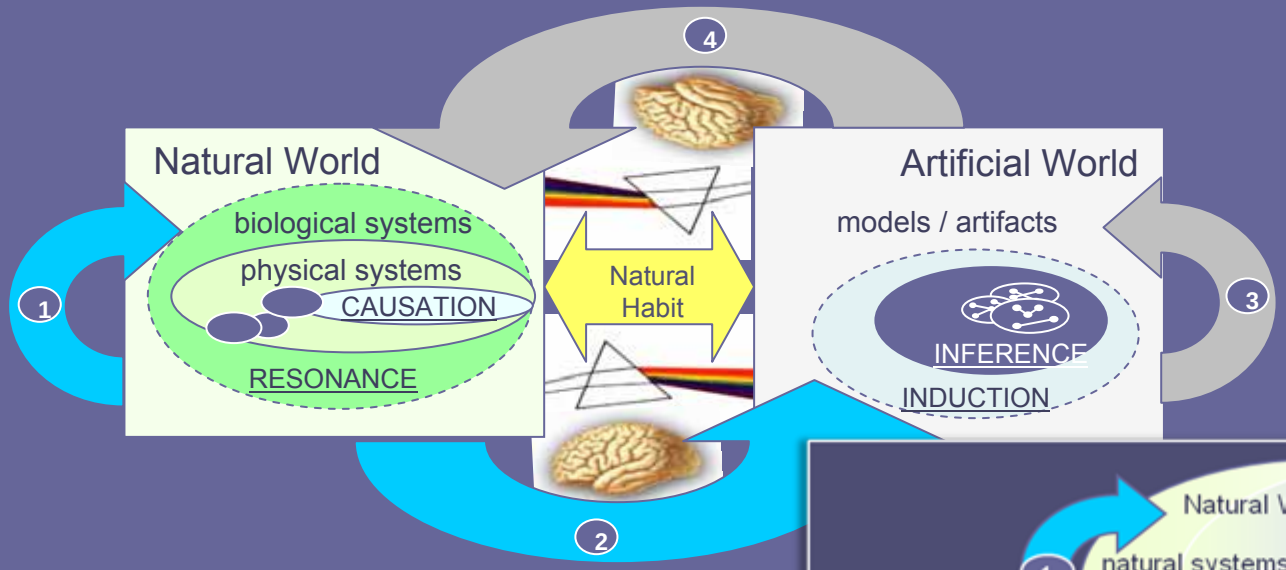
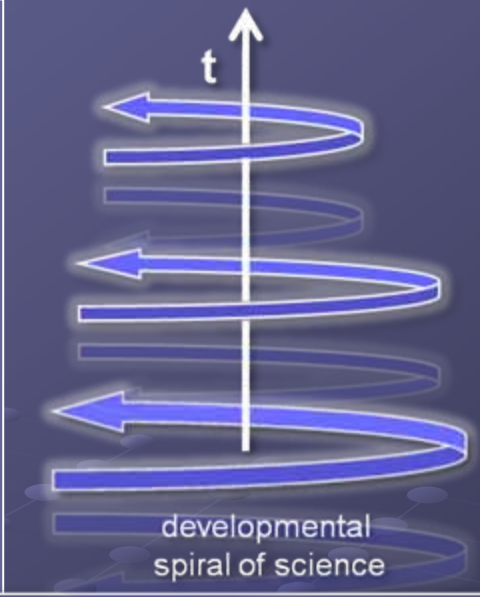
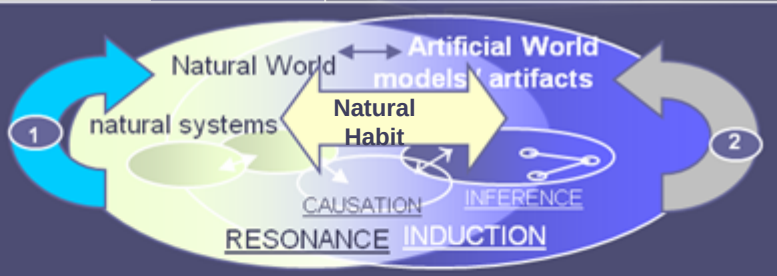
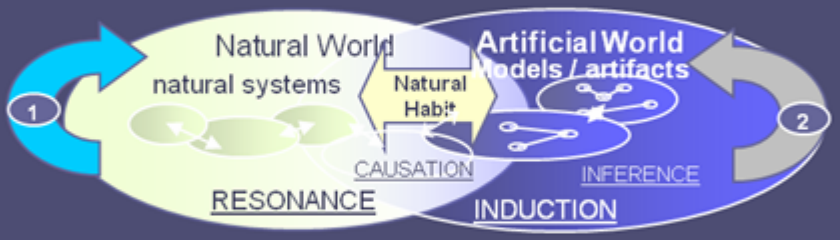
prediction ↔ synthesis ↔ decoding

