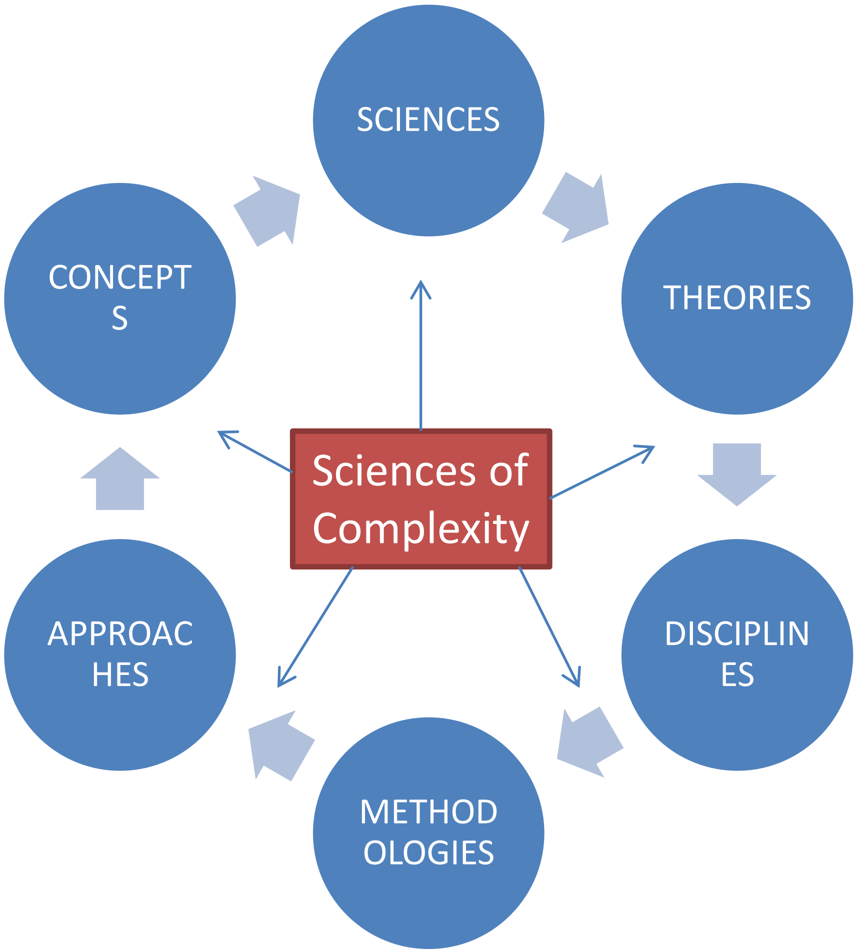
QUANTUM BIOLOGY AND COMPLEXITY

Carlos Eduardo Maldonado

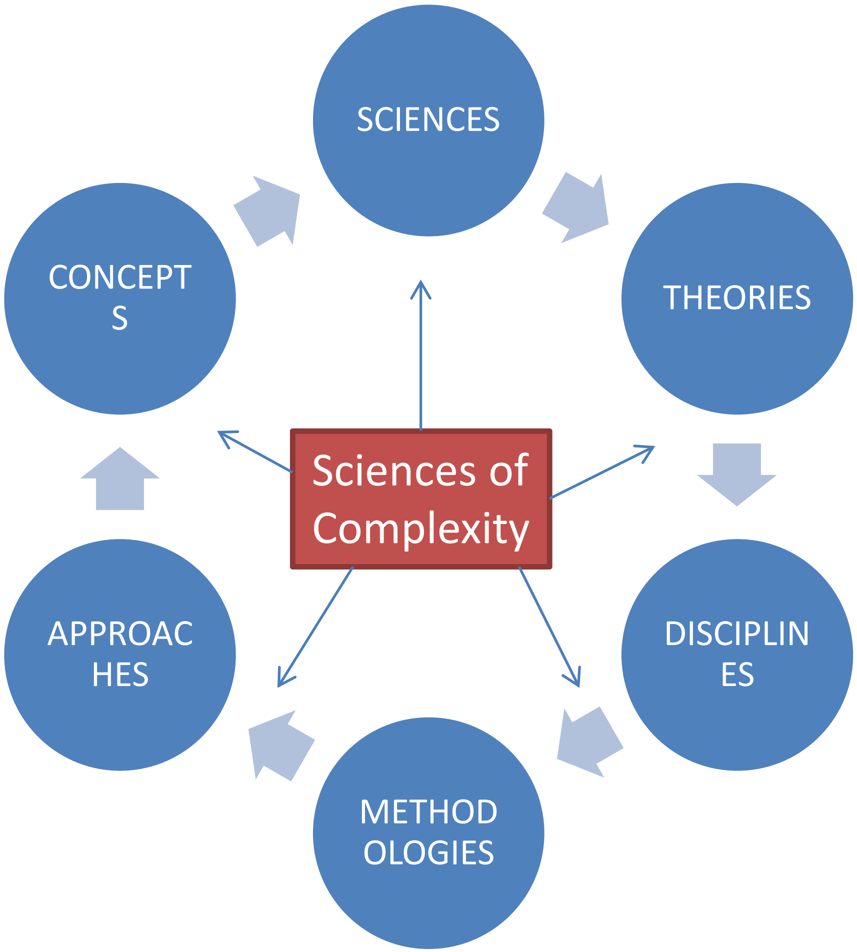
Full Professor

Universidad del Rosario

Complexity science

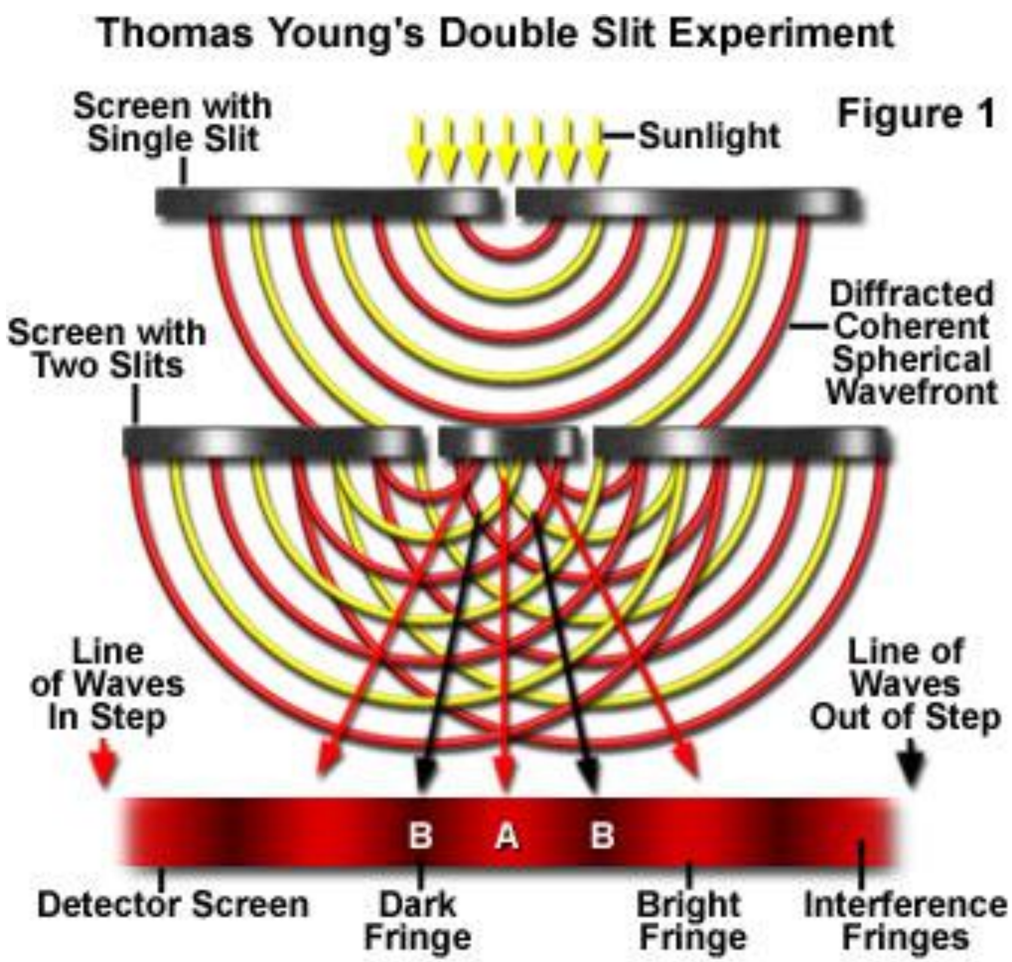


Complexity science



QUANTUM PHYSICS – QUANTUM THEORY

1801

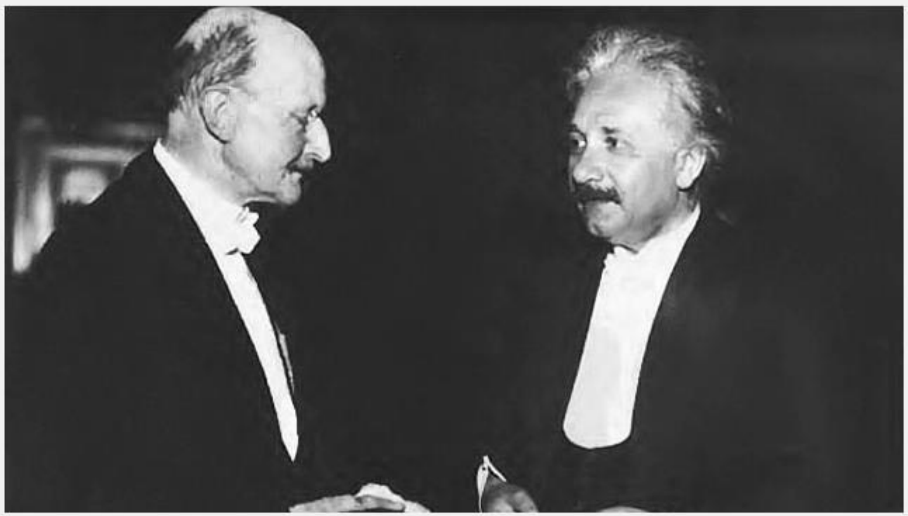


"On the Theory of Light and Colours"

1803

¿Cómo fue el origen de la física cuántica?

Publicado: Domingo, 21 Septiembre 2014 21:47
Escrito por Carlos Eduardo Maldonado



Max Planck | Albert Einstein

La física cuántica nace del resultado de varios antecedentes, directos e indirectos, y de un feliz almuerzo una tarde de domingo con un comensal inteligente y activo en

Profesor Titular, Facultad de Ciencia Política y Gobierno, Universidad del Rosario.

Áreas de trabajo:
Filosofía contemporánea, filosofía política y filosofía social, filosofía de la ciencia.

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www.carlosmaldonado.org

Últimos artículos:

- ¿Qué dice el concepto "grados de libertad"?
- ¿Qué son las matemáticas de sistemas discretos?
- ¿Qué es el yo biológico?
- ¿Cómo fue el origen de la física cuántica?
- ¿Qué es la hipercomputación biológica?

Two Moments in QP (1)

The Copenhaguen Debate

Bohr

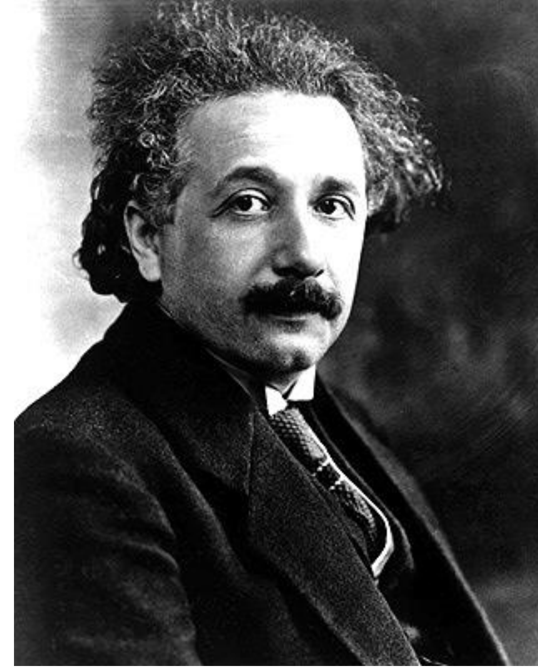
- Heisenberg
- Dirac

Einstein

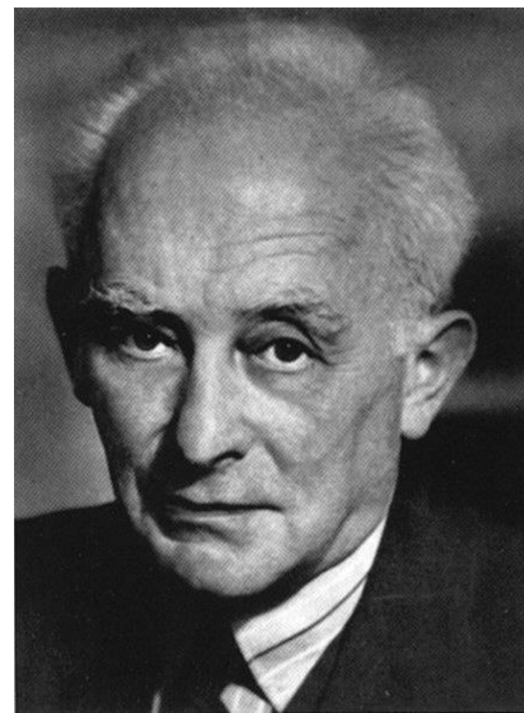
- Born
- Pauli

Schrödinger

De Broglie



Library of Congress



The Copenhaguen Debate

Indeterminism

- Complementarity
- Uncertainty

Determinism

- Quantum Mechanics
- Realism

Schrödinger´s Paradox

Hidden Variables

A. PICCARD E. HENRIOT P. EHRENFEST Ed. HERZEN Th. DE DONDER E. SCHRÖDINGER E. VERSCHAFFELT W. PAULI W. HEISENBERG R.H. FOWLER L. BRILLOUIN
P. DEBYE M. KNUDSEN W.L. BRAGG H.A. KRAMERS P.A.M. DIRAC A.H. COMPTON L. de BROGLIE M. BORN N. BOHR
I. LANGMUIR M. PLANCK Mme CURIE H.A. LORENTZ A. EINSTEIN P. LANGEVIN Ch.E. GUYE C.T.R. WILSON O.W. RICHARDSON
Absents : Sir W.H. BRAGG, H. DESLANDRES et E. VAN AUBEL

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SOLVAY CONFERENCE 1927

A. PICARD E. HENRIOT P. EHRENFEST Ed. HERSEN Th. DE DONDER E. SCHRÖDINGER E. VERSCHAFFELT W. PAULI W. HEISENBERG R.H FOWLER L. BRILLOUIN

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Absents : Sir W.H. BRAGG, H. DESLANDRES et E. VAN AUBEL

