On Integral Biomathics and Biological Computation

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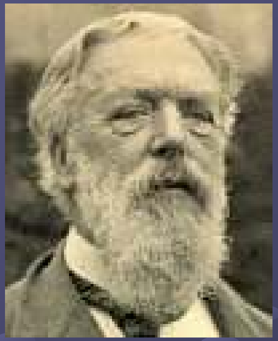
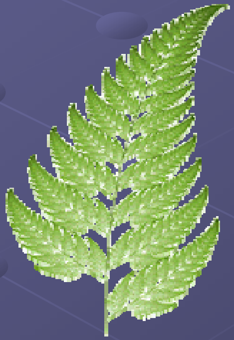


"The fact that the germ-cell develops into a very complex structure is no absolute proof that the cell itself is structurally a very complicated mechanism: nor yet does it prove, though this is somewhat less obvious, that the forces at work or latent within it are especially numerous and complex..."



D'Arcy W. Thompson (*Growth and Form*, 1917)

„This theory cries out for *causal* explanation…

Perhaps the time is close when
comparative developmental genetics
will be able to provide such an explanation.“

Wallace Arthur, National University of Ireland,
Department of Zoology, Galway, Ireland
D'Arcy Thompson and the theory of transformations

Nature Reviews Genetics 7, 401-406 (May 2006) |
doi:10.1038/nrg1835

Reference

Integral Biomathics: A Post-Newtonian View into the Logos of Bios (On the New Meaning, Relations and Principles of Life in Science)

Authors: Plamen L. Simeonov

http://arxiv.org/abs/cs/0703002

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Abstract: This work addresses the phenomena of emergence, adaptive dynamics and evolution of self-assembling, self-organizing, self-maintaining and self-replicating biosynthetic systems. We regard this research as an integral part of the studies in nature-inspired and natural computation within complex systems, emergent phenomena and artificial biology. Our ultimate objective is to unify classical mathematical biology with biomathics (or biological mathematics) on the way to genuine biological system engineering.

Outline

I. Introduction
II. Motivation
III. Objectives
IV. Approach
V. Challenges

Today's Information Systems

I. Introduction
II. Motivation
III. Objectives
IV. Approach
V. Challenges

- Systems depend on many modules, data sources, network connections, and I/O devices
- The overall complexity of the networked infrastructure, services and applications grows super-exponentially
- We experience constant change in hardware, software, protocols, data, and user expectations
- Predicting & controlling system's interactions has become impossible.

Conclusions:

- Human mind can no longer learn all procedures needed.
- We need a radically different approach to overcome this bottleneck.

Future Information Systems

I. Introduction
II. Motivation
III. Objectives
IV. Approach
V. Challenges

- One step forward is IBM's autonomic-computing initiative (ACI):
  http://www.research.ibm.com/autonomic
  - envisioning systems that function largely independently from their human supervisors, adapting, correcting, and repairing themselves whenever a problem occurs.
  - ACI is focused around models of **feedback**, **adaptation**, and **control** first proposed in the 1950s.
- The Autonomic Communication Forum (ACF) is a EU IST FET initiative to stimulate research in AC:
  http://www.autonomic-communication.org/
- However, an even more radical vision is needed for networks to cope with complexity, e.g.: **autopoiesis**.

Autopoietic Systems

I. Introduction
II. Motivation
III. Objectives
IV. Approach
V. Challenges

- An autopietic system not only regulates or adapts its behaviour, it also <u>creates</u> its own organization — i.e. it is “self-creating”, (Maturana & Varela, 1980)
  - Organization is basically *structure with function.*
  - *Self-organization (in the context of autopoiesis) means that a functional structure <u>emerges and maintains itself spontaneously</u>.*
- The control (if any) needed to achieve this result must be distributed over all participating components.

Self-Organization & Autopoiesis

- Self-organizing systems are:
  - **intrinsically robust** — they can withstand various errors, perturbations, or even partial destruction.
  - **self-healing and fault-tolerant** — they will repair or correct most damage themselves, returning to their initial state; when the damage becomes too great, their function will start to deteriorate, but “gracefully,” without sudden breakdown.
  - **adaptive, context-aware and ingenious** — they will mutate and adapt their organization to environmental changes, learning new tricks to cope with unforeseen problems.

- Autopoietic systems are self-organizing ones that are also self-replicating (autocatalytic). Out of chaos, they will generate patterns and order.

Autopoiesis & Autonomy

I. Introduction
II. Motivation
III. Objectives
IV. Approach
V. Challenges

Autopoiesis (Maturana and Varela, 1979)

Definition: Autopoietic systems are those systems which maintain their defining organization throughout a history of environmental perturbations and structural changes, they regenerate their components during operation.

Autopoietic systems which are realized in the physical space are *living systems*.

