

Keynote Talk  
**Structure and Outlook  
of Digital Ecosystems Research**

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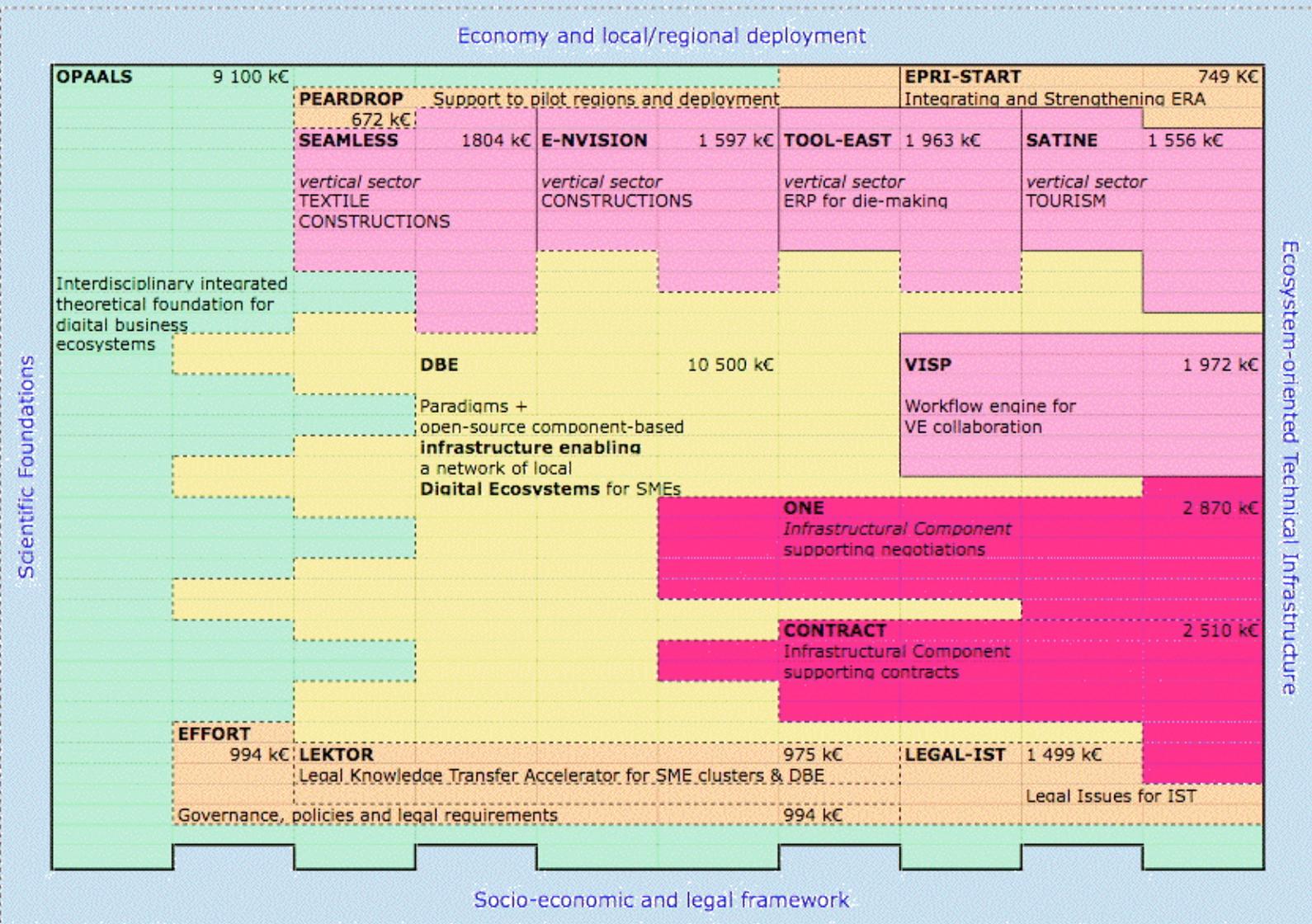
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# Overview