P. Dirac,
The Principles of Quantum Physics

- Superposition
- Dynamical Variables and Observables
- Representations

Decoherence

Uncertainty

Non-locality

- The Quantum Conditions
- The Equations of Motion
- Perturbation Theory

Complementarity

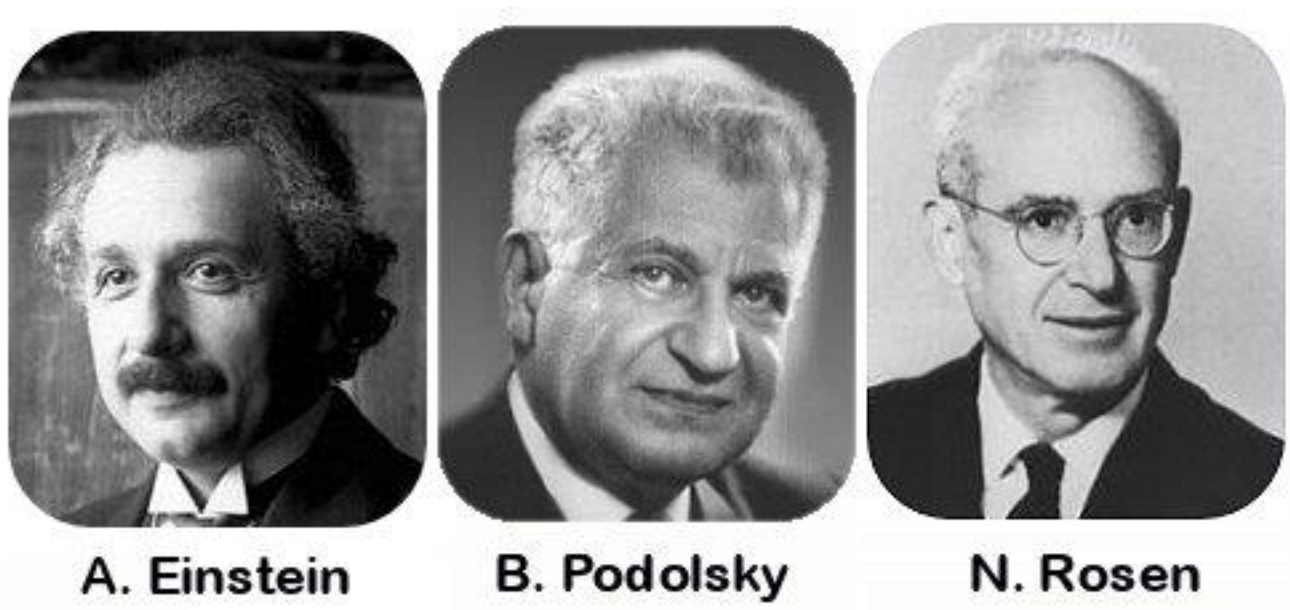
Interference

Heisenberg

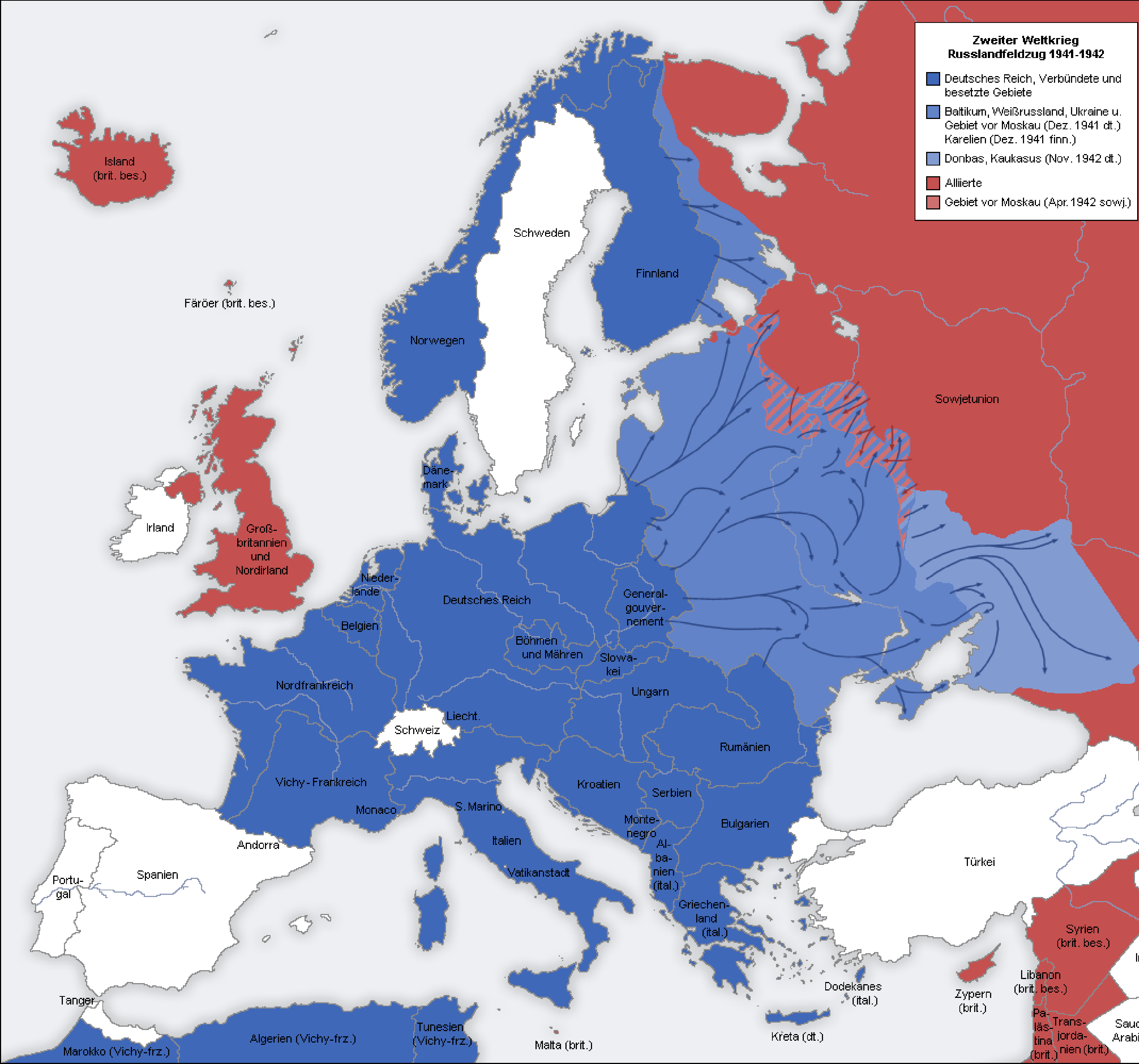
- “’If we know the present exactly, we can predict the future” – it is not’ the conclusion but rather the premise which is false

EPR's Paper: 1934

- Can Quantum Mechanical Description of Reality Be Complete?



And then…


Zweiter Weltkrieg
Russlandfeldzug 1941-1942
Deutsches Reich, Verbündete und besetzte Gebiete
Baltikum, Weißrussland, Ukraine u. Gebiet vor Moskau (Dez. 1941 dt.) Karelien (Dez. 1941 finn.)
Donbas, Kaukasus (Nov. 1942 dt.)
Alliierte
Gebiet vor Moskau (Apr. 1942 sowj.)
Island (brit. bes.)
Färöer (brit. bes.)
Schweden
Finnland
Norwegen
Sowjetunion
Däne-mark
Irland
Groß-britannien und Nordirland
Nieder-lande
Deutsches Reich
General-gouver-nement
Belgien
Böhmen und Mähren
Slowa-kei
Nordfrankreich
Ungarn
Liecht.
Schweiz
Rumänien
Vichy-Frankreich
Kroatien
Serbien
Monaco
S. Marino
Monte-negro
Bulgarien
Andorra
Italien
Al-ba-nien (ital.)
Türkei
Portu-gal
Spanien
Vatikanstadt
Griechen-land (ital.)
Syrien (brit. bes.)
Irak
Libanon (brit. bes.)
Dodekanes (ital.)
Zypern (brit.)
Tanger
Pa-läs-tina (brit.)
Trans-jorda-nien (brit.)
Saudi-Arabien
Tunesien (Vichy-frz.)
Algerien (Vichy-frz.)
Marokko (Vichy-frz.)
Malta (brit.)
Kreta (dt.)

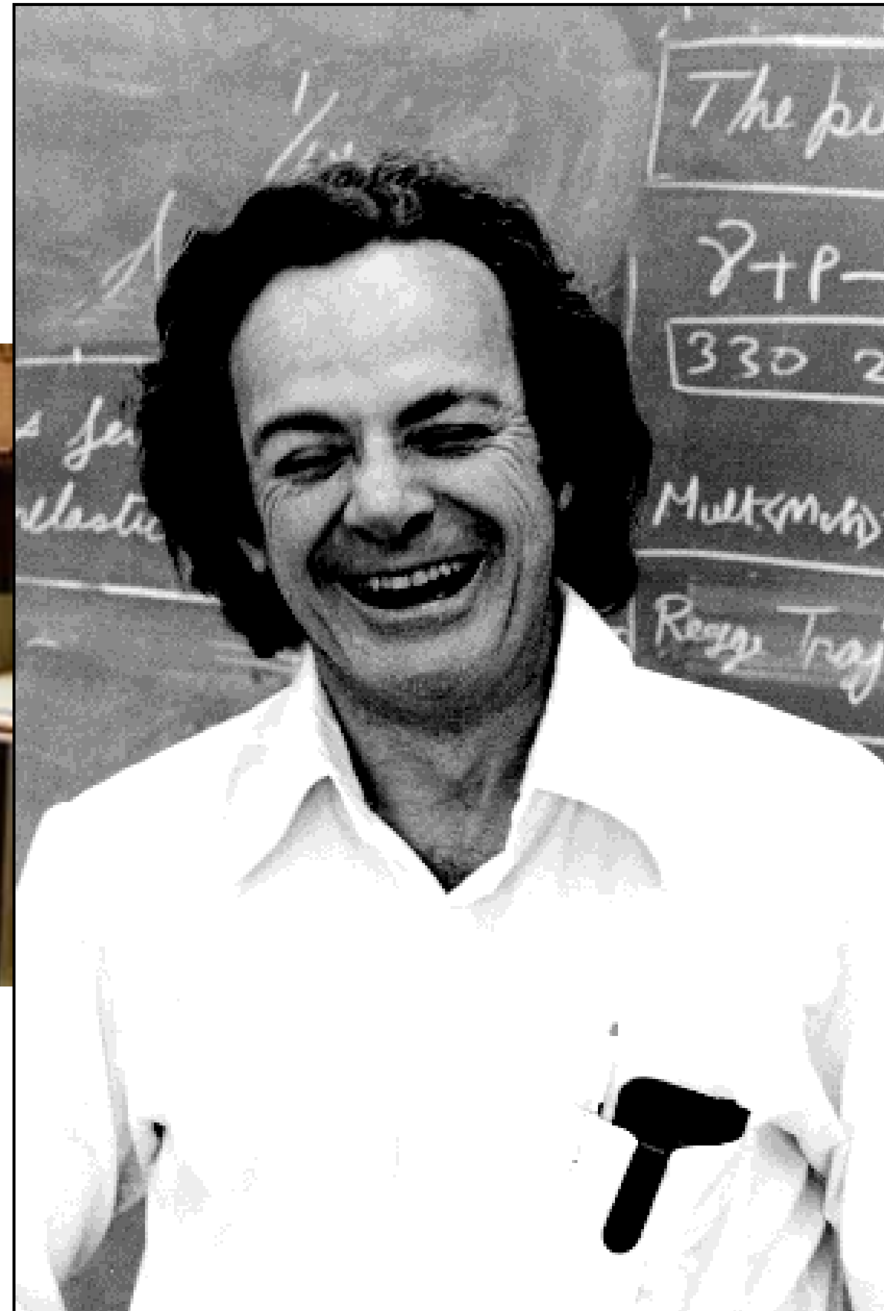


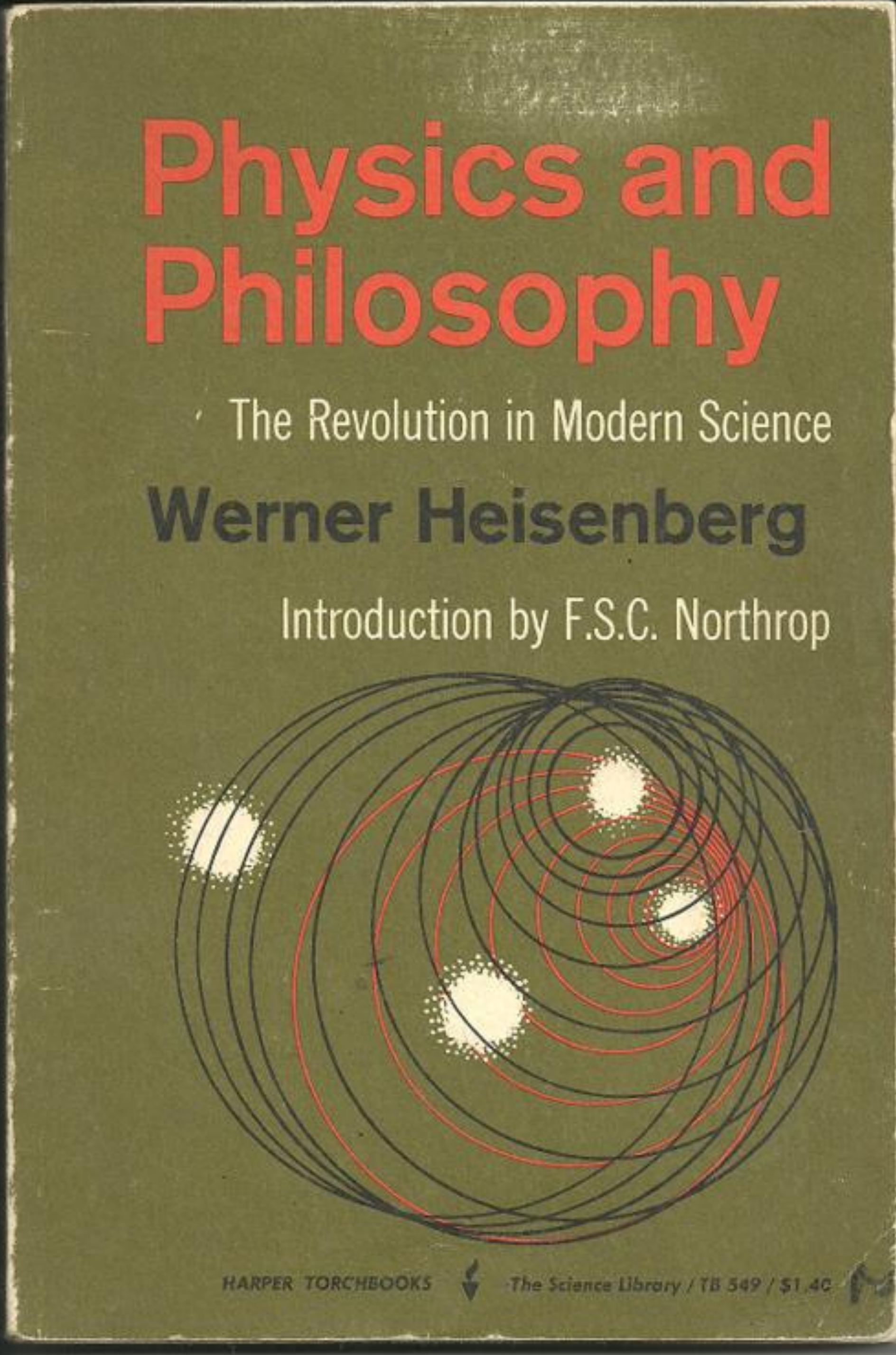

Two Moments in QP (2)

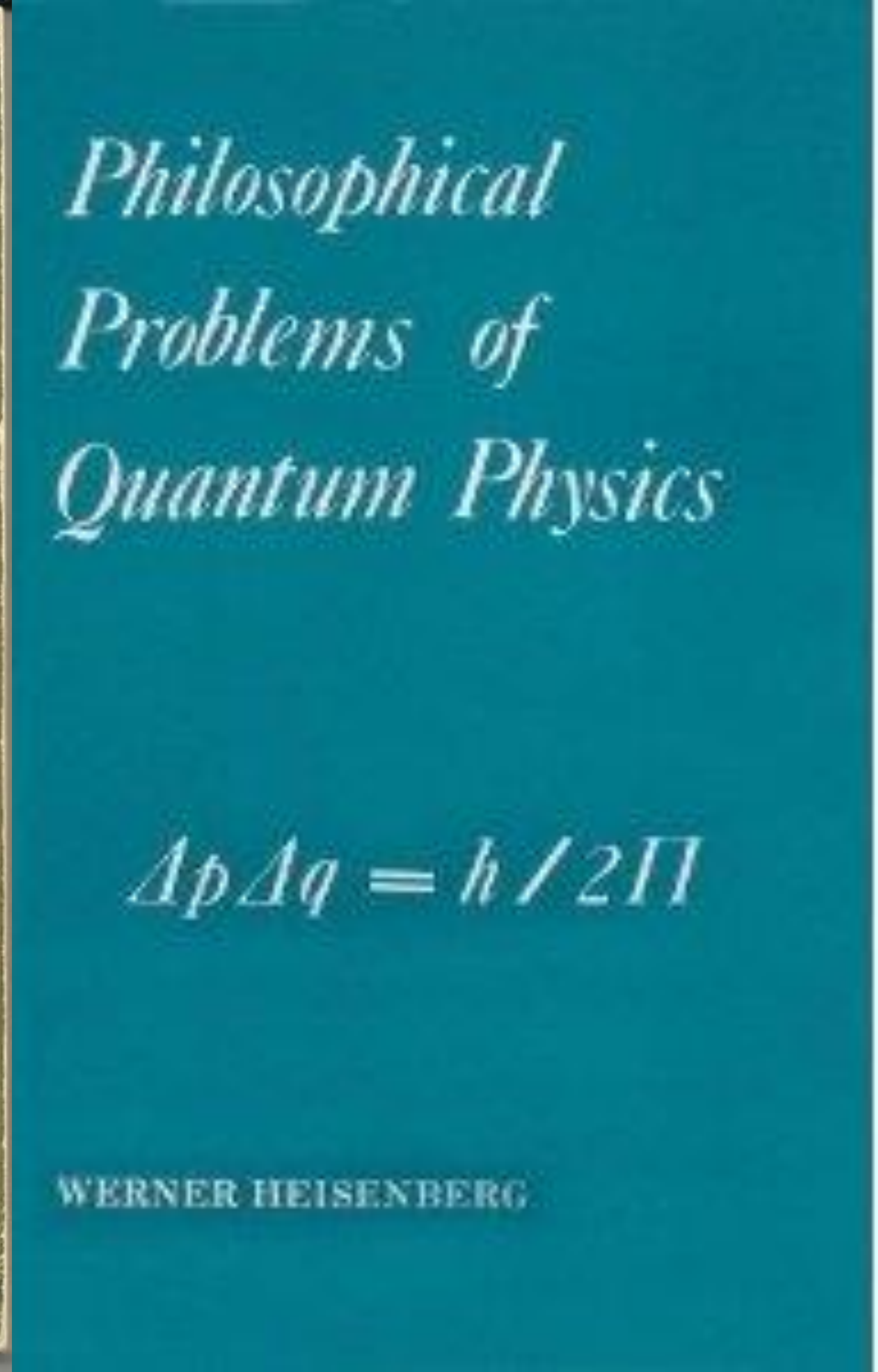
The 1960s

- The “Wholeness”
- Cfr. System thinking, system science, cybernetics. Complex thinking

- …The sciences of complexity…

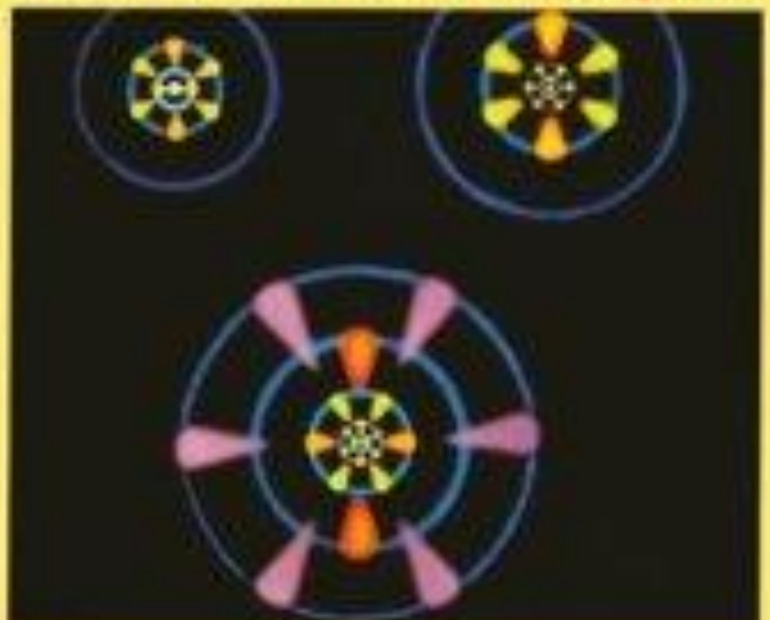



Physics and Philosophy
The Revolution in Modern Science
Werner Heisenberg
Introduction by F.S.C. Northrop
HARPER TORCHBOOKS
The Science Library / TB 549 / $1.40


Philosophical Problems of Quantum Physics
$\Delta p \Delta q = h / 2\Pi$
WERNER HEISENBERG