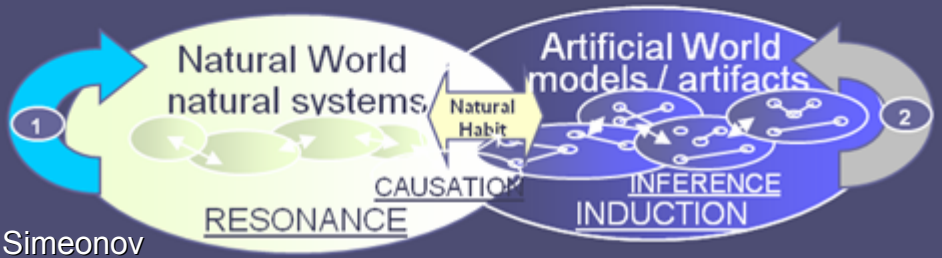




observation ↔ analysis ↔ encoding







Idea

to accelerate scientific development and evolution through balanced fusion of the Real and Artificial Worlds based on unifying classical mathematical biology with biomathics or biological mathematics with system biology on the way to genuine biological system engineering

6/14/2010

Integral Biomathics: Ambition

- **Objective:** a unifying approach to understanding Nature, aiming at unraveling and *explaining the gap between machines and living organisms*

- **Challenges:**
- to investigate the biological imperatives of computation in a profoundly new way based on understanding the fundamental characteristics of emergence, organization, development and evolution in biology
- to devise a new framework for research of complex biological phenomena
  - by integrating the multiple levels of organization and activity in living systems
  - by evolving the model autonomously, thus mimicking the system itself
  - by understanding intrinsic *bio*-logic based on different premises from the logic of today's engineered systems
- to inaugurate a *breakthrough paradigm change towards bio-logically driven mathematics and computation*
- to develop novel mathematical formalisms capable of addressing the multiple facets of an *integral model and a general theory for biocomputing* within an adequate engineering frame of relevance
- to design *novel biosynthetic systems which go beyond Turing's discrete computation* and von Neumann's self-replicating automata

Integral Biomathics: Impact

- **Scope:** to discover new relationships and deliver new ecological insights into the interaction and interdependence between natural and artificial phenomena

- **Associated research domains:** life sciences, physics, chemistry, computer science and engineering, information technology, electrical and mechanical engineering, bioengineering, material sciences (including nanoscience and nanotechnology), aeronautics and astronautics, civil and environmental engineering, architecture and design, energy and earth sciences (geology, ecology, meteorology, geophysics, seismology), business and education (global and political economy, economics, management science and engineering, finance and marketing, organizational behavior, decision and risk analysis, production strategy and policy, operations management) and the humanities (visual and performing arts, history, languages, literature, psychology and philosophy).

- *In particular, we anticipate that this field will have impact on the interpretation that is put on very small structures that have active (non-linear) capabilities. Such structures may involve highly localized physical, molecular or ionic interactions.*

Integral Biomathics: Integration

- R & D agenda: to revise the conceptual framework of contemporary computing and communication theory and develop profoundly new theoretical foundations for integrating systems biology into computation capable to answer such questions as:
  - **What is computation? – within the biological context**, because there is "no computer into which we could insert the DNA sequences to generate life, other than life itself" (Noble, 2010).
  - **How useful is computation? – for living systems**, where "usefulness" is studied from the viewpoint of the entity performing the computation.
  - **To what extent can a computation be carried out?** – in an organism or an ecosystem, with the available resources (energy supply, time, number of 'computing' elements, etc.).

- Some Related FET Flaghip ideas:
  - Living Technology: Exploiting Life's Principles for ICT (Steen Rasmussen)
  - Using evolution to compute (François Képès, Marc Schoenauer)
  - Designing a Life Capsule with Bio-Engineering Ontologies (Wybo Houkes)
  - Towards Augmented Humanity: Tuning Bionic Man (Gusz Eiben)
  - Ubiquitious Complex Event Processing (Rainer von Ammon)
  - Towards a theory of the evolution of the web (Wendy Hall)

Integral Biomathics: Plausibility

Living systems are characterized by the *complexity of biotonic phenomena*: *finiteness of classes* and *non-reducibility / individuality* (Elsasser); they are heterogeneous sets, the componets of which cannot be replaced by each other as physicalistic models do with homogeneous systems of molecules, atoms, etc.