- **Conceptualisation of digital ecosystems research**
- **Theoretical perspectives:**
  - **Social science**
  - **Computer science**
  - **Natural science**

# The Cluster of FP6 Research Projects on Digital Ecosystems

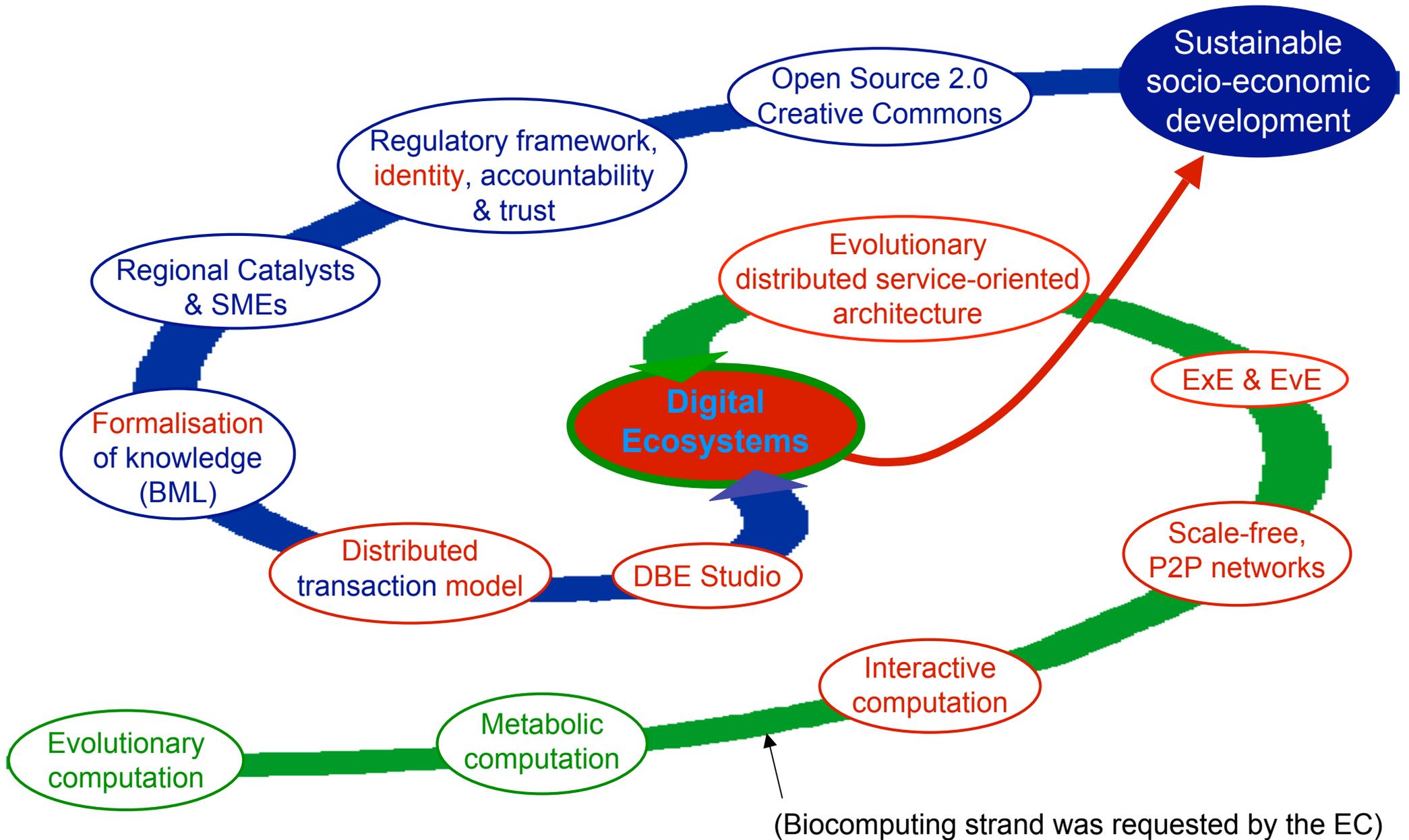