Louis de
BROGLIE

NOUVELLES
PERSPECTIVES
EN MICROPHYSIQUE

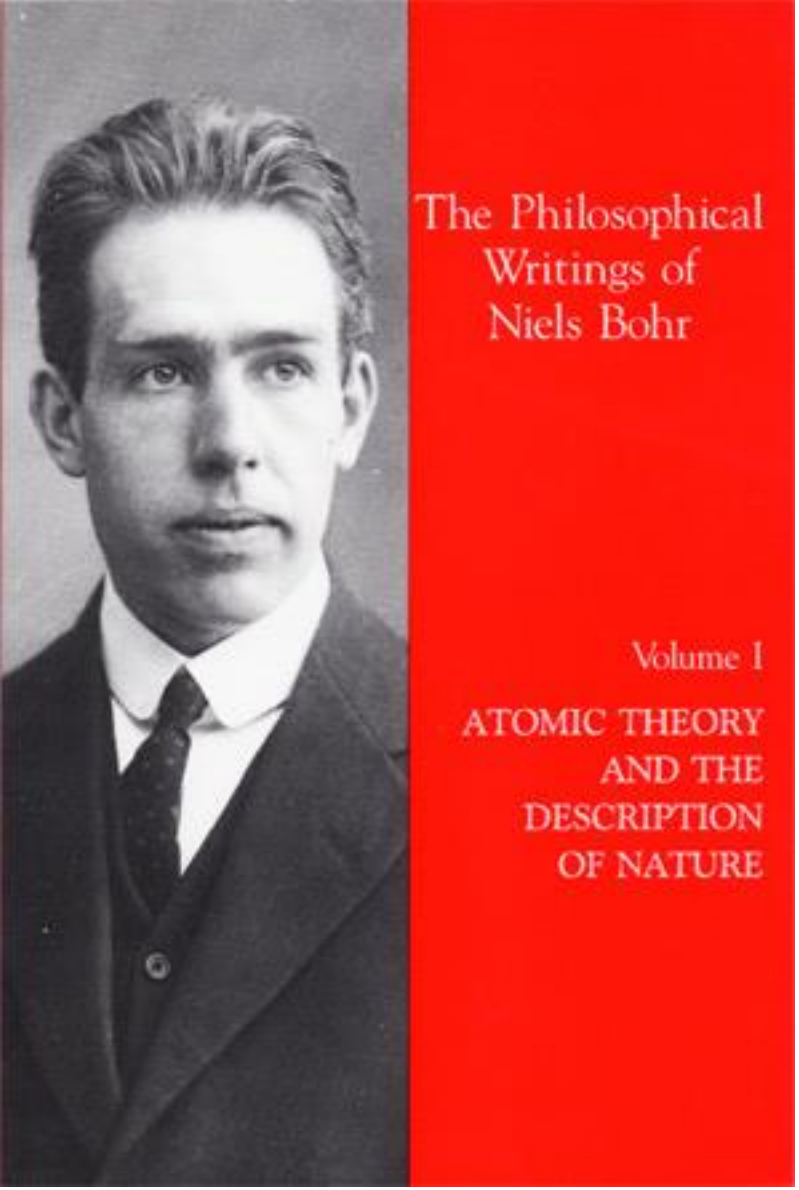


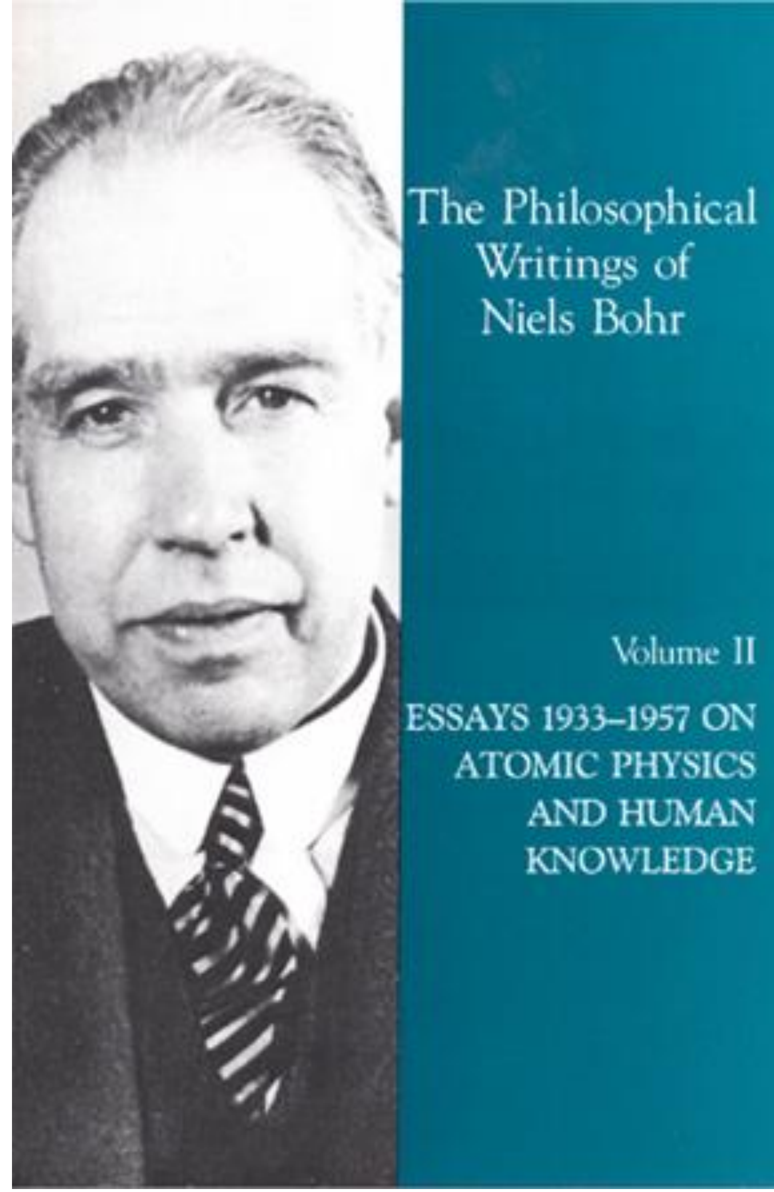
Champs
Flammarion

BROGLIE

LA
PHYSIQUE NOUVELLE
ET LES QUANTA

Champs
Flammarion


The Philosophical
Writings of
Niels Bohr
Volume I
ATOMIC THEORY
AND THE
DESCRIPTION
OF NATURE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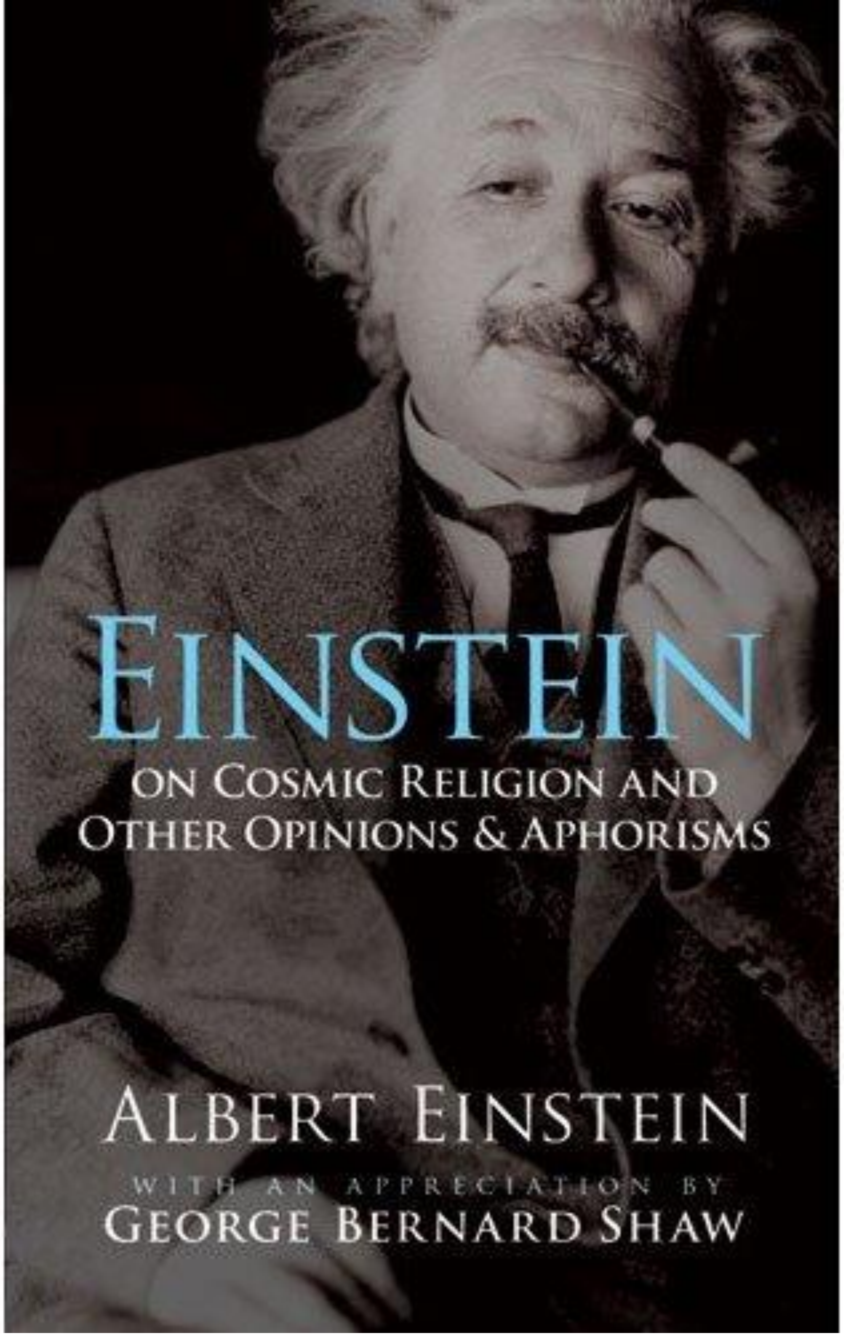
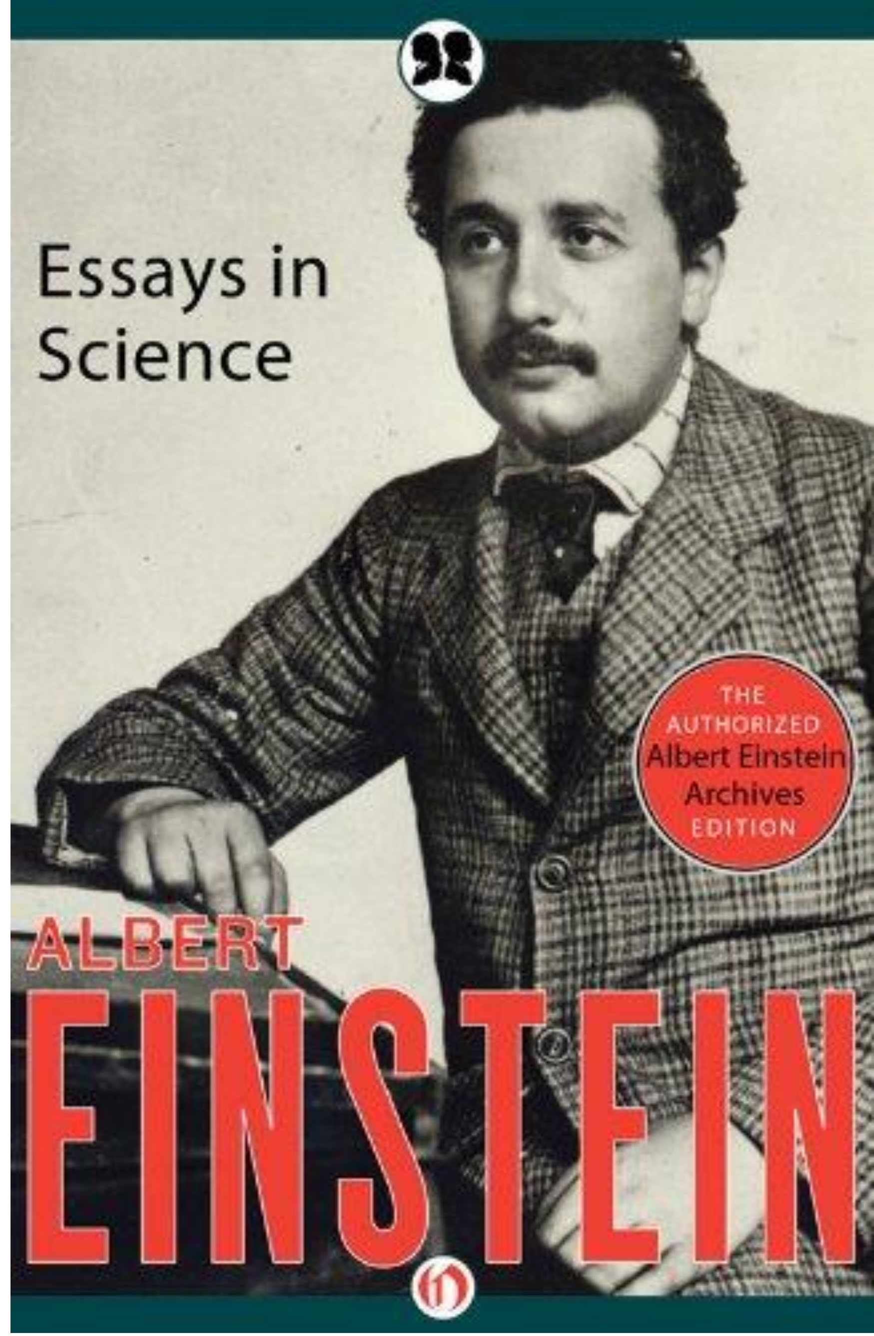
ATOMIC PHYSICS
AND HUMAN
KNOWLEDGE


EINSTEIN
ON COSMIC RELIGION AND
OTHER OPINIONS & APHORISMS
ALBERT EINSTEIN
WITH AN APPRECIATION BY
GEORGE BERNARD SHAW


Essays in
Science
THE
AUTHORIZED
Albert Einstein
Archives
EDITION
ALBERT
EINSTEIN

Bohm and Feymann

- Hidden Variables

- The spirit of wholeness: three parts: quantized motion, statistical causality, and

  Indivisible wholeness

- Quantum Mechanics

  and Quantum Electrodynamics

Oppenheimer

- If we cannot disprove Bohm, then we must agree to ignore him

Hidden Variables

- Critique of non-locality
- A determinist system of reality

REALITY

- MACROSCOPIC

  second = 1/60 m

  minute = 1/60 h

  day = 24 hs

  year = 365 ds

  century = 100 ys

  million years = 10^6

  billion years = 10^{12}

- MICROSCOPIC

  mili = 10^{-3}

  micro = 10^{-6}

  nano = 10^{-9}

  pico = 10^{-12}

  femto = 10^{-15}

  atto = 10^{-18}

Planck time: 10^{42} secs

Learning the Dimensionality of Hidden Variables

ABSTRACT: We examine how to determine the number of states of a hidden variable when learning probabilistic models. This problem is crucial for improving our ability to learn compact models and complements our earlier work of discovering hidden variables. We describe an approach that utilizes a score-based agglomerative state-clustering. This approach allows us to efficiently evaluate models with a range of cardinalities for the hidden variable. We extend our procedure to handle several interacting hidden variables. We demonstrate the effectiveness of this approach by evaluating this on several synthetic and real-life data sets. We show that our approach learns models with hidden variables that generalize better and have better structure then previous approaches.

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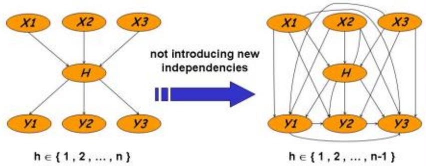
1 Importance of dimensionality



Representation: The minimal **I-map** — minimal structure which implies only independencies that hold in the marginal distribution — is typically complex

Improve Learning: Models with fewer parameters allow us to learn faster and more robustly.

2 Problem with Naive Approach

Why not apply EM estimation for each cardinality until optimum is found?

➢ Score is not decomposable and estimations are used (e.g. Cheeseman-Stutz)

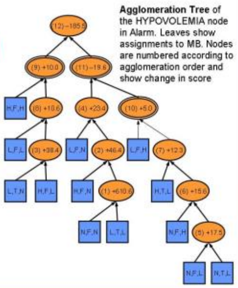
➢ Several EM iterations for each cardinality are computationally intensive

Idea: When data is complete, different models are compared using a decomposable score such as the **Bayesian scoring metric**:

$$Score(G : D) = \log P(G \mid D) = \sum_i FamScore_{X_i}(Pa_{X_i} : D)$$

3 Choosing the dimensionality

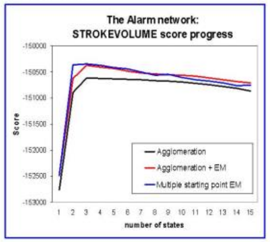
- Start with a unique state for each **Markov Blanket** assignment
- Combine two states for maximal improvement
- Choose the best number of states



Agglomeration Tree of the HYPOVOLEMIA node in Alarm. Leaves show assignments to MB. Nodes are numbered according to agglomeration order and show change in score

4 Behavior of the score

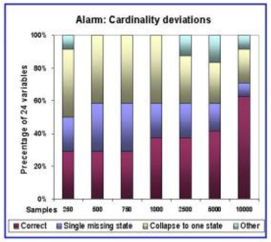
- Efficient computation: $N[h_i, Pa_H] + N[h_j, Pa_H] = N[h_{ij}, Pa_H]$ and does not depend on other states
- Complexity reduction increases the score
- Score of $Family_H$ is increased when |H| is smaller
- Score of $Family_{Child(H)}$ is decreased and towards a single state drops rapidly



5 Single Hidden Variable

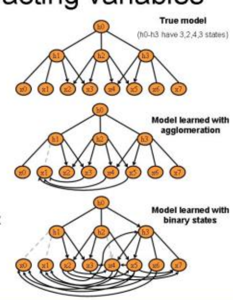
24 Variables in the **Alarm** network were hidden separately and the agglomeration method was applied:

- Perfect recovery for 15 variables, single missing state for 2 variables
- 2 variables received an extra state to explain random dependencies for children with stochastic CPTs
- 5 redundant variables collapse to a single state (confirmed by exhaustive EM runs)



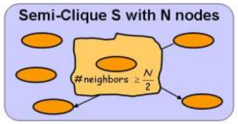
6 Several interacting variables

- Bottom-up Round-robin iteration between hidden variables
- Initialize using only observable nodes
- Improvement to score guarantees convergence
- Naive binary model is significantly more complex



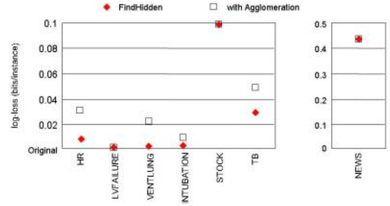
7 The **FindHidden** Algorithm

A hidden variable discovery algorithm (Elidan et al, 2000) that uses structural signatures (approximates cliques) to detect hidden variables.