Autonomy (Varela, 1980)

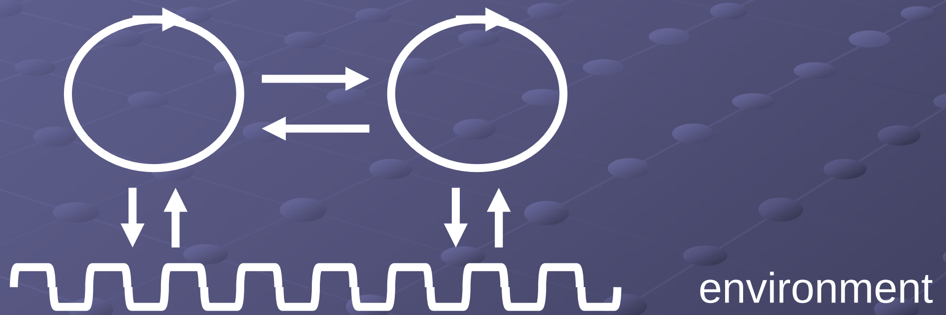
- is broader concept of which autopoiesis is special case.

Autonomous systems maintain their organization, but do not necessarily regenerate their own components.

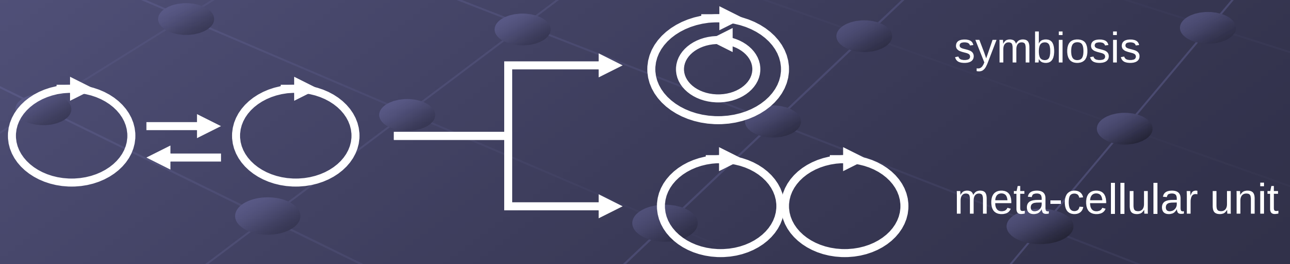
Autopoietic Principles

I. Introduction
II. Motivation
III. Objectives
IV. Approach
V. Challenges

Autopoietic entities interact autonomously with each other and with their environment via recursive relationships.