Integrated Project  
 Network of Excellence  
 Specific Support Action

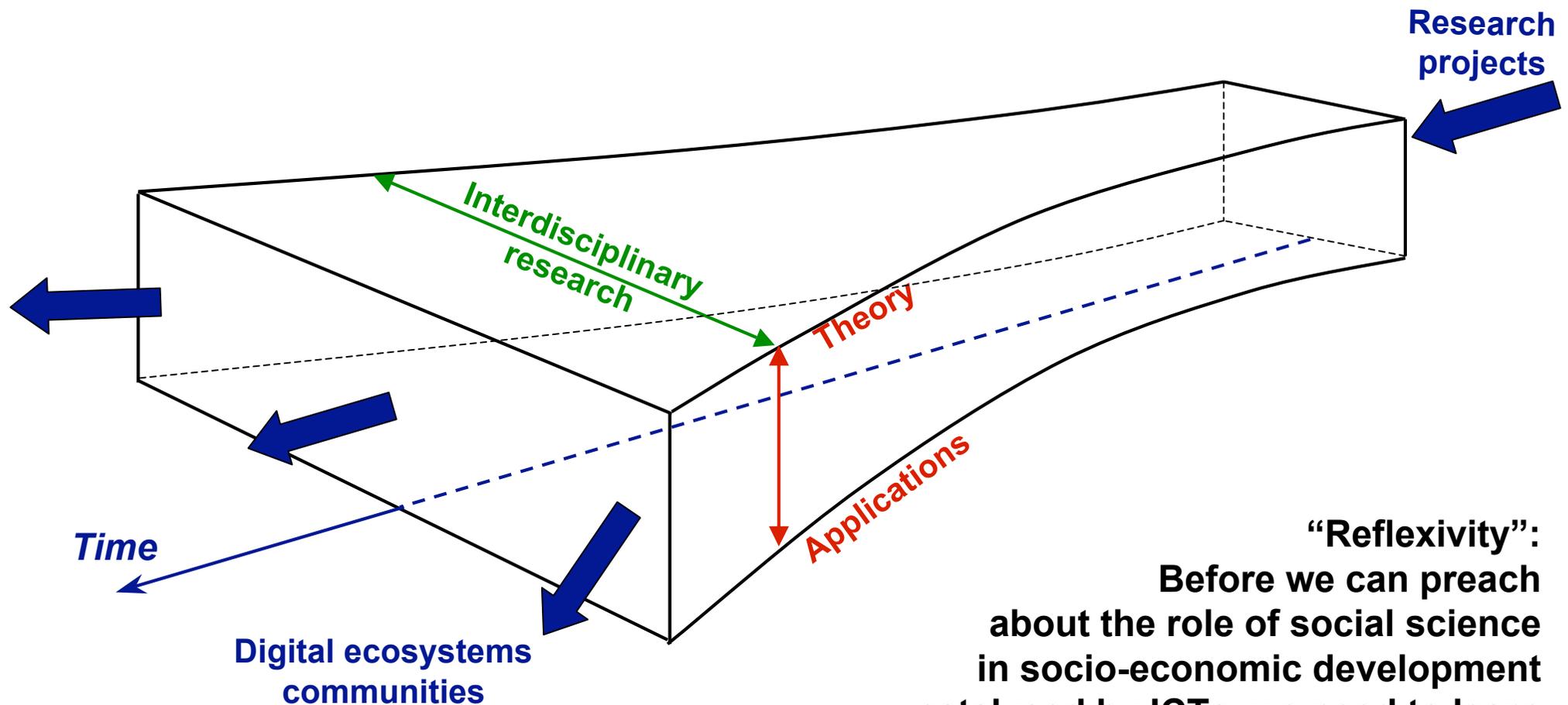
STREPs (vertical sectorial projects)  
 STREPs (infrastructural and generic components)