◆ Propose a candidate network:
(1) Introduce *H* as a parent of all nodes in *S*
(2) Replace all incoming edges to S by edges to *H*
(3) Remove all inter-*S* edges
(4) Make all children of S children of *H* if acyclic

8 Integration with **FindHidden**



Log-loss performance of **FindHidden** with and without agglomeration on test and real-life data. Base line is the performance of the original input network.

9 Summary and Future Work

✓ Introduced importance of cardinality for hidden variables

✓ Implemented a computationally effective agglomerative method to determine the number of states

✓ Showed effectiveness for single and many hidden variables

✓ Improved performance and quality of models learned when combined with **FindHidden**

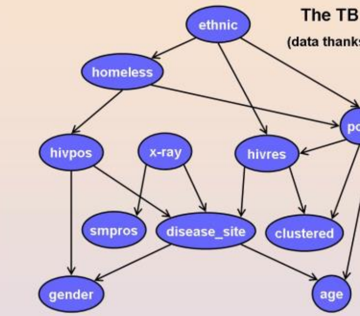
Future work:

➢ Use additional measures to discover hidden variable such as edge confidence, information measures computed directly from the data, etc.

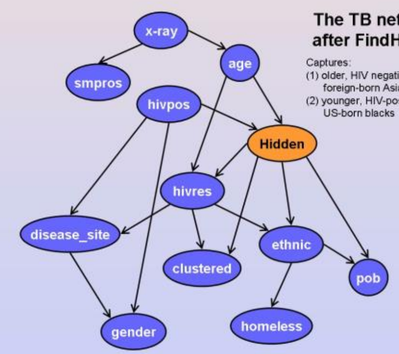
➢ Handle hidden variables when the data is sparse

➢ Explore hidden variables in **P**robabilistic **R**elational **M**odels

The TB network
(data thanks to P. Small)

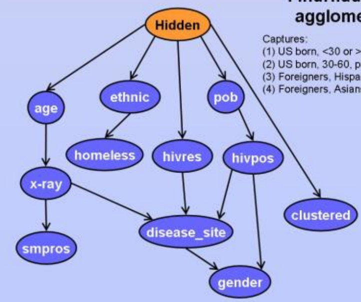


The TB network after FindHidden



Captures:
(1) older, HIV negative, foreign-born Asians
(2) younger, HIV-positive, US-born blacks

The TB network after FindHidden with agglomeration



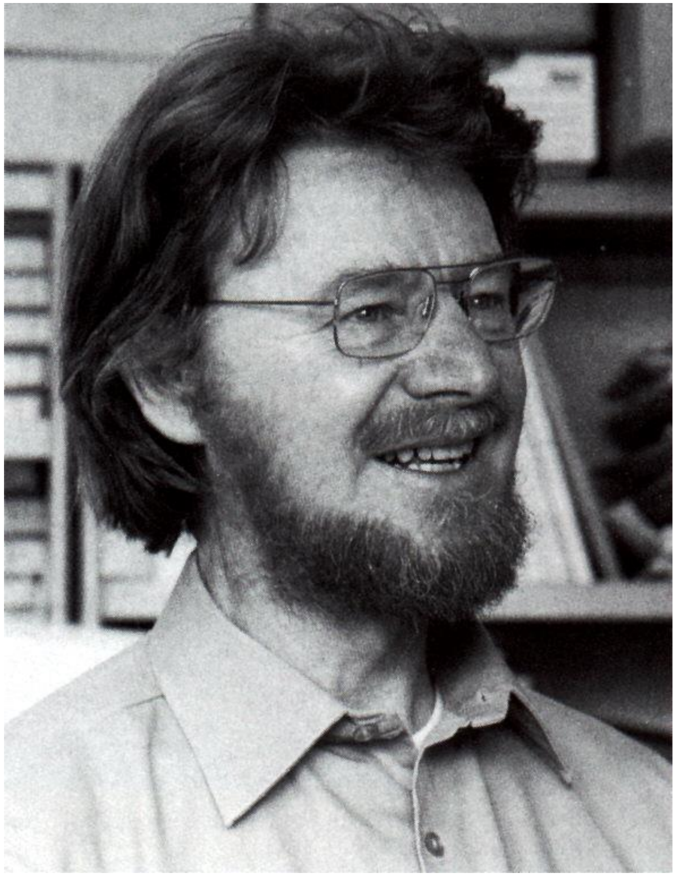
Captures:
(1) US born, <30 or >60, HIV
(2) US born, 30-60, probable HIV
(3) Foreigners, Hispanics, possible HIV
(4) Foreigners, Asians, HIV negative

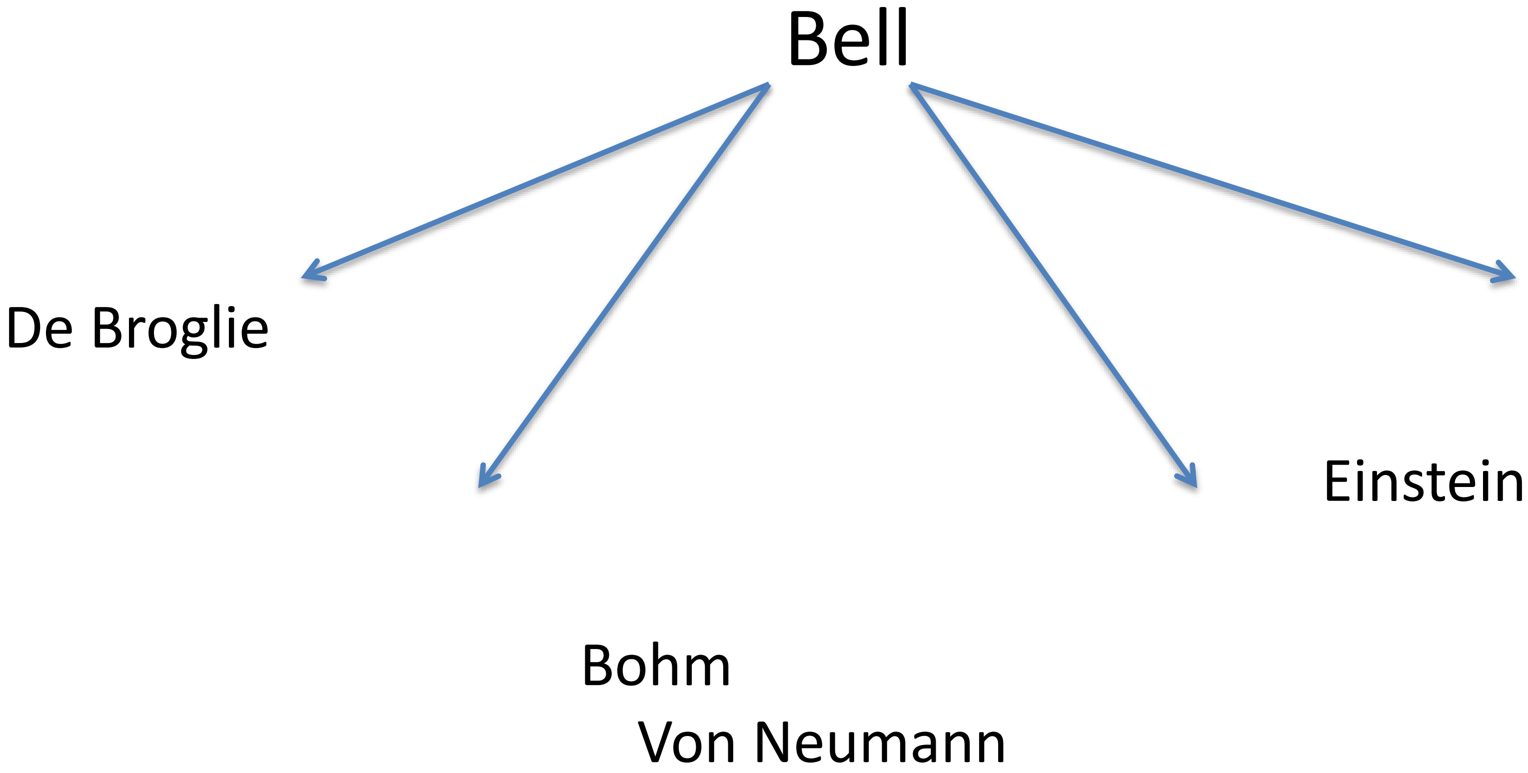
FAPP

- We believe that some things happen with such high probability that FAPP it is reasonable to suppose that they happen with certainty

J. Bell

- CERN
- Quantum Entanglement
- Bell dreamed of a theory with entities that were real regardless of the actions of the experimentalists, which nonetheless produced the same results as quantum mechanics




Bell
De Broglie
Einstein
Bohm
Von Neumann

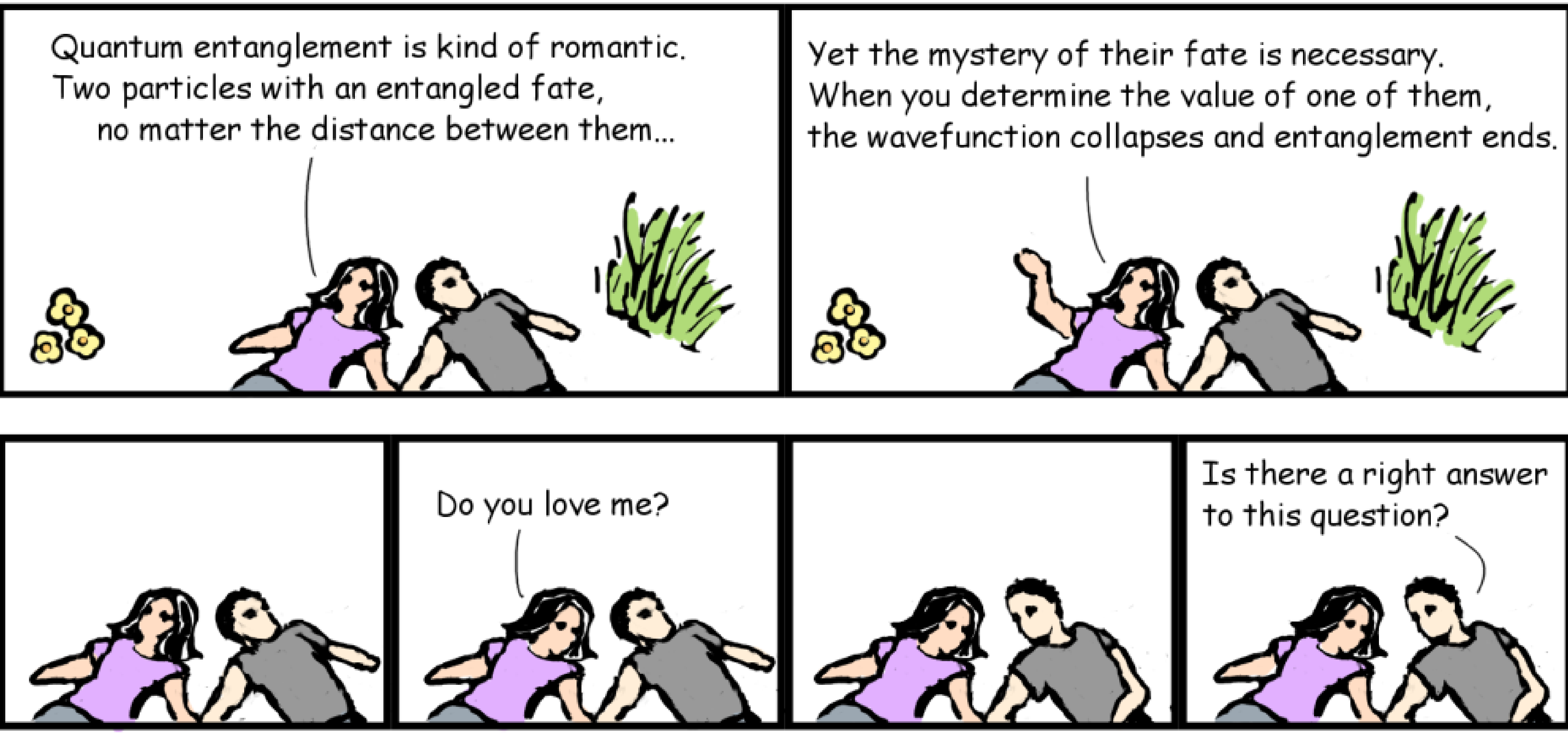
- The Moral Aspect of Quantum Mechanics, by Bell and Nauenberg: “We look forward to a new theory which

- Bell, *Speakable and Unspeakable in Quantum Mechanics* (2004, 2011)

Entanglement

- Bell dreamed of a theory with entities that were real regardless of the action of the experimentalists, which nonetheless produced the same results as quantum mechanics

- An entangled state is not the product of two individual states – two particles in an entangled state have *no* individual states


Quantum entanglement is kind of romantic. Two particles with an entangled fate, no matter the distance between them...
Yet the mystery of their fate is necessary. When you determine the value of one of them, the wavefunction collapses and entanglement ends.
Do you love me?
Is there a right answer to this question?

1976

- Fry: demonstrated entanglement, and the absence of any local, realistic explanation
- At MIT, a decade after, entanglement of three particles

Relativity and Entanglement

- Relativity is adamantly a local theory about separable, real objects
- seems to deny that these attributes can actually all coexist in nature

Quantum Parallelism

- Quantum computation and entanglement
- Could a classical computer simulate a quantum system? No! This is called the hidden-variable problem

C. Fuchs

- “Almost all the formal structure of the quantum theory is not really about physics at all. It is about the formal tools for describing what we know” (1998)

- i.o.w: The wave function is knowledge

Zurek

- An unending process of movement and unfolding
- Of Information

Criptography

- S. Lloyds: The universe is a quantum system, and almost all of its pieces are entangled.

Matter – Energy - Information

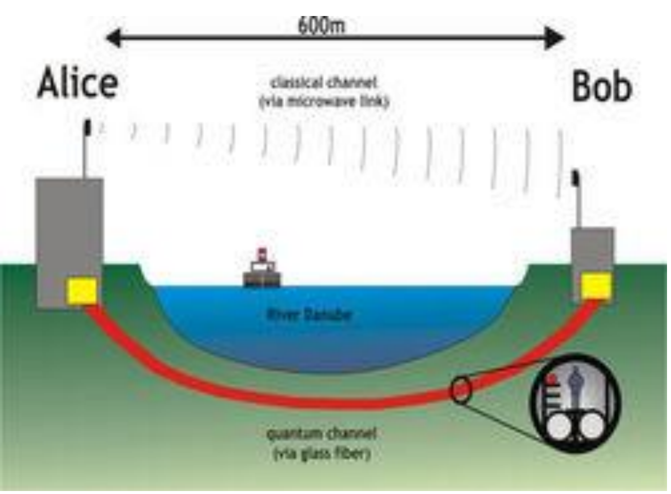
- Uncertainty provides the seeds from which new detail and structure emerge, and through entanglement, quantum mechanics, unlike classical mechanics *can create information out of nothing*.

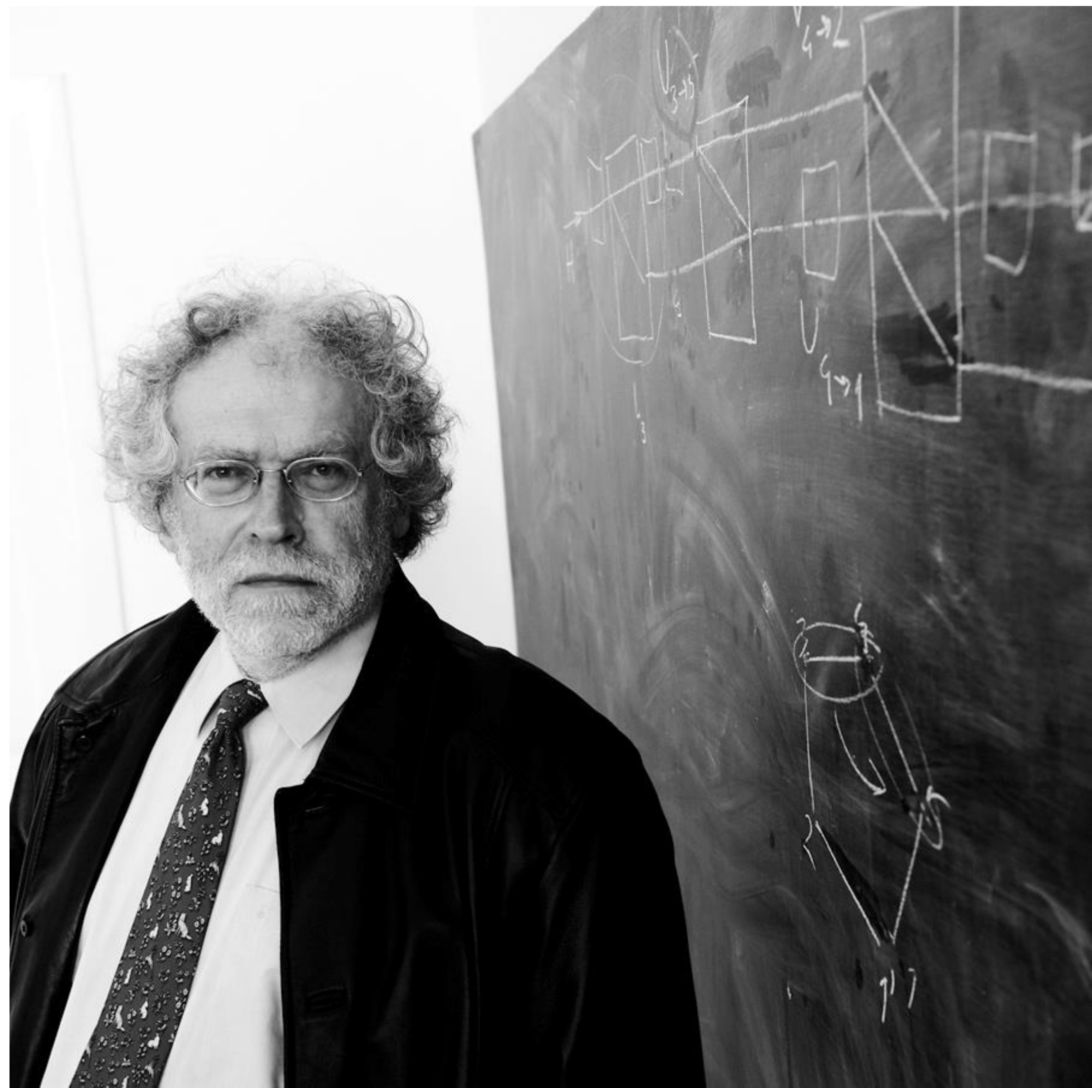
- If the quantum computer entangles with its environment, it will produce random results (that is, results that are correlated with things the computer programmer does not want and cannot control).