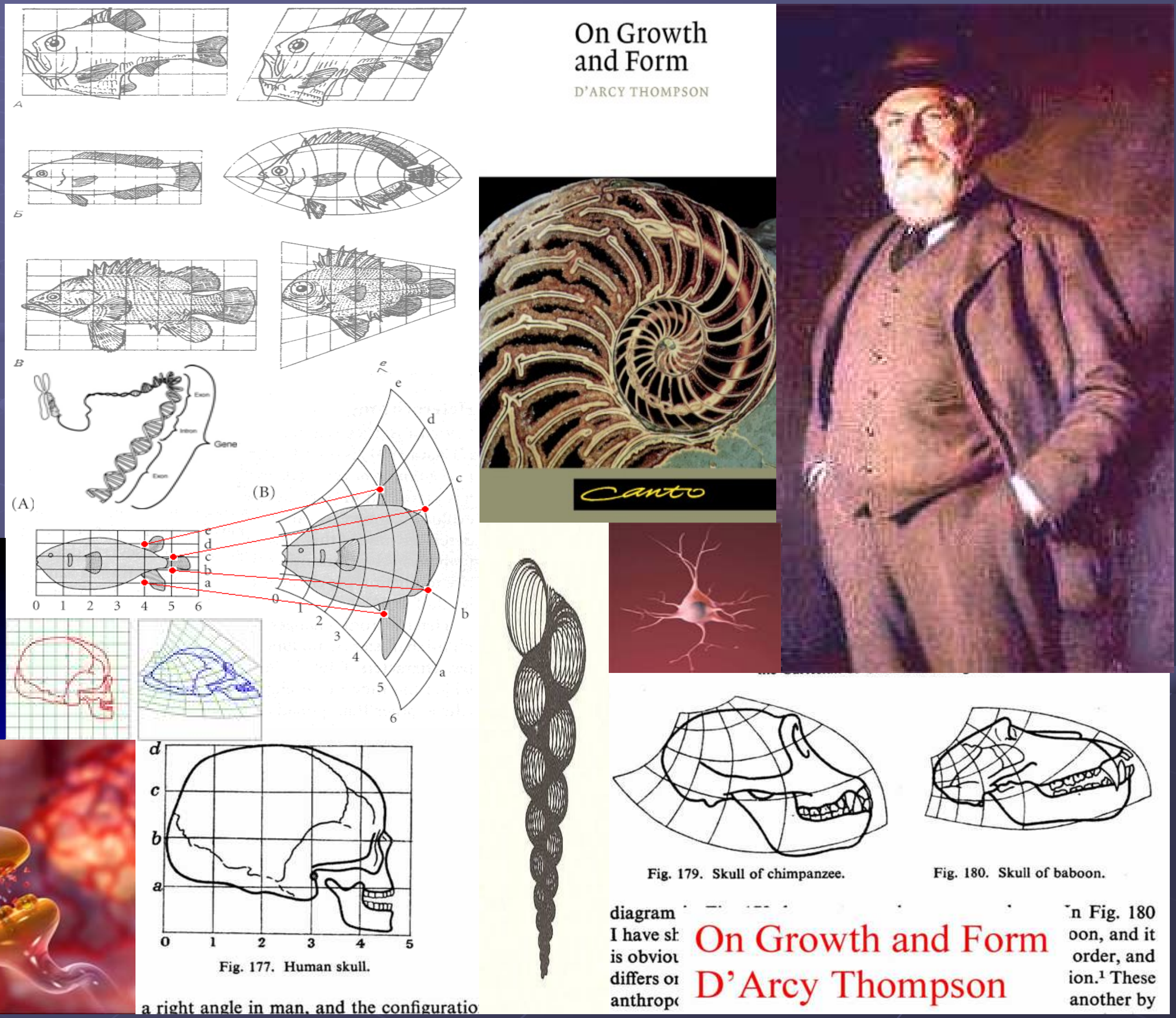


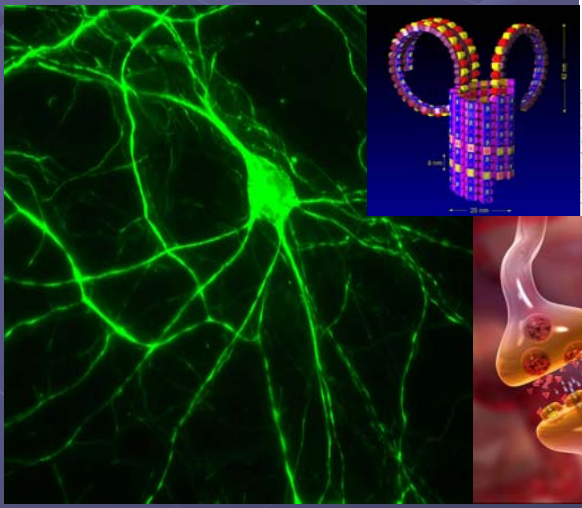
Productions of the recursive relationships result either in a symbiotic structure or in a meta-cellular unit.



Today's Biological Systems

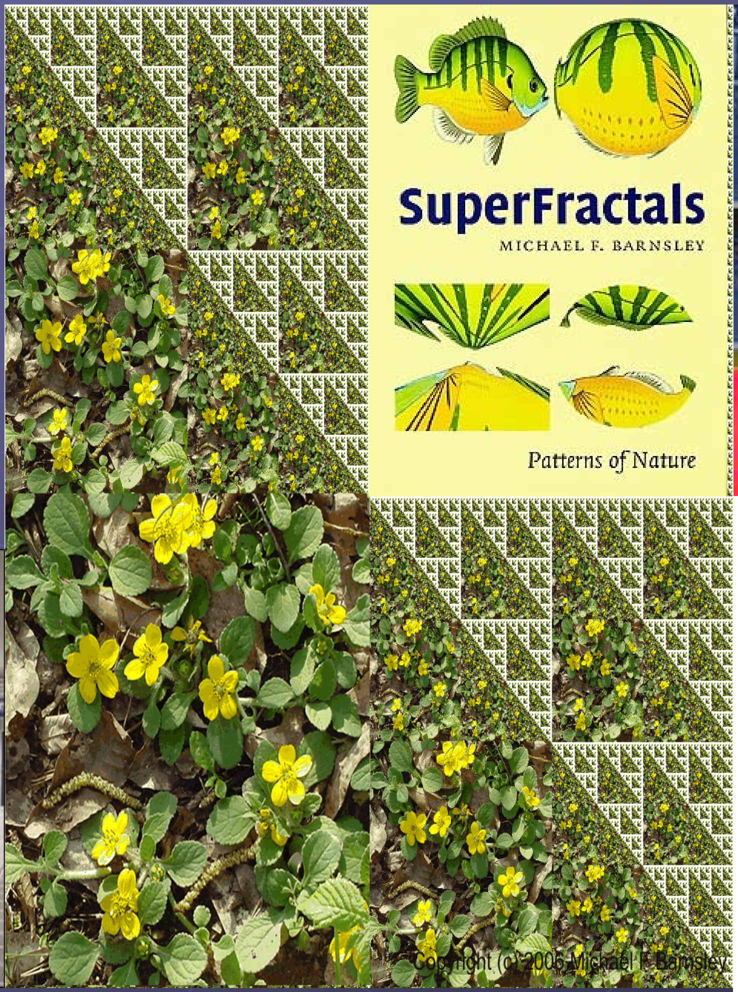
I. Introduction
II. Motivation
III. Objectives
IV. Approach
V. Challenges