**EC Contribution:**  
**1box = 100k€**

# Strands of Research



# Process View of Digital Ecosystems Research



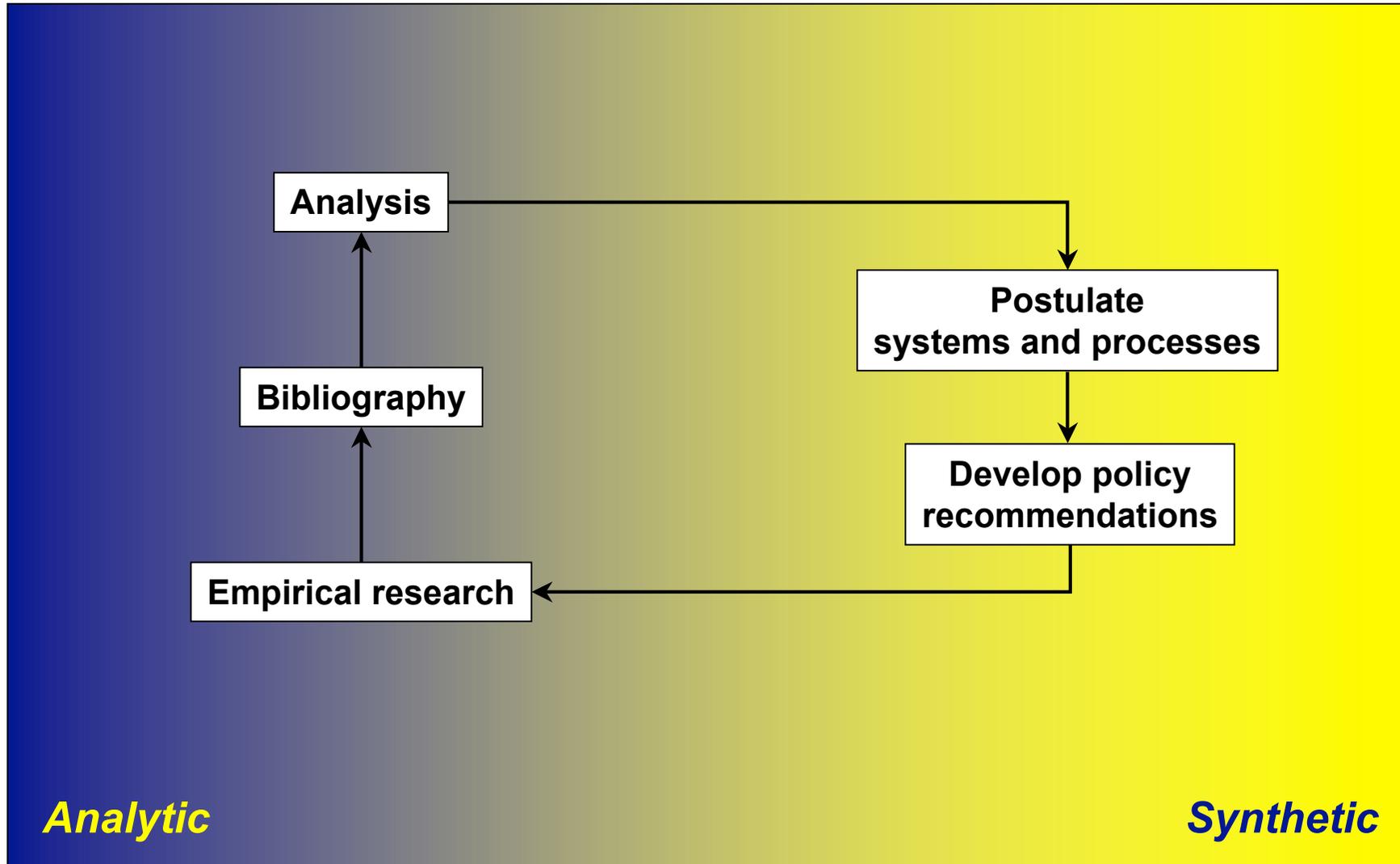
**“Reflexivity”:**  
Before we can preach about the role of social science in socio-economic development catalysed by ICTs, we need to learn how to communicate and work together across disciplinary boundaries