- The more entanglement is available, the better suited a system is to quantum information processing

1997

- Quantum Teleportation: A. Zeilinger





Zeilinger

- Quantum mechanics: there is no difference between epistemology and ontology: being and knowing are intertwined

The Importance of QT

- All new technology is QP-based
- It is by far the best tested and most predictive theory, ever
- It is (my contention) along with the theory of evolution the two hard-core theories in science, at large

However…

- General Theory of Relativity
- Quantum Theory
- The challenge of unification

→ Quantum field theory (etc.)

Two of the ultimate problems

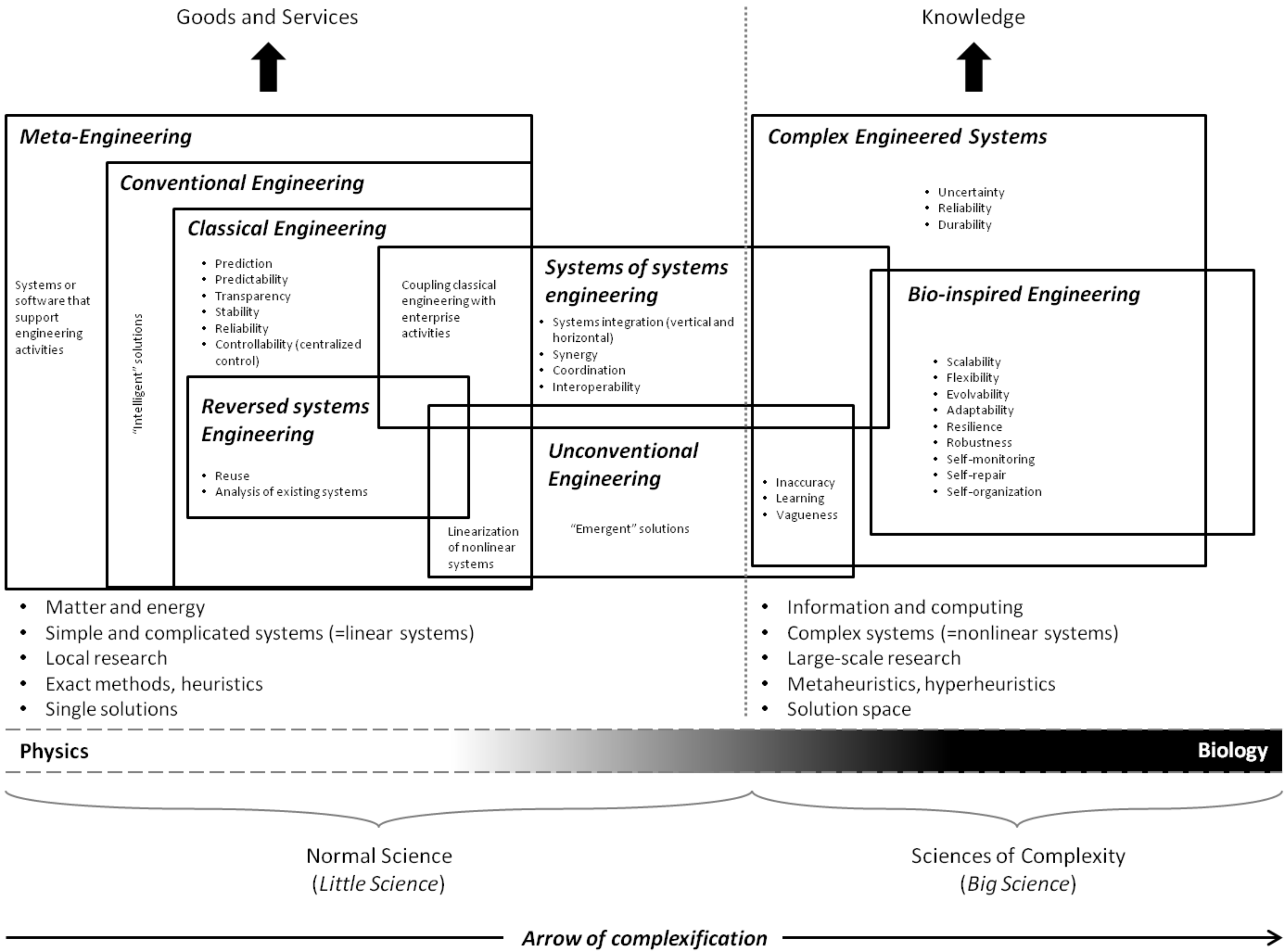
- A) Understanding or explaining the origins of life – P1
- Understanding the logics of life – P2

- We tackle problem P1 via P2, i.e. not what life is, but what do living beings do in order to live

Claim

- Living beings solve NP problems, NP-Hard problems and NP-complete problems as P problems
- For living beings computing is a matter of lif or death
- Living beings hypercompute

Complexification of Engineering



Goods and Services
Knowledge
Meta-Engineering
Systems or software that support engineering activities
Conventional Engineering
"Intelligent" solutions
Classical Engineering
Prediction
Predictability
Transparency
Stability
Reliability
Controllability (centralized control)
Reversed systems Engineering
Reuse
Analysis of existing systems
Coupling classical engineering with enterprise activities
Systems of systems engineering
Systems integration (vertical and horizontal)
Synergy
Coordination
Interoperability
Linearization of nonlinear systems
Unconventional Engineering
"Emergent" solutions
Complex Engineered Systems
Uncertainty
Reliability
Durability
Bio-inspired Engineering
Scalability
Flexibility
Evolvability
Adaptability
Resilience
Robustness
Self-monitoring
Self-repair
Self-organization
Inaccuracy
Learning
Vagueness
Matter and energy
Simple and complicated systems (=linear systems)
Local research
Exact methods, heuristics
Single solutions
Information and computing
Complex systems (=nonlinear systems)
Large-scale research
Metaheuristics, hyperheuristics
Solution space
Physics
Biology
Normal Science (Little Science)
Sciences of Complexity (Big Science)
Arrow of complexification

The Complexification of Engineering

This paper deals with the arrow of complexification of engineering. We claim that the complexification of engineering consists in (a) that shift throughout which engineering becomes a science; thus it ceases to be a (mere) praxis or profession; (b) becoming a science, engineering can be considered as one of the sciences of complexity. In reality, the complexification of engineering is the process by which engineering can be studied, achieved, and understood in terms of knowledge, and not of goods and services any longer. Complex engineered systems and bio-inspired engineering are so far the two expressions of a complex engineering. *Complexity 17: 8–15, 2012*

Key Words: complexity; engineering sciences; complex engineered systems; bio-inspired engineering

CARLOS E. MALDONADO AND NELSON A. GÓMEZ CRUZ

1. INTRODUCTION

We are currently facing a dynamic process of complexification of engineering sciences. To be sure, such is a proof of vitality and change that, nonetheless, is to be fully understood and explained. The aim of this paper is

Biological hypercomputation

Biological Hypercomputation: A New Research Problem in Complexity Theory

This article discusses the meaning and scope of biological hypercomputation (BH) that is to be considered as new research problem within the sciences of complexity. The framework here is computational, setting out that life is not a standard Turing Machine. Living systems, we claim, hypercompute, and we aim at understanding life not by what it is, but rather by what it does. The distinction is made between classical and nonclassical hypercomputation. We argue that living processes are nonclassical hypercomputation. BH implies then new computational models. Finally, we sketch out the possibilities, stances, and reach of BH. *Complexity 000: 00–00, 2014*

Key Words: complex systems; biological information processing; nonclassical hypercomputation; theoretical biology; complexification of computation

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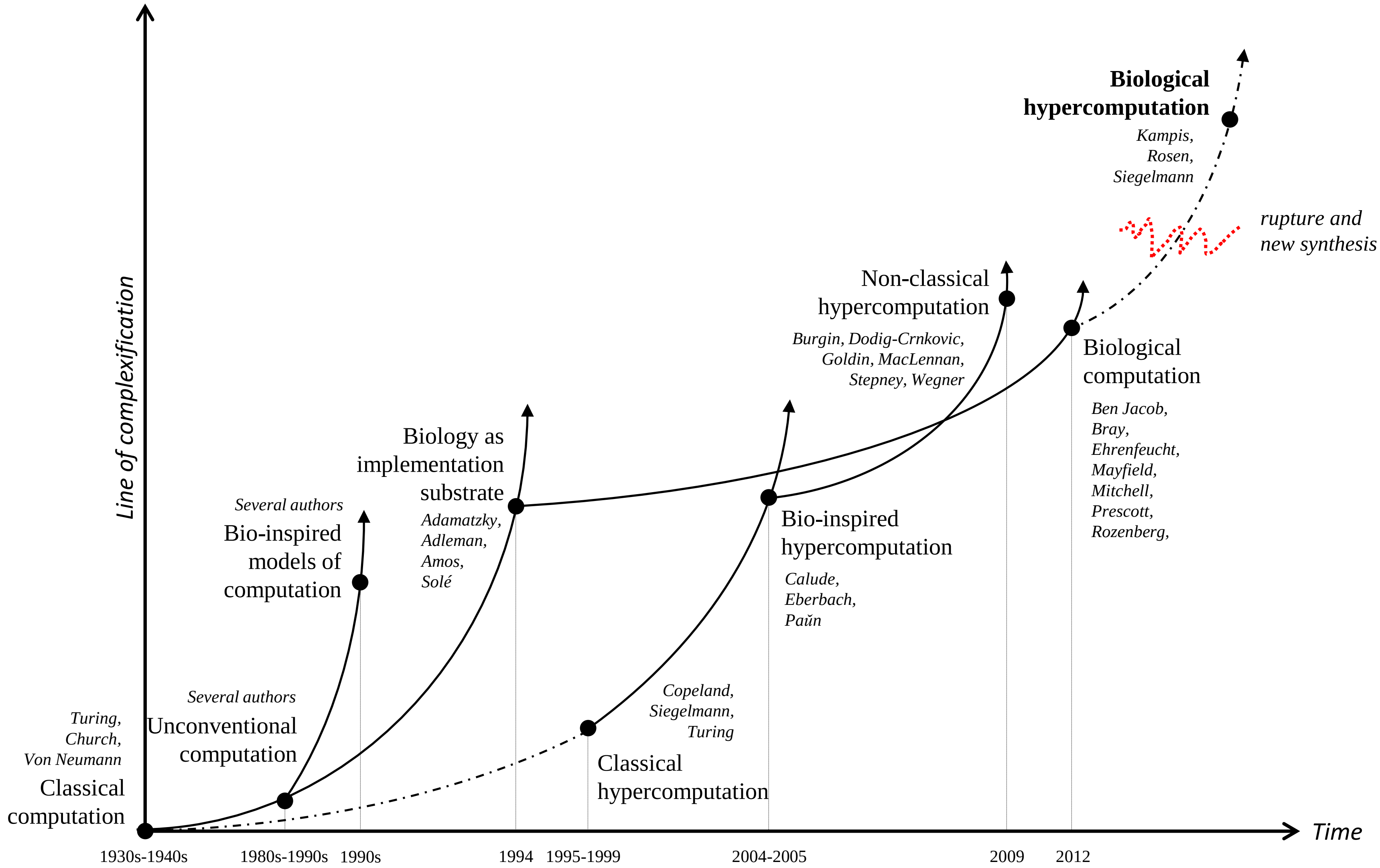

Line of complexification
Time
Turing,
Church,
Von Neumann
Classical
computation
Several authors
Unconventional
computation
Several authors
Bio-inspired
models of
computation
Biology as
implementation
substrate
Adamatzky,
Adleman,
Amos,
Solé
Copeland,
Siegelmann,
Turing
Classical
hypercomputation
Bio-inspired
hypercomputation
Calude,
Eberbach,
Paŭn
Non-classical
hypercomputation
Burgin, Dodig-Crnkovic,
Goldin, MacLennan,
Stepney, Wegner
Biological
computation
Ben Jacob,
Bray,
Ehrenfeucht,
Mayfield,
Mitchell,
Prescott,
Rozenberg,
Biological
hypercomputation
Kampis,
Rosen,
Siegelmann
rupture and
new synthesis
1930s-1940s
1980s-1990s
1990s
1994
1995-1999
2004-2005
2009
2012

Quantum Biology

Available online at www.sciencedirect.com

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Procedia Computer Science 00 (2014) 000–000

Procedia Computer Science

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Complex Adaptive Systems, Publication 4
Cihan H. Dagli, Editor in Chief
Conference Organized by Missouri University of Science and Technology
2014-Philadelphia, PA

Does quantum biology contribute to the understanding of complex systems?

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Abstract

Since its origins quantum biology (QB) has seen an astonishing and promising growth. Ranging from experimental to theoretical approaches, the concerns are wide and deep. This paper asks whether QB does contribute to complexity science (CS), and provides five arguments, thus: (i) Firstly a state-of-the art of QB and its relationship to CS is provided. Thereafter, the attention is directed to answering the question set out. The paper argues that QB can contribute to complexity theory via four steps, thus: (ii)

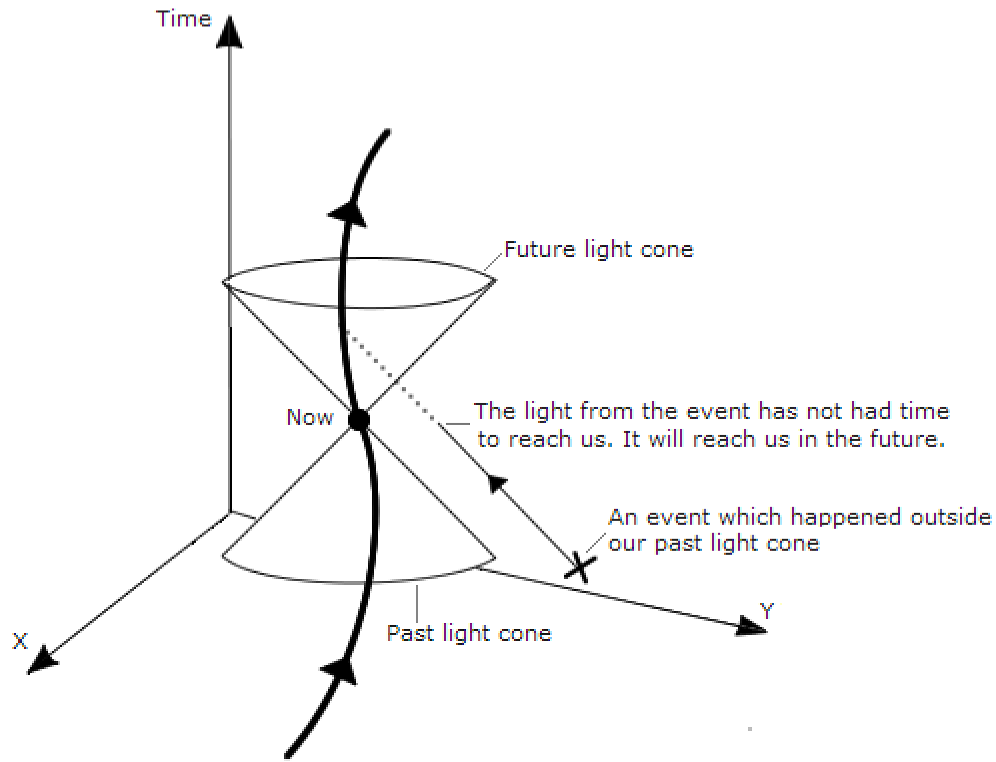
Living organism layers	**Time scale**	**References**
Molecular dynamics	Nanoseconds	Secrier & Schneider, 2013
Organelle subprocesses	Nanoseconds	Secrier & Schneider, 2013
Sound localization	Microseconds	Buonomano, 2007
Motion detection	Milliseconds/seconds	Buonomano, 2007
Motor coordination	Milliseconds/seconds	Buonomano, 2007
Protein complexes processes	Hours/days	Secrier & Schneider, 2013
Protein networks dynamics	Days	Secrier & Schneider, 2013
Cell cycle / biological clock	Days	Buonomano, 2007; Secrier & Schneider, 2013
Cell division	Days/weeks	Secrier & Schneider, 2013
Organ development	Days/weeks	Secrier & Schneider, 2013
Organism development	Weeks	Secrier & Schneider, 2013
Population dynamics	Billion years	Secrier & Schneider, 2013