- *Different properties of (living) matter at different topological scales*
  - We need the kind of mathematics, *biomathematics*, able to describe these properties: at molecular scale, at cellular scale, at organic scale, etc.
  - We need *scalability of models*, but neither greedy reductionism, nor greedy holism
- *Different kind of computational models*
  - Internalist, implicit and integral models instead of *purely* explicit and externalist ones.
  - Relational, evolutionary and developmental models instead of absolute and static ones.
- *Different purpose (base) for computation in living systems*
  - **Present day biocomputation** approaches, such as cellular, membrane, DNA computing, etc. *(mis)use biological systems* to perform calculations which are ***not really natural*** (e.g. Adleman's DNA solution of the NP-complete Hamiltonian Path problem in combinatorics).
  - We need a **new concept for computation** in biological context, a new eco-*bio-logic*.
  - We need to ask **new questions** about *living computation* and *computation for life*.

Integral Biomathics: Support

- Prof. Tatsuya Nomura, *Mathematics*, Ryukoku University (Japan)
- Prof. Leslie S. Smith, *Neuroinformatics*, University of Stirling (UK)
- Prof. emer. Stanley Salthe, *Zoology & Natural Phylosophy*, Binghampton University (USA) & University of Copenhagen (Denmark)
- Prof. emer. Dr. habil. Peter J. Plath, *Physical & Theoretical Chemistry*, University of Bremen & Fritz-Haber Institute, Max-Planck Society (Germany)
- Prof. emer. Koichiro Matsuno, *Biophysics & Bioengineering*, Nagaoka University of Technology (Japan)
- Prof. Otto E. Rössler, *Biochemistry*, University of Tübingen (Germany)
- Prof. Felix T. Hong, *Physiology & Biocomputing*, Wayne State University (USA)
- Prof. Hava T. Siegelmann, *Neural Computing*, University of Massachussetts at Amherst (USA)
- Prof. Kenneth J. Turner, *Computer Science*, University of Stirling (UK)
- Prof. William Seaman, *Visual Arts & Science*, Duke University (USA)
- Prof. emer. Denis Noble, *Cardiovascular Physiology*, University of Oxford (UK)
- et al. + anyone else who wishes to join this fantastic journey !

Integral Biomathics: Plausibility

Research areas of major interest in Integral Biomathics:

1. **Fields**: exploration of the *physical base* of biocomputation in terms of regular assemblies of structural elements and functional patterns excited by the oscillatory character of the underlying processes allowing the evolution of stable nonlinear systems through moving equilibria. Expected results: findings in support of a new *biological information theory* that complements the classical one into an *integral information theory* for both artificial and natural systems.
2. **Relations:** Relational variables are created by the system itself, as it evolves (Smolin, 2003). Organisms can be represented as *n*-placed predicates or *n*-ary relations (Rashevsky, 1965-1968). Expected results: i) definition of a formal *bio-logic* (Elsasser, 1981; Rosen, 1991); ii) development of a relational calculus that depends on the observer (Smolin, 2000) and capable of addressing such phenomena as instant response to *unpredicted stimuli, variableness, fuzziness, uncertainty, entanglement and superposition.*
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. *Any formal description of such a living network is impossible with current mathematics* (Nomura, 2007). Expected results: i) new insights in autopoiesis; ii) new consistent definition of autopoiesis, new formalism, or both.
4. **Evolving Hierarchies:** Computation occurring in nature always involves implicit semantics and semiotics. Hence, it cannot be formalised in the conventional way using purely explicit (syntactic) and static Hilbert logic. Expected results: i) development of a meta-model describing the emergence of dynamic attributed ontologies in terms of *multi-layered patterns* (living system codes), capable of expressing such phenomena as both natural and artificial neuronal activity. ii) explanation of the patterns, their spatio-temporal formation, use and recognition as signals followed by transformation into signs (semiosis) in terms of higher layers of order studied in the domains of semiotics (Peirce, 1869b, 1903; Uexküll 1940, 1982), physiosemiotics (Deely, 2001) and biosemiotics (Salthe, 1985-2000; Barbieri, 2007).