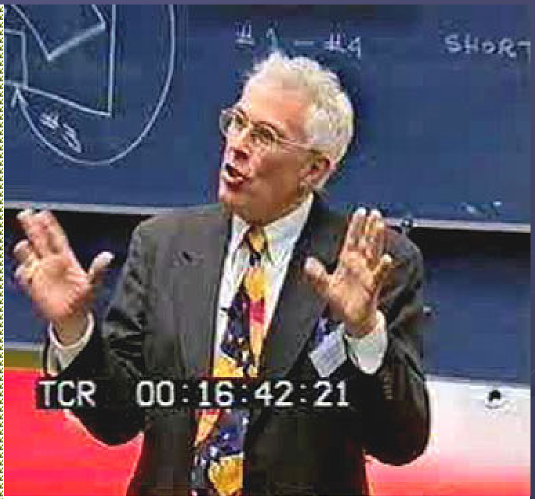


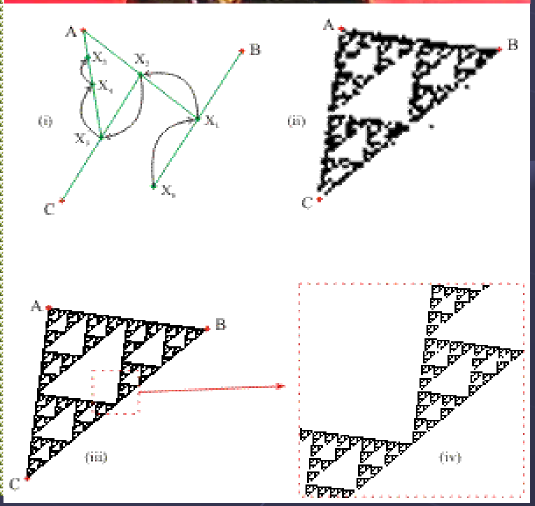


Today's Computational Systems

I. Introduction
II. Motivation
III. Objectives
IV. Approach
V. Challenges







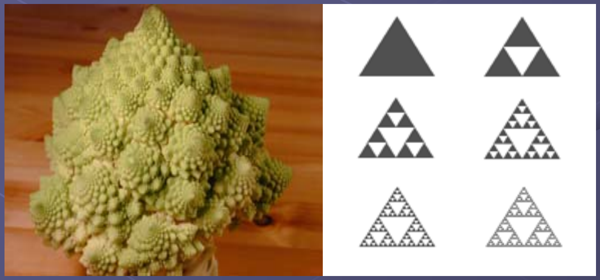
State of the Science

- Recent research roadmaps both in computational systems biology and autonomic systems are targeting to perpetuate and enrich the knowledge, technology and methodology transfer between analytic life sciences and synthetic engineering sciences

- However, it is impossible to make any significant progress in this multidisciplinary field of research without inaugurating a breakthrough paradigm change towards *biologically driven mathematics and computation*