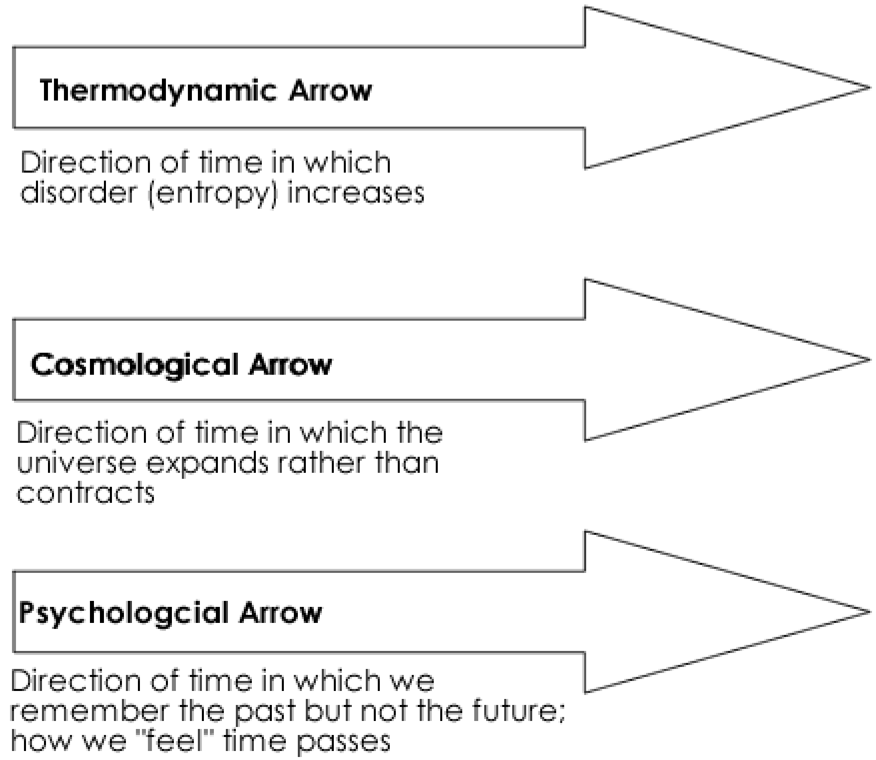
Understanding QT in Complexity Theory

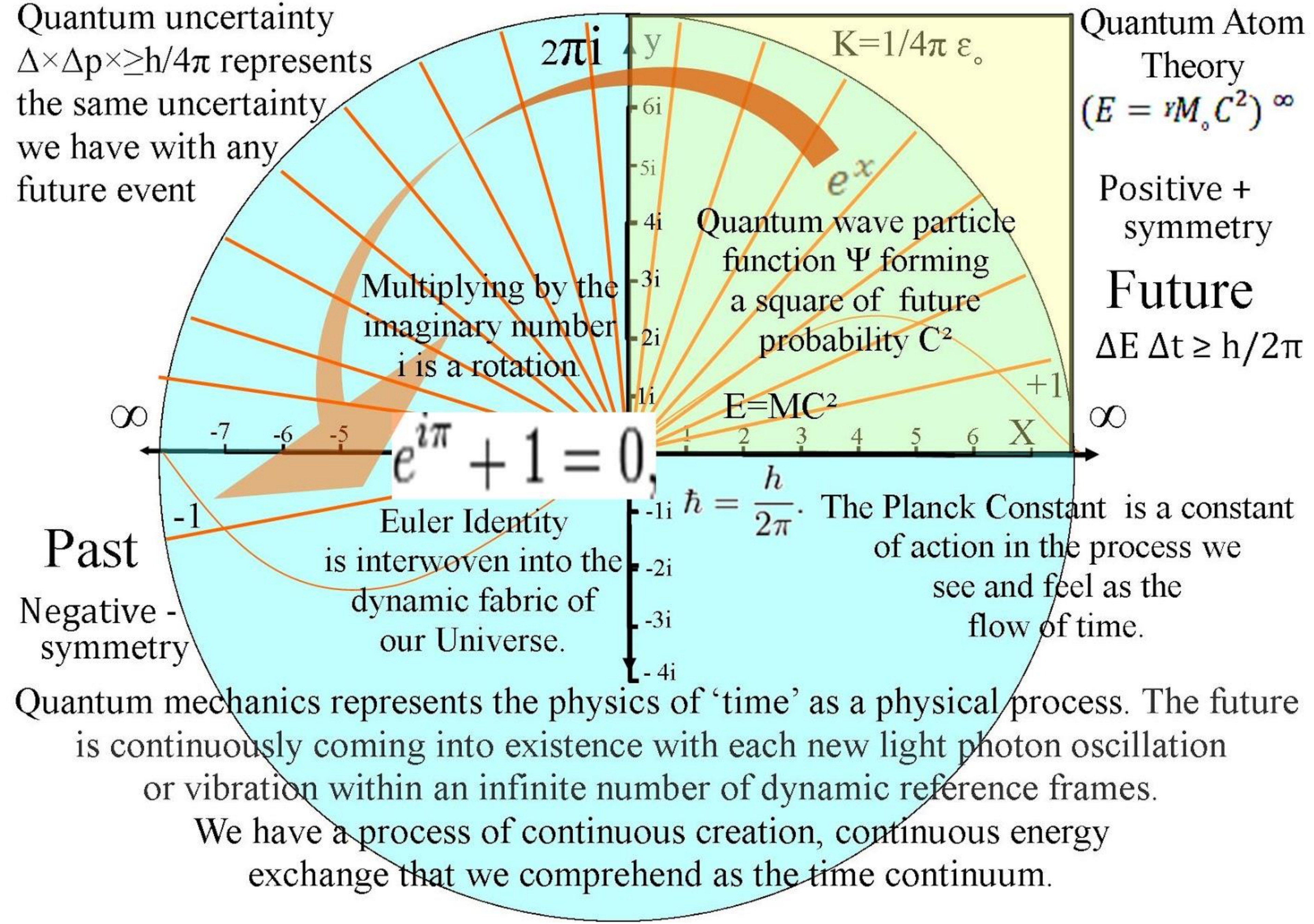
- Most subjects and domains in CT pertain the macroscopic universe

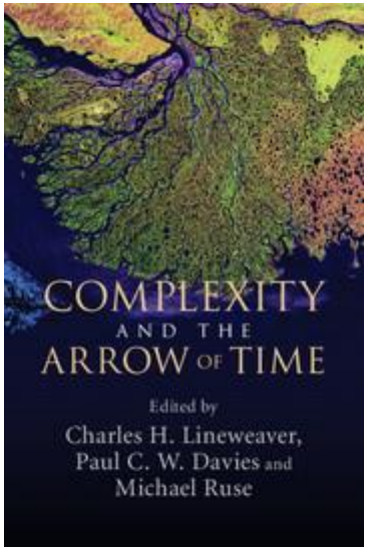
Complexity is Time

- Without being reductionist we claim safely claim that complexity is (= is rooted, embedded, coincides with, grounds, …) in time, i.e. the arrow of time


Time
Future light cone
Now
The light from the event has not had time
to reach us. It will reach us in the future.
An event which happened outside
our past light cone
X
Y
Past light cone


Thermodynamic Arrow
Direction of time in which disorder (entropy) increases
Cosmological Arrow
Direction of time in which the universe expands rather than contracts
Psychologcial Arrow
Direction of time in which we remember the past but not the future; how we "feel" time passes


Quantum uncertainty
Δ×Δp×≥h/4π represents
the same uncertainty
we have with any
future event
2πi
y
K=1/4π ε∘
Quantum Atom
Theory
$(E = \gamma M_\circ C^2)^\infty$
6i
5i
e^x
Positive +
symmetry
4i
Quantum wave particle
function Ψ forming
a square of future
probability C²
3i
Multiplying by the
imaginary number
i is a rotation
2i
Future
ΔE Δt ≥ h/2π
+1
1i
E=MC²
∞
∞
-7
-6
-5
1
2
3
4
5
6
X
$e^{i\pi} + 1 = 0,$
-1i
$\hbar = \frac{h}{2\pi}$.
The Planck Constant is a constant
of action in the process we
see and feel as the
flow of time.
-1
Past
Euler Identity
is interwoven into the
dynamic fabric of
our Universe.
-2i
-3i
Negative -
symmetry
- 4i
Quantum mechanics represents the physics of 'time' as a physical process. The future
is continuously coming into existence with each new light photon oscillation
or vibration within an infinite number of dynamic reference frames.
We have a process of continuous creation, continuous energy
exchange that we comprehend as the time continuum.


COMPLEXITY
AND THE
ARROW OF TIME
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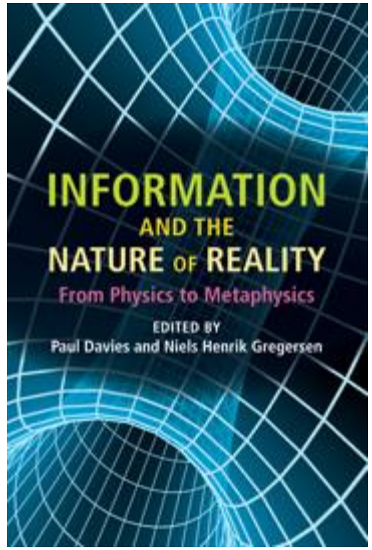
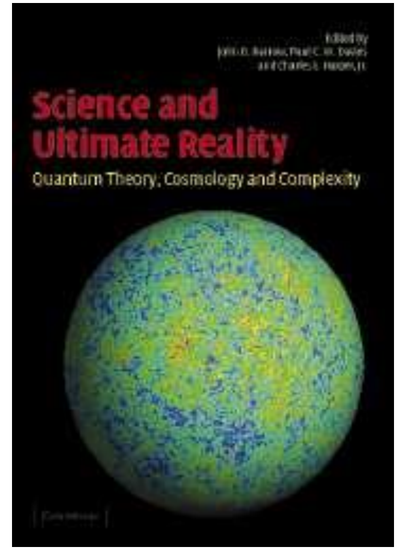
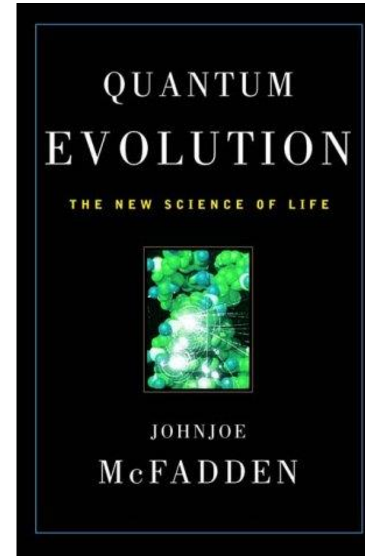
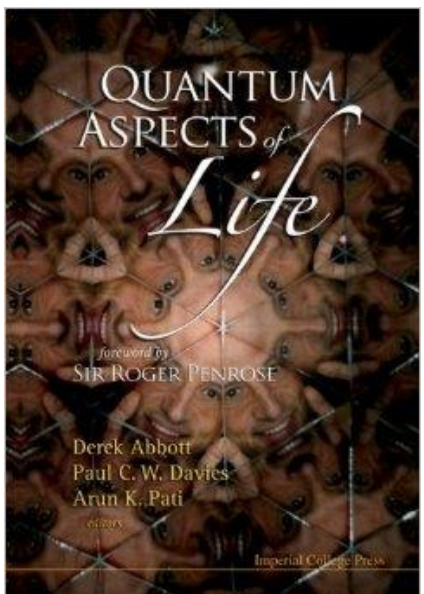
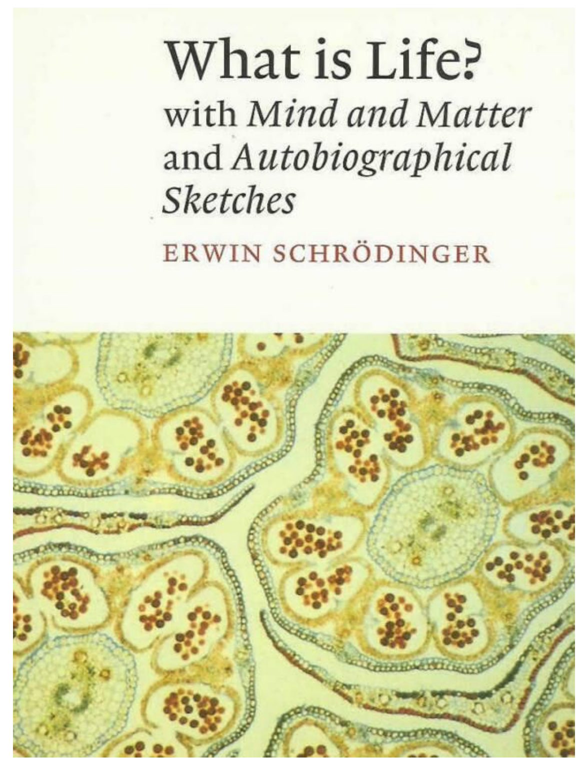
Paul C. W. Davies and
Michael Ruse


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

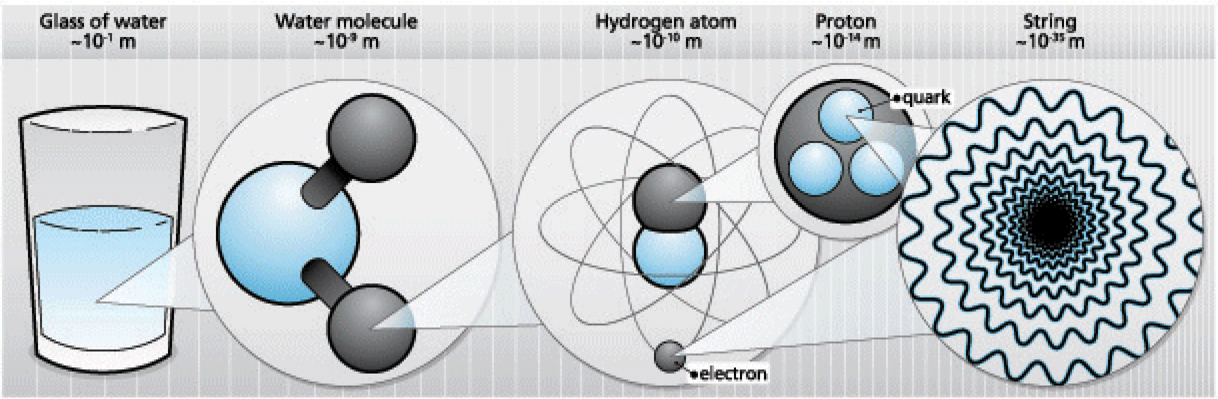

Science and
Ultimate Reality
Quantum Theory, Cosmology and Complexity


QUANTUM
EVOLUTION
THE NEW SCIENCE OF LIFE
JOHNJOE
McFADDEN

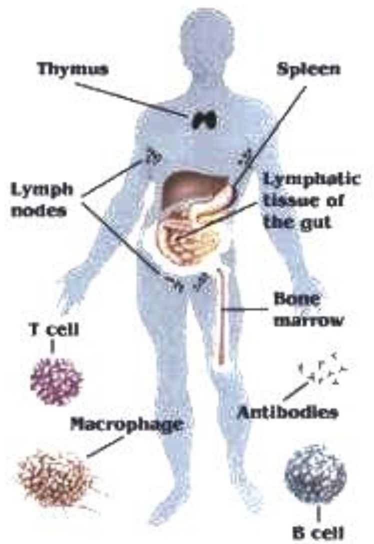

QUANTUM
ASPECTS of
Life
foreword by
SIR ROGER PENROSE
Derek Abbott
Paul C. W. Davies
Arun K. Pati
editors
Imperial College Press


What is Life?
with Mind and Matter
and Autobiographical
Sketches
ERWIN SCHRÖDINGER

THE SIZE OF STRINGS

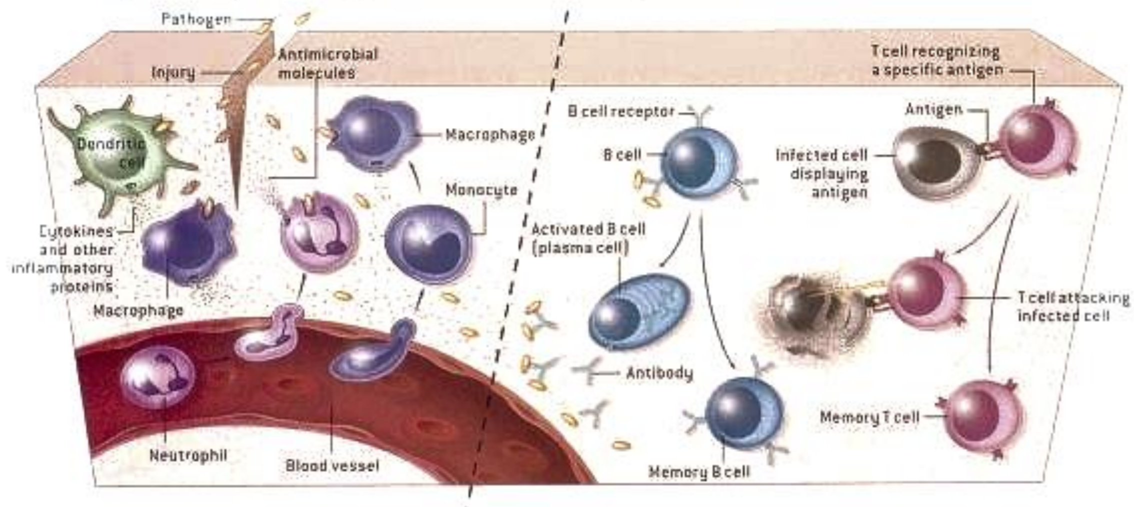


Strings are the smallest, least accessible objects known to physics. Here, a progressive zoom into a glass of water reveals the relative scales of a water molecule, a hydrogen atom, a proton, an electron, a quark, and a string. The sizes of these objects ranges across thirty-four orders of magnitude. For perspective, if an atom were the size of our solar system, a string would be somewhat larger than an atomic nucleus.



Among the most dangerous enemies we humans face are our own distant relatives, the microbes. No human being can long withstand their onslaught unprotected. We survive because the human body has a variety of effective defenses against this constant attack.

The mammalian immune system has two overarching divisions. The innate part (*left side*) acts near entry points into the body and is always at the ready. If it fails to contain a pathogen, the adaptive division (*right side*) kicks in, mounting a later but highly targeted attack against the specific invader.

