whose purpose is defined by their application, not a fixed definition or mental image.

* Wittgenstein, Ludwig (1953). Philosophical Investigations: The German Text, with a Revised English Translation. Blackwell. § 23. ISBN 978-0-631-23159-2.

https://en.wikipedia.org/wiki/Philosophical_Investigations
https://en.wikipedia.org/wiki/Umwelt

From Classical to Quantum Relationality

Classical Physics
Galilean Relativity

Relativity Theory
Einstein's Spacetime

Quantum Mechanics
Observer Dependence

Galilean Relativity

- Velocity relative to reference frame
- Relational aspects implicit in classical mechanics

Einstein's Spacetime

- Time, simultaneity, space relative to observer
- Objectivity through translation rules

Quantum Relationality

- Properties relative to interactions
- Observer dependence as structural feature
- Info-computational perspective

Key Insight: Objectivity emerges through inter-agent translation rules rather than observer independence

Relational Quantum Mechanics Framework

Core Principles of RQM

Relational States
Quantum state of system A relative to system B

Measurement Creates Facts
Measurement establishes new relational facts

Observer Independence
No observer-independent description

Fact-Not-State Theory
Focus on facts, not quantum states

Interactive Framework

Quantum states are constraints on possible interactions

QBism
Quantum state as agent's expectations

Entanglement
Correlated informational constraints

Contemporary Relational Approaches

QBism

- Quantum state = agent's expectations
- Measurement = Bayesian updating
- Different states until information exchange

Proponents: Fuchs, Mermin, Schack

Perspectival Q. Realism

- Properties relative to physical perspectives
- Not absolute, not observer-independent
- Reconciliation across perspectives

Proponents: Dieks, Calosi & Riedel

Info-Theoretic Interpretations

- Axiomatic reconstructions based on info constraints
- Operation-based approach
- Focus on information limits

Proponents: Brukner, Zeilinger

Approach	Core Thesis	Relative?	Ontology	Measurement
Relational QM	Fact existence relative to interactions	Fact, states	No global state	Creates relational facts
QBism	Agent's expectations based on info	Knowledge	Participatory realism	Bayesian update
Perspectival Q. Realism	Properties relative to perspective	Properties	Perspectival realism	Reconciliation across perspectives

These approaches converge on a view of physics grounded in relations and information flow

Comparative Analysis of Interpretations

A systematic comparison of relational, perspectival, and informational approaches to quantum mechanics:

Approach	Core Thesis	Ontology	Measurement	Proponents
Relational QM	Facts exist relative to interactions	No global state	Creates relational facts	Rovelli, Di Biagio
Perspectival QM	Properties relative to perspective	Perspectival realism	Reconciliation across perspectives	Dieks, Calosi & Riedel
Pragmatist QM	Meaning = practical context	Use-based ontology	Contextual predictive tool	Healey
QBism	Beliefs of agent	Participatory realism	Bayesian update	Fuchs, Mermin, Schack
Info-theoretic	Axio-derivation of QM	Informational	Operation-based	Zeilinger, Brukner

Relational Focus: Facts emerge through interaction, not intrinsic properties

Perspectival Unity: Different perspectives may assign different states until information exchange

Informational Structure: Physical theory as constraint on information processing

Formal Mathematical Frameworks

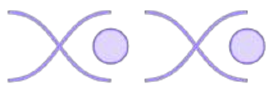
Technical developments supporting relational interpretations of quantum mechanics

Relational Observables

- Loveridge et al. (2018)
- Observables depend on reference systems
- Apparent absolute observables are relational

"Formal treatment shows relationality is structurally grounded"

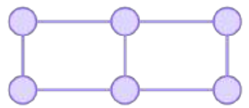
Categorical Quantum Mechanics



- Abramsky & Coecke (2008)
- Reformulates quantum theory in terms of processes
- Diagrammatic ZX-calculus represents informational flow

"Processes and composition rather than systems with intrinsic states"

Graph-Based Formalizations



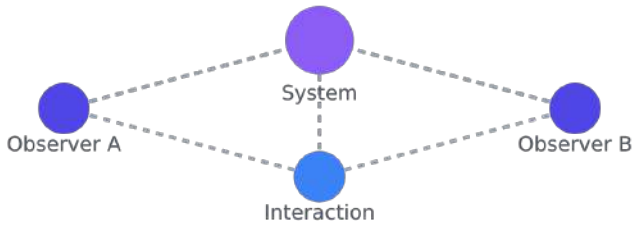
- Martin-Dussaud et al. (2022)
- Fact-nets as graphs of relational facts
- Eliminates need for global state

"Systematic embedding of relationality into mathematical formalism"

Key Insight: These frameworks show that relationality can serve as a mathematical foundation for physics

Info-Computational Perspective

Information Processing Network



Core Principles

Network of Information Processes
Physical reality as interconnected information processing events

Observers as Agents
Active computational entities within physical systems

Measurement as Update
Observation as computational update affecting informational structure

Traditional View

- Object-independent reality
- Observer as passive receiver
- Collapse of wave function

Info-Computational View

- Relational informational structure
- Active computational agents
- Local update rules

Consequences

- Relational objectivity
- Structural operationalism
- Intersubjective coherence

Synthesis and Integration

Integration Insight: QBism clarifies agent perspective,
RQM focuses on relational facts, Info-computationalism provides physical mechanism for RQM & QBism

Feature	Relational Quantum Mechanics	QBism	Info-Computationalism
Quantum State	Relational information	Agent's personal beliefs	Computational structure
Observer Status	Physical systems	Bayesian agents	Information-processing agents
Physical Fact	Event created in interaction	Agent's experience	Computational state update
Objectivity	Emergent from observer agreement	Personal coherence	Structural objectivity

Integration Framework → Complementary Perspectives → Integrated Understanding

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