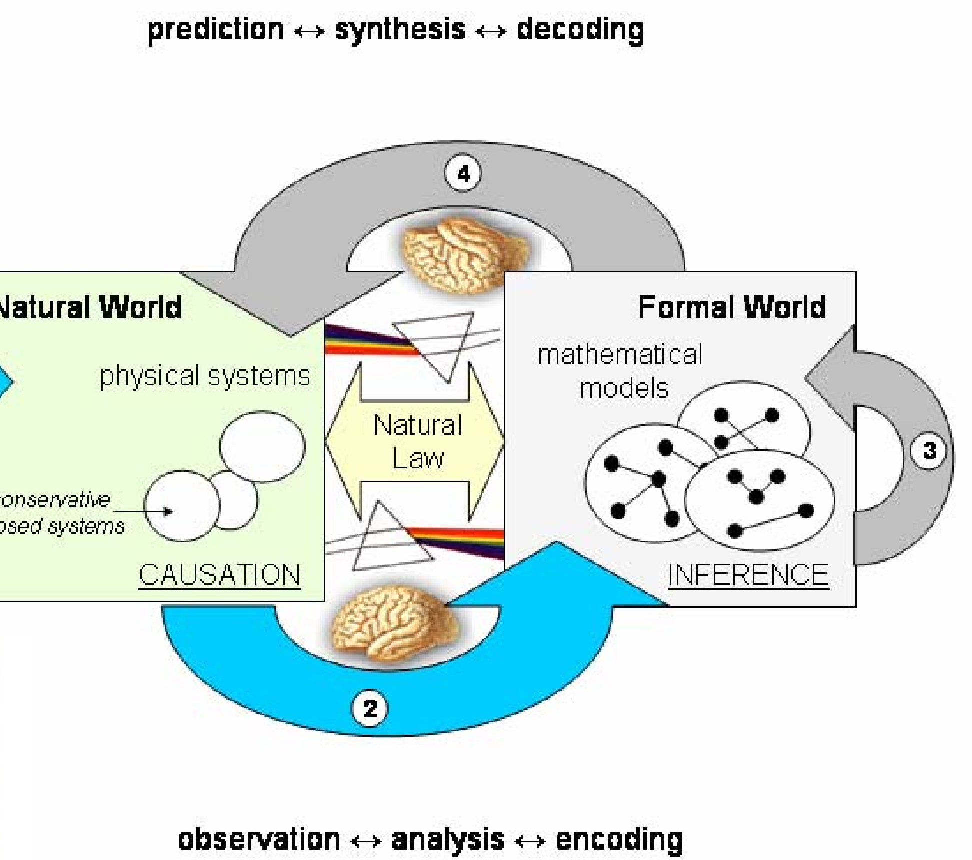
Assumptions

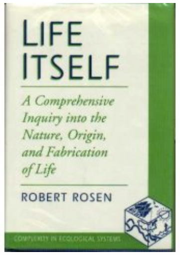
- I. Introduction
- II. Motivation
- III. Objectives
- IV. Approach
- V. Challenges



- Living systems have fundamentally different notions for self-organization from those conceived in engineering sciences today.
- When devising the plan for future converging sciences, one should be aware of the limits of engineering and of the fact that "various relations within organisms…are outside the scope of *metric* mathematical biology" (Rashevsky, 1958) and contemporary science.
- *Nature-inspired* or *natural computation* (MacLennan, 2004) and constructivist approaches such as evolutionary, neural and neuromorphic, as well as cellular/membrane and molecular/DNA computation still suffer the inertness of exclusively syntactic and "mechanistic computing models …by utilizing numerical computation algorithms which are based on *recursive* functions" (Baianu, 2006).

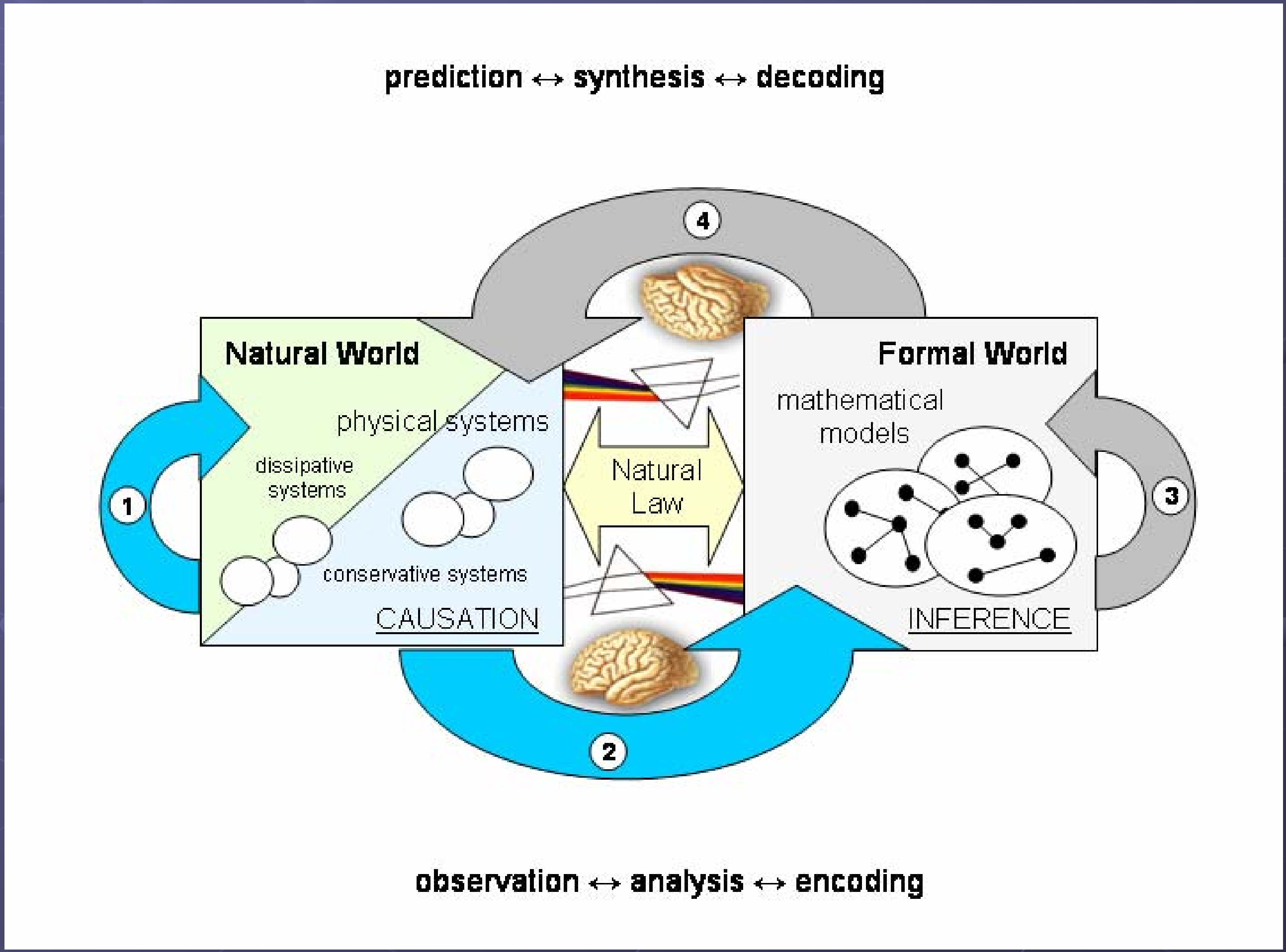
Rosen's Modelling Relation of Science (Rosen, 1991)