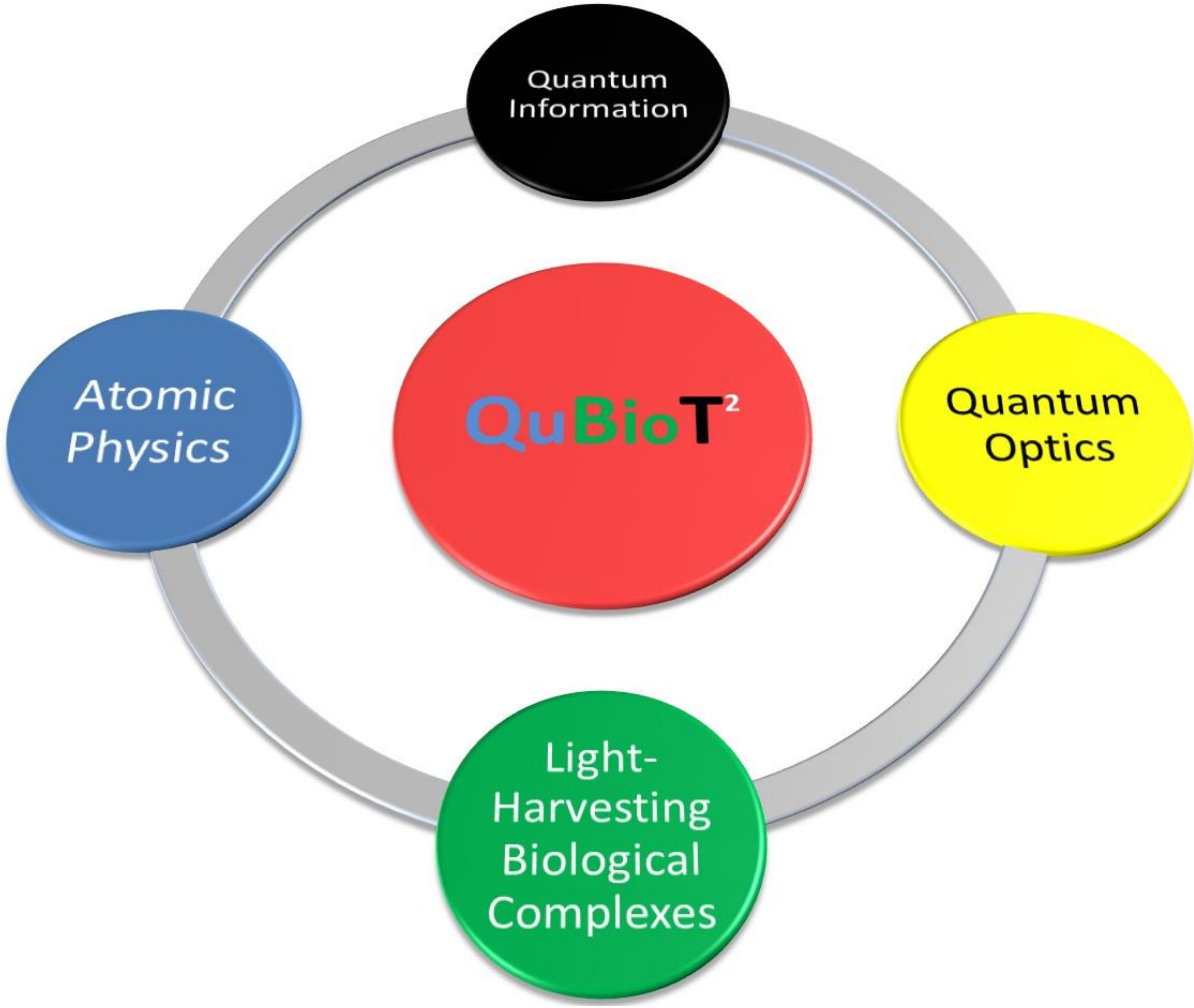


INNATE IMMUNE SYSTEM

This system includes, among other components, antimicrobial molecules and various phagocytes (cells that ingest and destroy pathogens). These cells, such as dendritic cells and macrophages, also activate an inflammatory response, secreting proteins called cytokines that trigger an influx of defensive cells from the blood. Among the recruits are more phagocytes—notably monocytes (which can mature into macrophages) and neutrophils.

ADAPTIVE IMMUNE SYSTEM

This system "stars" B cells and T cells. Activated B cells secrete antibody molecules that bind to antigens—specific components unique to a given invader—and destroy the invader directly or mark it for attack by others. T cells recognize antigens displayed on cells. Some T cells help to activate B cells and other T cells (not shown); other T cells directly attack infected cells. T and B cells spawn "memory" cells that promptly eliminate invaders encountered before.



Quantum Information
Atomic Physics
QuBioT²
Quantum Optics
Light-Harvesting Biological Complexes

- Working on a theory of life. Now, a theory of life entails a theory of the material reality. As yet, these are complex phenomena.

- Working on a (general, crossed, transversal, united, …. theory of complexity

TC < -- > TL

Macroscopic world			Microscopic world	
Time scale	*Conversion*	*Factor*	*Time scale*	*Factor*
Second		10^{0}	Millisecond	10^{-3}
Kilosecond	16.7 minutes	10^{3}	Microsecond	10^{-6}
Megasecond	11.6 days	10^{6}	Nanosecond	10^{-9}
Gigasecong	32 years	10^{9}	Picosecond	10^{-12}
Terasecond	32 000 years	10^{12}	Femtosecond	10^{-15}
Petasecond	32 million years	10^{15}	Attosecond	10^{-18}
Exasecond	32 billion years	10^{18}	Zeptosecond	10^{-21}
Zettasecond	32 trillion years	10^{21}	Yoctosecond	10^{-24}
Yottasecond	32 quadrillion years	10^{24}	**Plank time**	10^{-44}

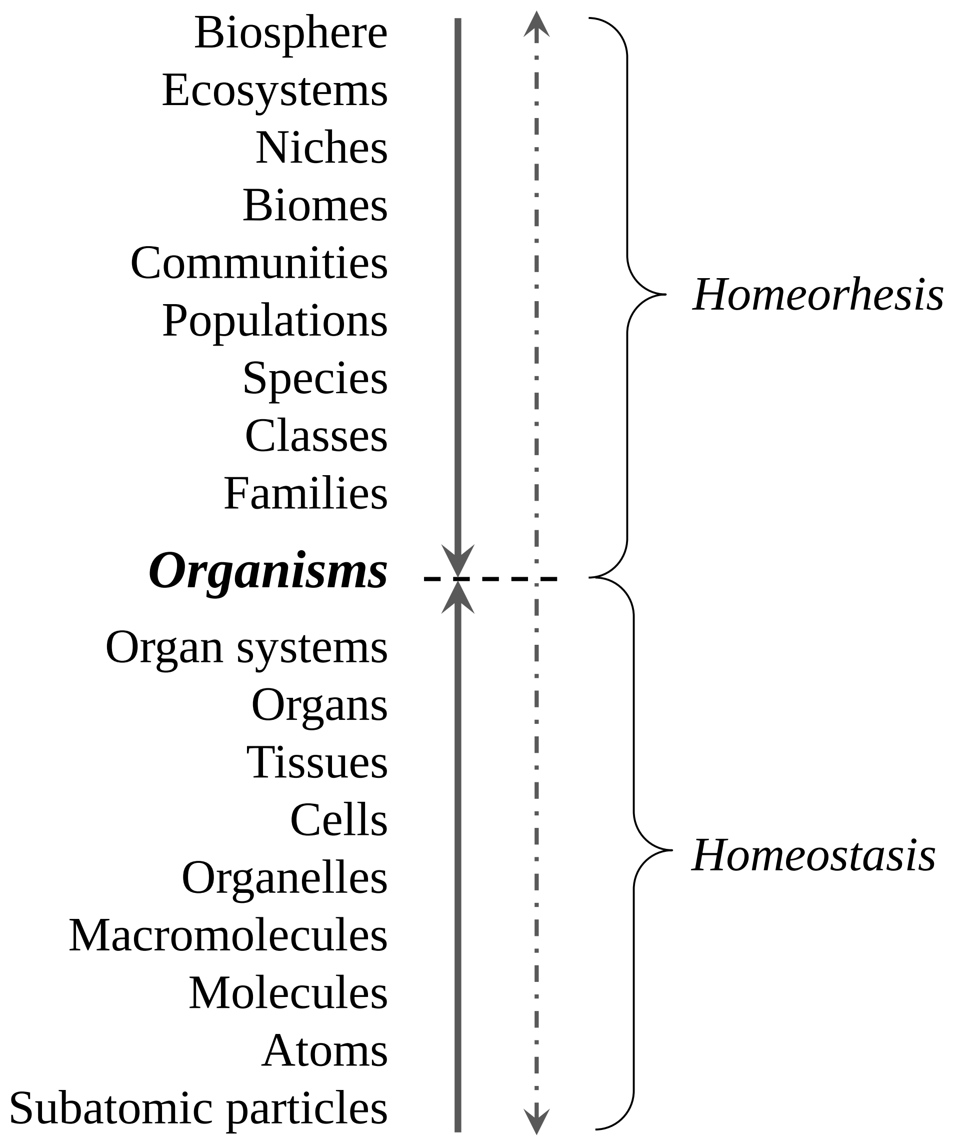

Biosphere
Ecosystems
Niches
Biomes
Communities
Populations
Species
Classes
Families
Organisms
Organ systems
Organs
Tissues
Cells
Organelles
Macromolecules
Molecules
Atoms
Subatomic particles
Homeorhesis
Homeostasis

Table 2: Physical scale and time scale in living beings

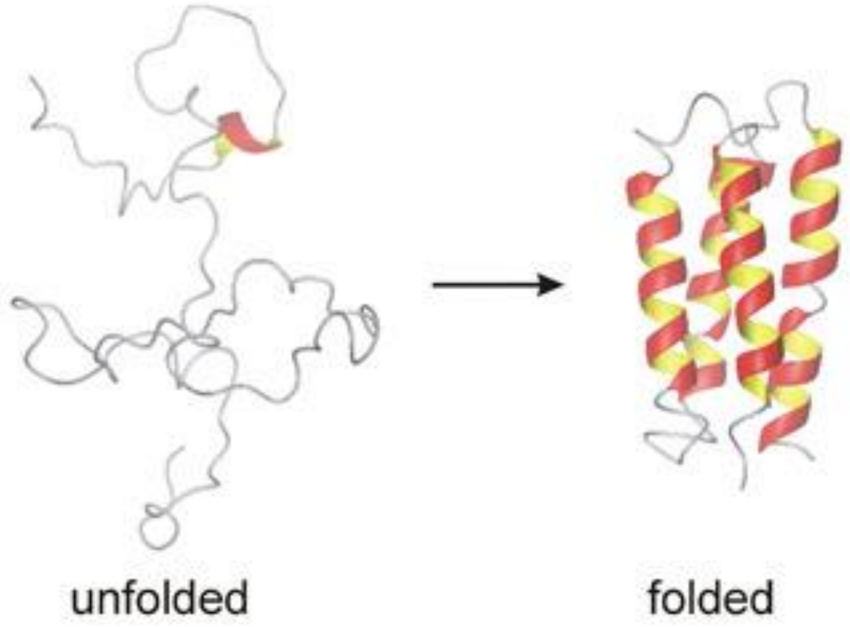
Living organism layers	Time/scale
Organism	Meter(s)
Organs	Centimeter(s)
Cells	Microns
Molecules	Nanoseconds
Genes	Femto to Picoseconds
(Most) Chemical reactions	Femto to Attoseconds

- Q effects in biology have been posited in:
  - Olfaction
  - Magnetic sensing
  - Photosynthetic energy transfer
  - Photoenzymology
  - Molecular motors
  - Ion channels
  - Consciousness

Summary of a selection of the main experimental and theoretical works on functional QB

Photosynthesis	**Cryogenic-temperature quantum coherence (QC)** **Ambient/room-temperarure QC (FMO)** **Ambient-/room temperature QC (Algae)** **Environment-assisted transport** **Alternative viwes**
Radical pair magnetoreception	Early proposals and evidence Mathematical models Indirect evidence (light dependence, magnetic field) Experiments on radical pairs
Other examples	Olfaction Vision Long-range electron transfer Enzyme catalysis

The most important steps in the transfer of information within a cell are the folding, transport and recognition of proteins



- Biology is remarkable in that the range of time and energy scales over which biological processes occur spans seven orders of magnitude, ranging from ultrafast solvation times in water on the order of femtoseconds to the slow rotation of a protein which can take tens of nanoseconds

- Computation can be thought of as a process that combines digital information with variation to produce complexity

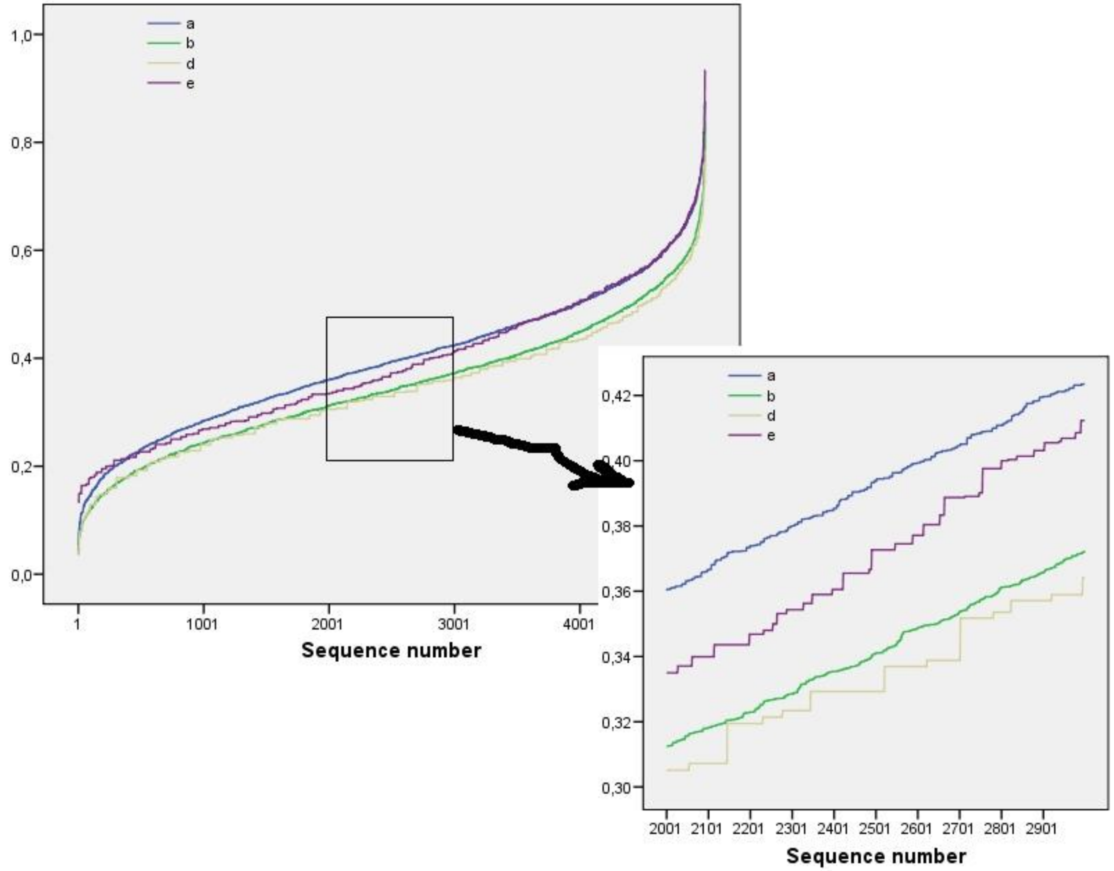
- The universe itself is a universal computer that is effectively programmed by random quantum fluctuations

What is life?

- Life is an information processing system
- Processing information is for living beings a matter of death or life

Quantum mechanics

- QM has two features that guarantees the emergence of complex systems such as life:
  - Discreteness



– Chanciness

- The outcomes of some quantum events are inherently probabilistic

- Because it is probabilistic, the computing universe is effectively programmed by random quantum events called quantum fluctuations

Q-decoherence

- The process by which QM generates new, random bits of information
- Decoherence is ubiquitous
- QM is constantly injecting brand new, random bits into the universe

- Apparenty all that is requiered for proto-life is the existence of physical systems that reproduce themselves with variation
- Reproduction and variation seem to suffice

- Computation can be thought of as a process that combines digital information with variation to produce complexity

- The universe itself is a universal computer that is effectively programmed by random quantum fluctuations

- Searches of sequence space or configuration space may proceed much faster quantum mechanically
- Decoherence time is the time that the full quantum superposition of all possible states in the combinatorial library before the interaction with the surrounding environment destroys it

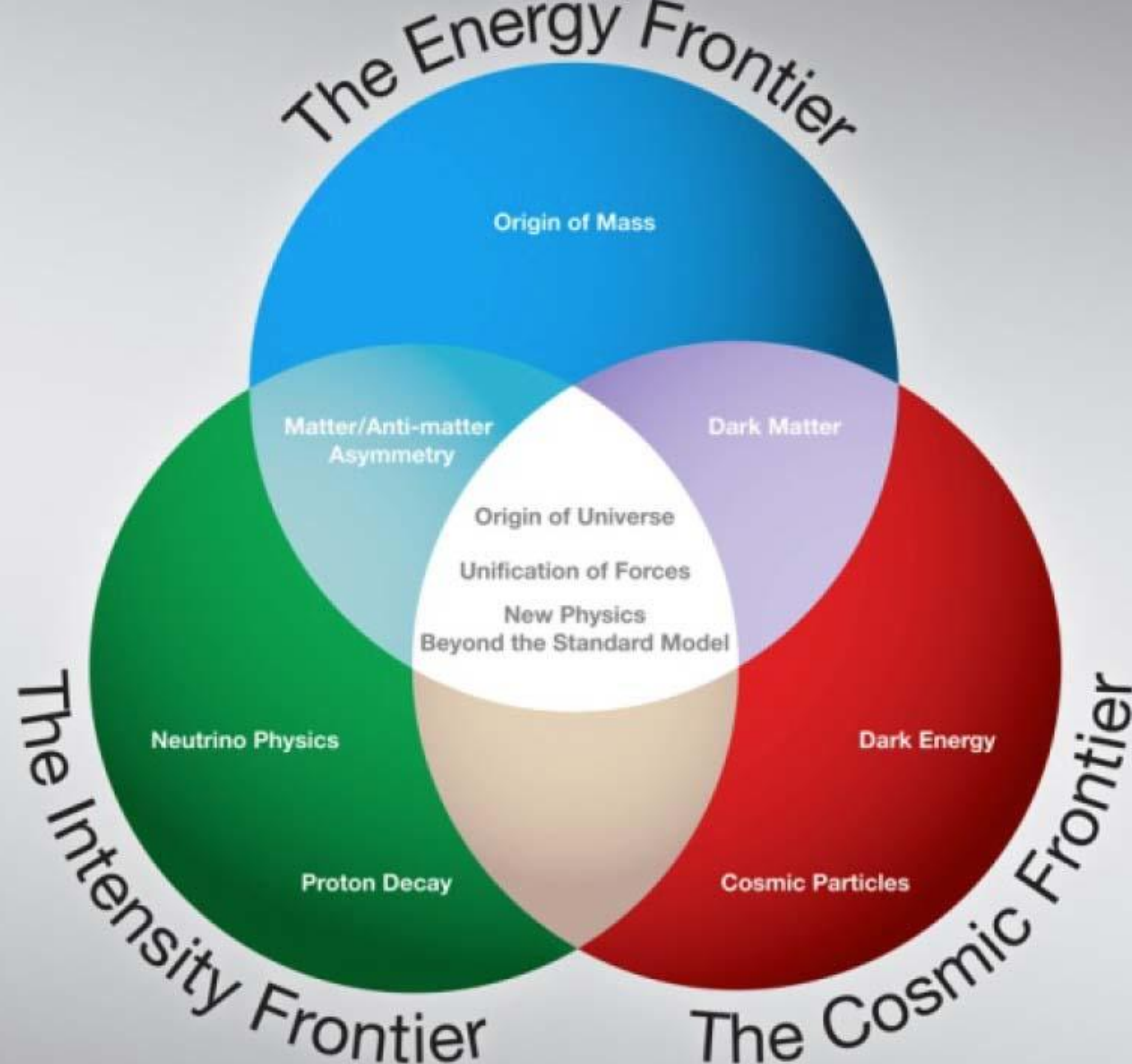
- Physics, i.e. QP may be incomplete
- The biosphere is doing something literally incalculable, nonalgorithmic
- 1944: Schrödinger brought QM, chemistry and “information” into biology
- QM comes to the rescue of life!