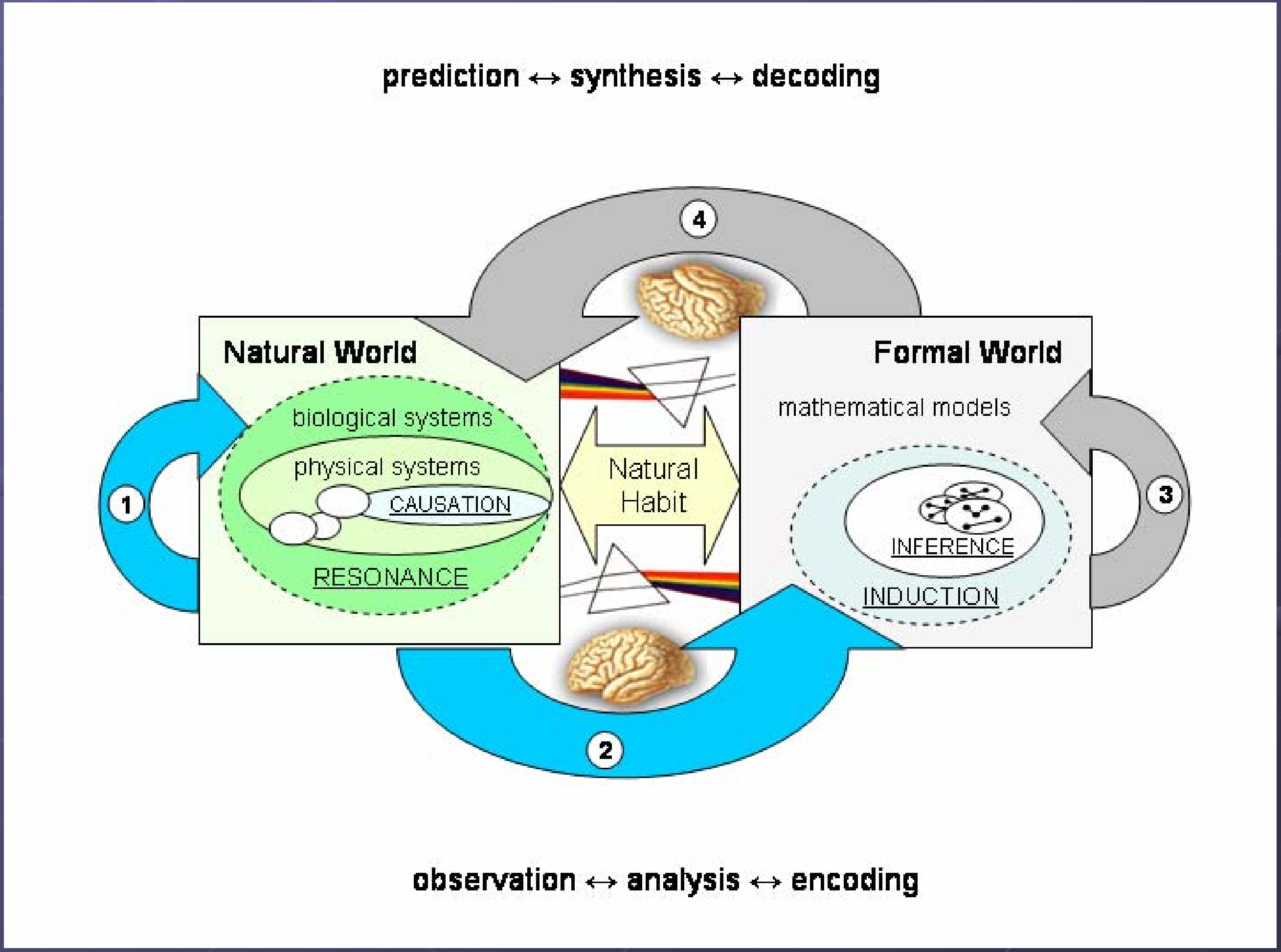
Rosen's Extended Modelling Relation of Science