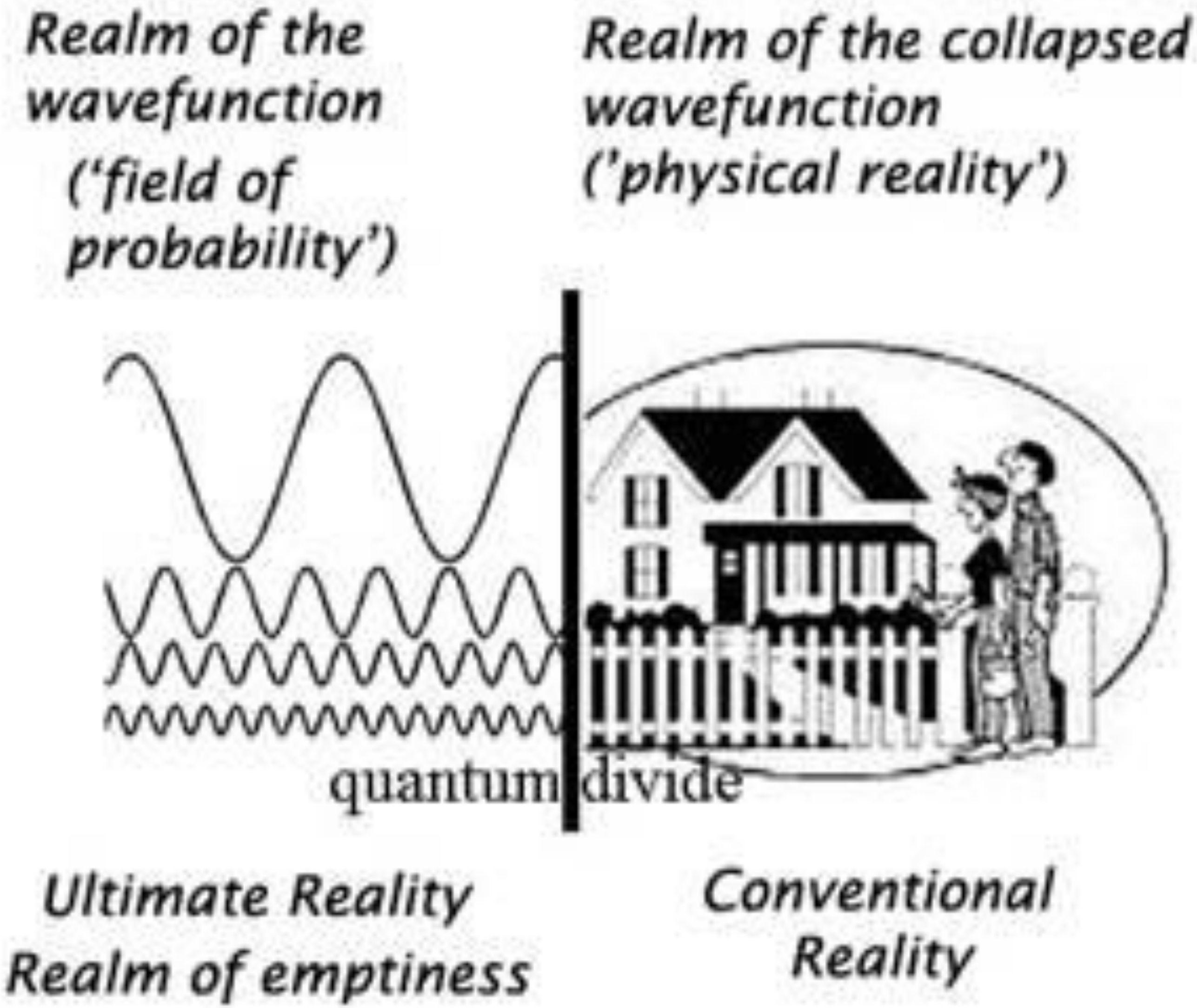
- What we call quantum theory is currently mostly information theory

- Along the line, it all is not just about description but about interpretation

- Entanglement is still calling for an explanation

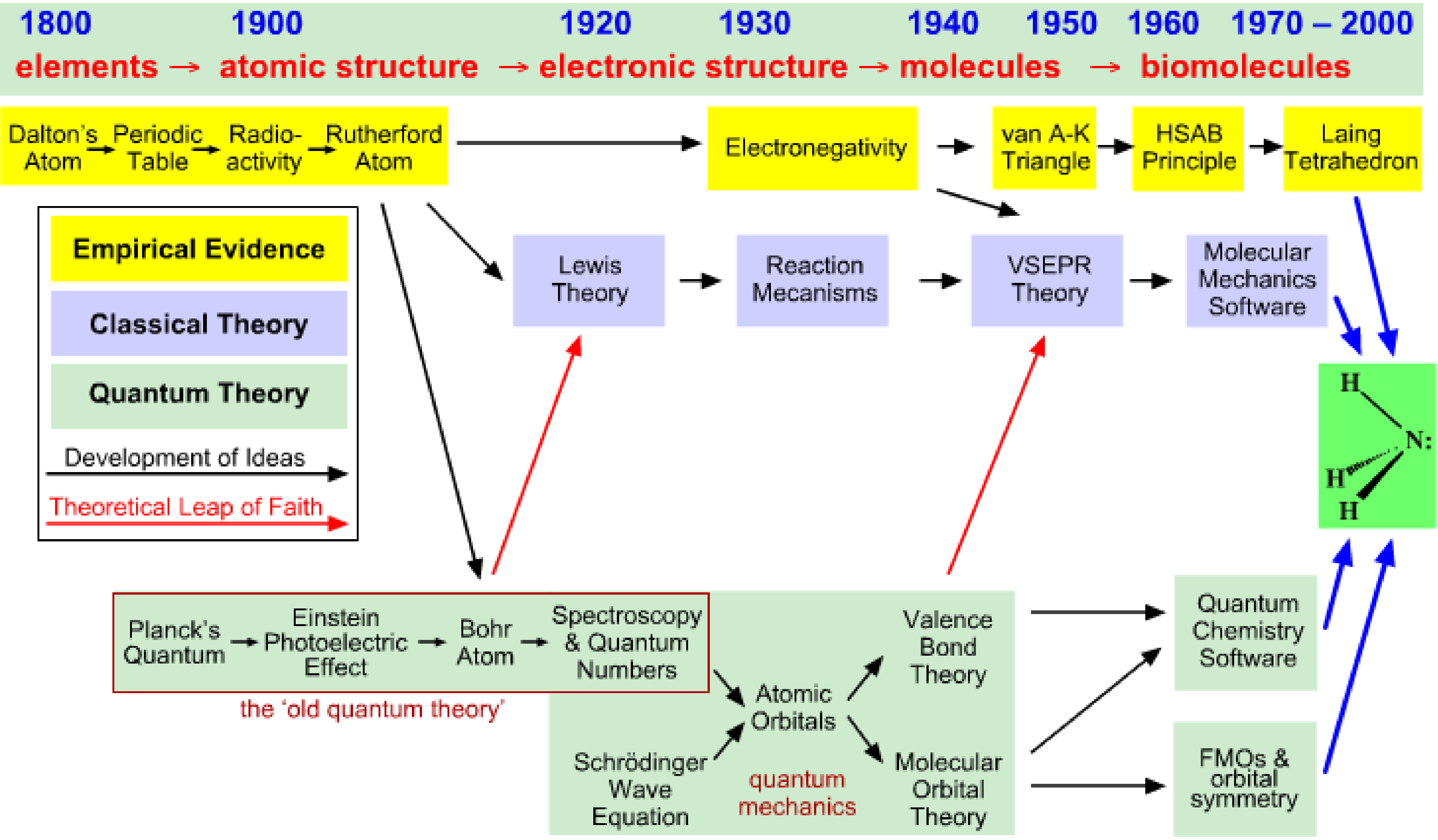
- From Matter to Enegy to Information
- To Matter-Energy-Information
- Physics is not about reality or nature but about what we know about the universe


The Energy Frontier
Origin of Mass
Matter/Anti-matter
Asymmetry
Dark Matter
Origin of Universe
Unification of Forces
New Physics
Beyond the Standard Model
Neutrino Physics
Dark Energy
Proton Decay
Cosmic Particles
The Intensity Frontier
The Cosmic Frontier

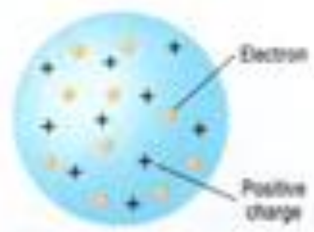


Realm of the wavefunction ('field of probability')
Realm of the collapsed wavefunction ('physical reality')
quantum divide
Ultimate Reality
Realm of emptiness
Conventional Reality

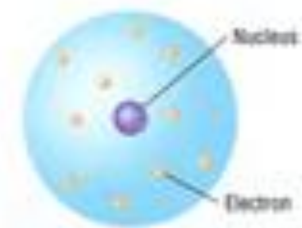
The Matrix


1800
1900
1920
1930
1940
1950
1960
1970 – 2000
elements → atomic structure → electronic structure → molecules → biomolecules
Dalton's Atom
Periodic Table
Radio-activity
Rutherford Atom
Electronegativity
van A-K Triangle
HSAB Principle
Laing Tetrahedron
Empirical Evidence
Classical Theory
Quantum Theory
Development of Ideas
Theoretical Leap of Faith
Lewis Theory
Reaction Mecanisms
VSEPR Theory
Molecular Mechanics Software
H
N:
H
H
Planck's Quantum
Einstein Photoelectric Effect
Bohr Atom
Spectroscopy & Quantum Numbers
the 'old quantum theory'
Atomic Orbitals
Valence Bond Theory
Schrödinger Wave Equation
quantum mechanics
Molecular Orbital Theory
Quantum Chemistry Software
FMOs & orbital symmetry

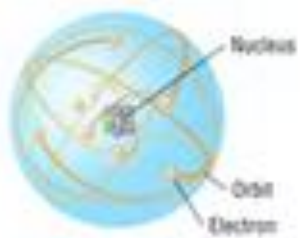
Development of Atomic Models



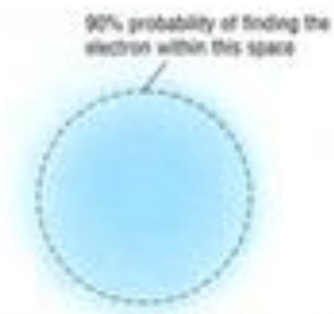
Thomson model
In the nineteenth century, Thomson described the atom as a ball of positive charge containing a number of electrons.



Rutherford model
In the early twentieth century, Rutherford showed that most of an atom's mass is concentrated in a small, positively charged region called the nucleus.



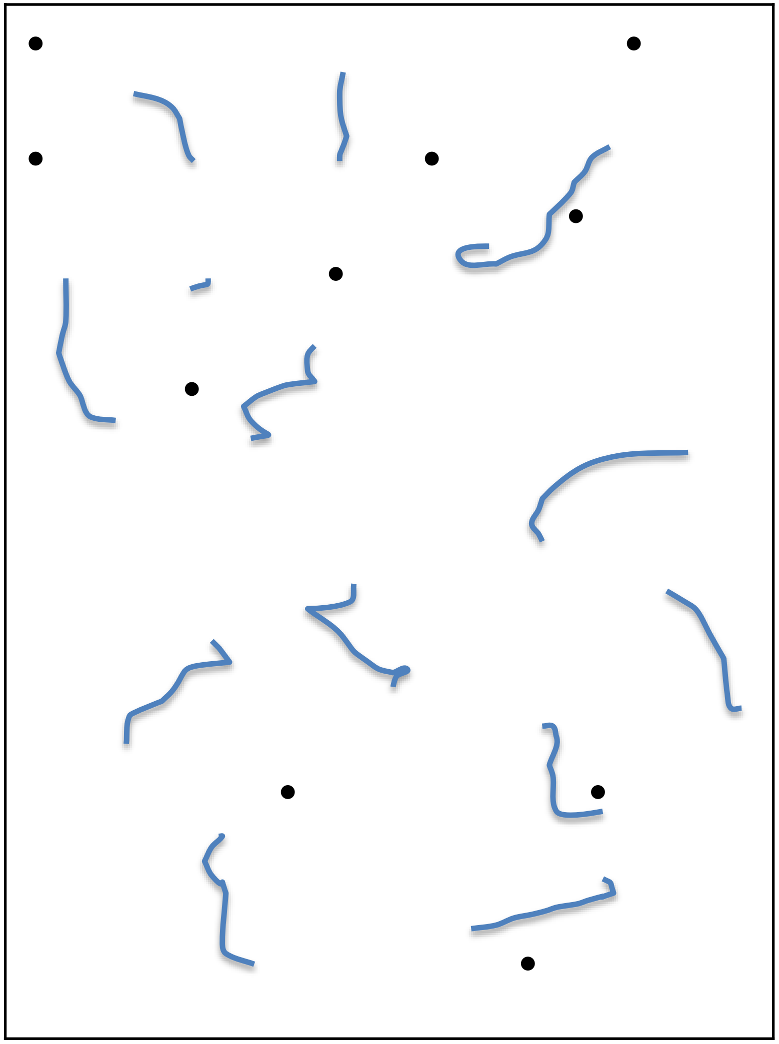
Bohr model
After Rutherford's discovery, Bohr proposed that electrons travel in definite orbits around the nucleus.



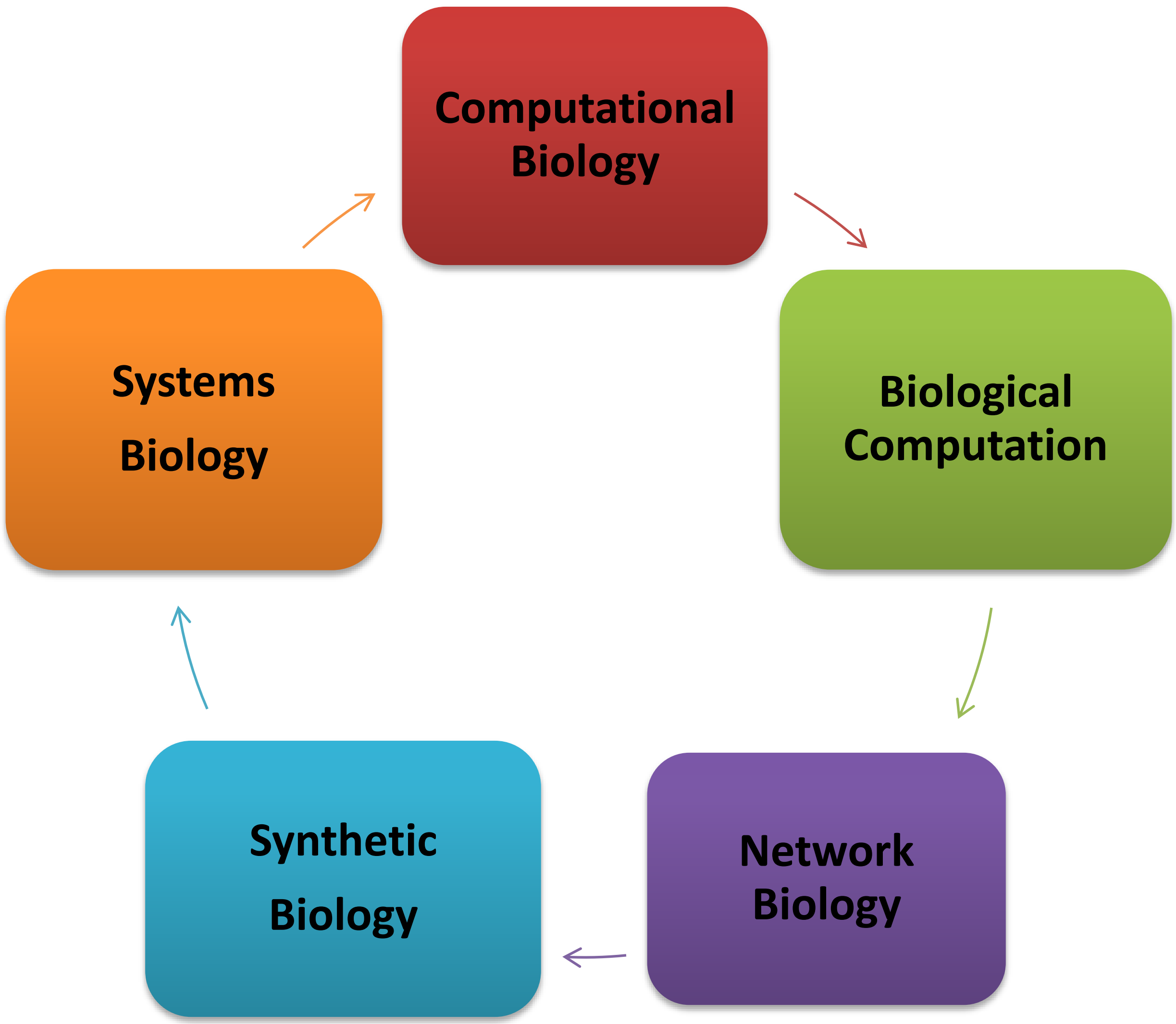
Quantum mechanical model
Modern atomic theory described the electronic structure of the atom as the probability of finding electrons within certain regions of space.

Classical Emptiness

Quantum Emptiness



COMPLEXITY OF THE UNDERSTANDING OF LIFE



- The debate remains open concerning the relationships between the discrete and continuous

- ¿Is reality continuous, or is it discrete?

- Thank you so much!