I. Introduction
II. Motivation
III. Objectives
IV. Approach
V. Challenges



Rosen's Revised Modelling Relation of Science

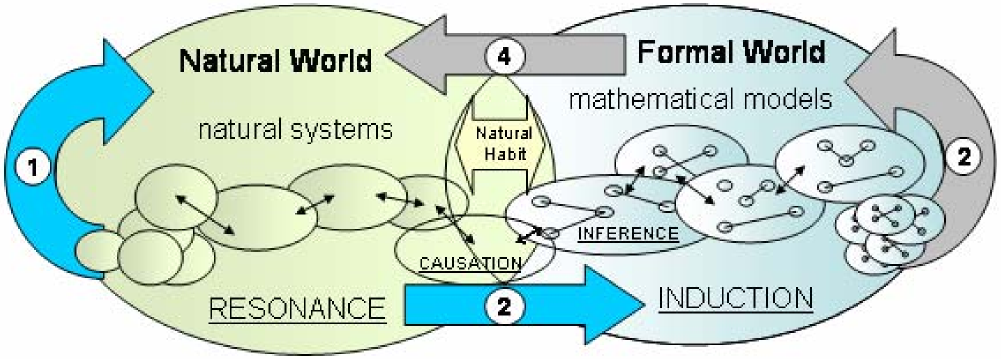
I. Introduction
II. Motivation
III. Objectives
IV. Approach
V. Challenges



The Converging Modelling Relation of Science

I. Introduction
II. Motivation
III. Objectives
IV. Approach
V. Challenges

prediction ↔ synthesis ↔ decoding



observation ↔ analysis ↔ encoding

Research Goals

1. a new kind of computation model capable of expressing the special *logic* of living systems (Elsasser, 1981) incl. cognition and consciousness (Crick, 1994).

2. biological imperatives for computation as seen by *integral biomathics* (Simeonov, 2007).

3. engineering naturalistic computing systems based on relational semantics models of neuronal system morphogenesis.

Methodological Frame

- **Focus**: understanding the premises for and the fundamental characteristics of organisation in biology.

- **Goal:** is the implementation of an *integral model for biocomputation* within an adequate engineering frame of relevance, rather than development of imitations and replicas via arbitrary selection and emulation of a set of limited 'organic' features.

Autonomic Systems

I. Introduction
II. Motivation
III. Objectives
IV. Approach
V. Challenges

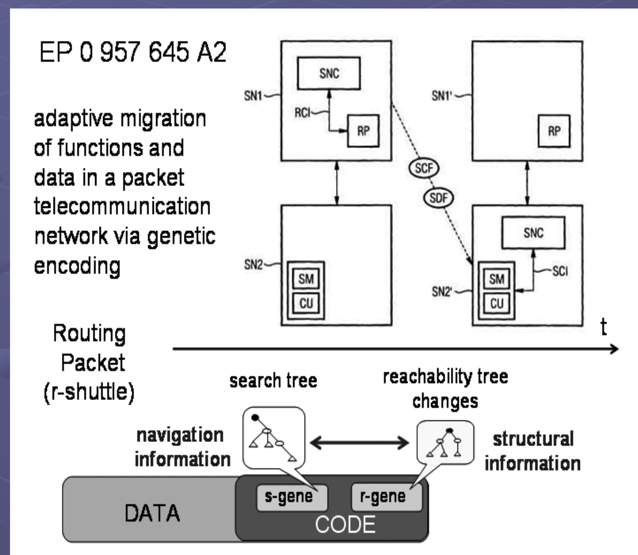


Figure 1: The Wandering Logic Intelligence

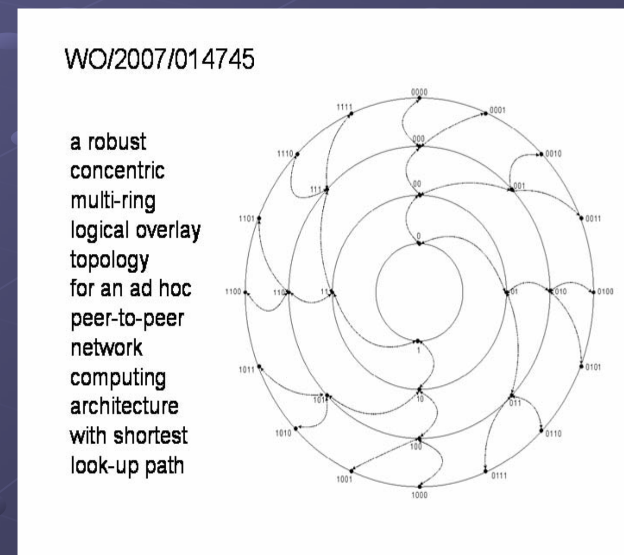


Figure 2: The HiPeer overlay model

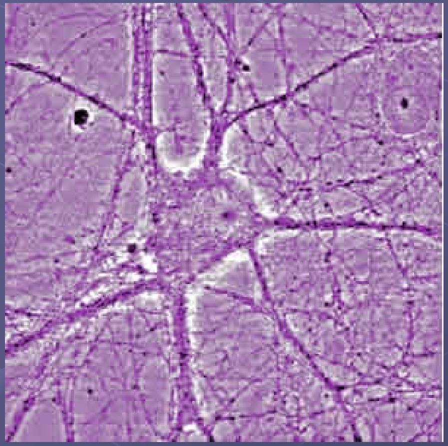
Living Systems

Definition: realizations of *morphogenetic fields* (Gurwitsch, 1910; Thompson, 1917; Weiss, 1939) manifested in structural-functional *relational patterns* (Andras, 2005) by means of *autopoietic networks* (Simeonov, 2002).

This process involves *‘hidden’ relational semantics* which dynamically enfolds and unfolds inside the constituent elements (Bohm, 1980) as a result of the composite interplay with each other and their environments.

Research Frame

I. Introduction
II. Motivation
III. Objectives
IV. Approach
V. Challenges

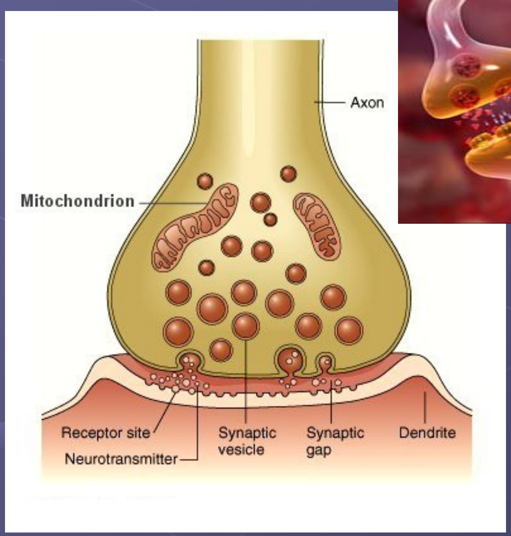


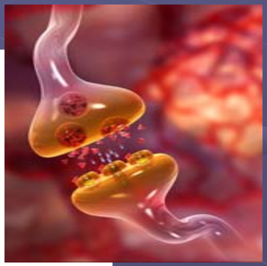
- *Fields*, *relations, networks* and *semantics* provide a new frame for exploring biological phenomena such as neurogenesis.

- My approach embodies the essence of neuronal systems in a naturalistic way to define *biological computation–communication*

Methodology

I. Introduction
II. Motivation
III. Objectives
IV. Approach
V. Challenges





- *Neuroplasticity* represents the physiological base of this research project.
- The expected result is a naturalistic model of *neuronal system computation* which explains how synaptic plasticity develops in terms of synaptic changes in response to external stimuli.
- This process will be traced from the level of neuron group interactions through molecular biochemical reactions within single neurons down to the level of quantum coherence in tubulin nanostructures in terms of continuous and discrete biocomputation.
- Artificial network computing systems lack this characteristic yet.

Expected Results

The project is expected to deliver answers to such questions as:

(i) *what is computation?* – in biological context;

(ii) *how useful is a computation?* – for living systems, where "usefulness" is studied from the viewpoint of the entity performing the computation;

(iii) *to what extent can a computation be carried out?* – in an organism or an ecosystem, with the available resources (power, time, number of computing elements, etc.).

Research Fields

1. evolutionary dynamic information systems (semantic networks)
2. distributed computation communications
3. artificial intelligence
4. formal methods and computation models
5. information theory
6. relational systems biology
7. molecular biology
8. neuroscience
9. genetics.

Highlights

- My approach neither follows classical discrete models of artificial neuronal networks based on Boolean algebra (McCulloch & Pitts, 1943), nor these based on continuous computation (Siegelmann, 1997), but rather a unifying approach carrying the complementary characteristics of both concepts within a dynamic multilayered relational semantics model of neurogenesis following my *Viator* approach (Simeonov, 2002).

- The latter will be endorsed by concept frames from evolutionary Turing machines, recurrent neural networks, evolving knowledge bases, ontology maps, and semantic entailments within *living ontologies* based on named graphs.

- In addition, my integral model is going to address optimal design principles such as minimal vulnerability, as well as robustness and evolvability.

Highlights

1. **Fields**: The expected results are findings in support of a new *biological information theory* which complements the classical one into an *integral information theory* for both artificial and natural systems.
2. **Relations:** The expected results are the definition a formal *bio-logic* analogous to Elsasser's (1981) and Rosen's (1991) concepts and the development of a relational calculus that depends on the observer (Smolin, 2000).
3. **Networks:** According to autopoietic theory biocomputation cannot be defined as a purposeful task for the solution of a specific problem or class of problems in the way expected from artificial computational systems today. Its fundamental *intent* is not decision making, but adaptation, life maintenance, survival and replication. The research in this field is expected to deliver new insights in autopoiesis, as well as a new consistent definition of autopoiesis, a new formalism, or both.
4. **Semantics:** I claim that computation occurring in nature always involves semantics. The expected result of this research is the design of a meta language construction model for the support of self-creating dynamic attributed ontologies based on multi-layered pattern recognition and capable to express both natural and artificial neuronal activity.