# Social Science

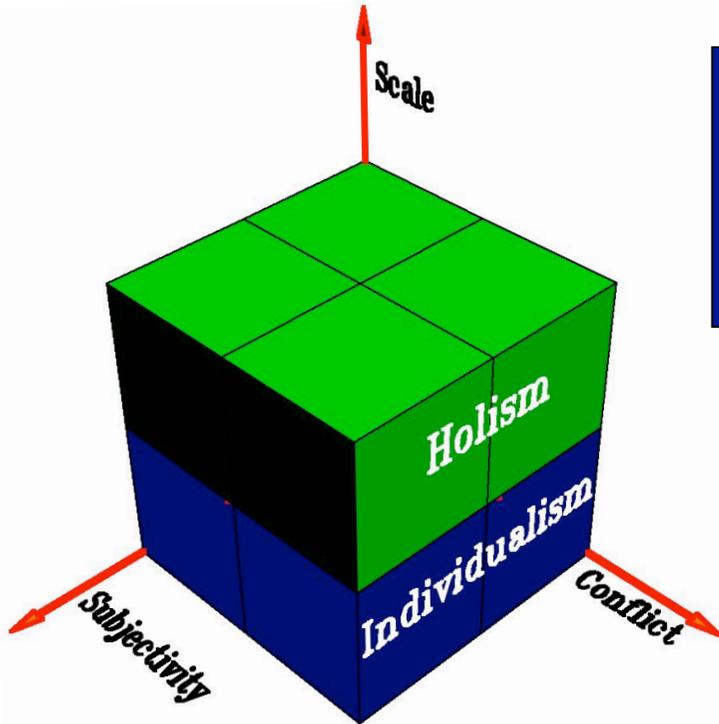
**“Translating the processes of knowledge generation and exchange into improvements in economic performance and employment is a complex social process”**

**Ed Steinmueller (2004)**

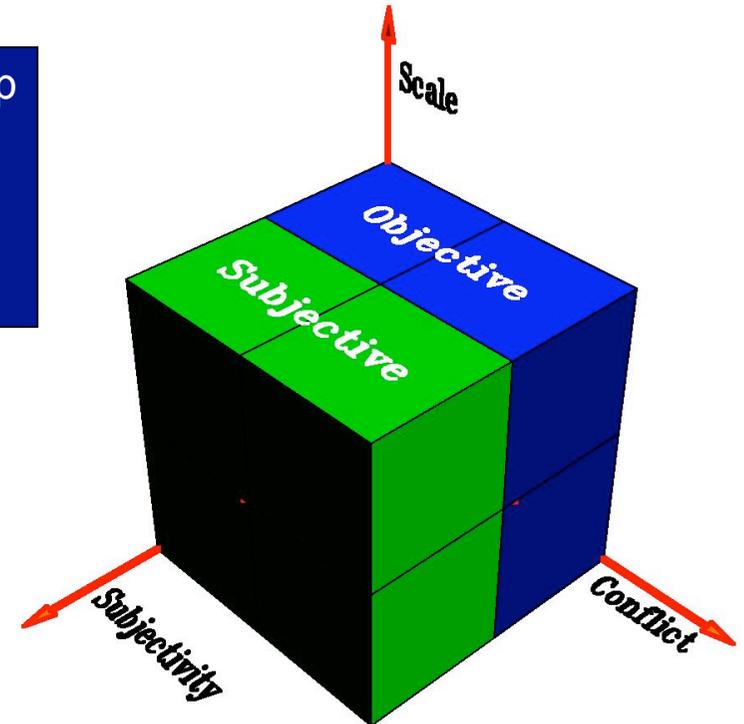
# Methodology



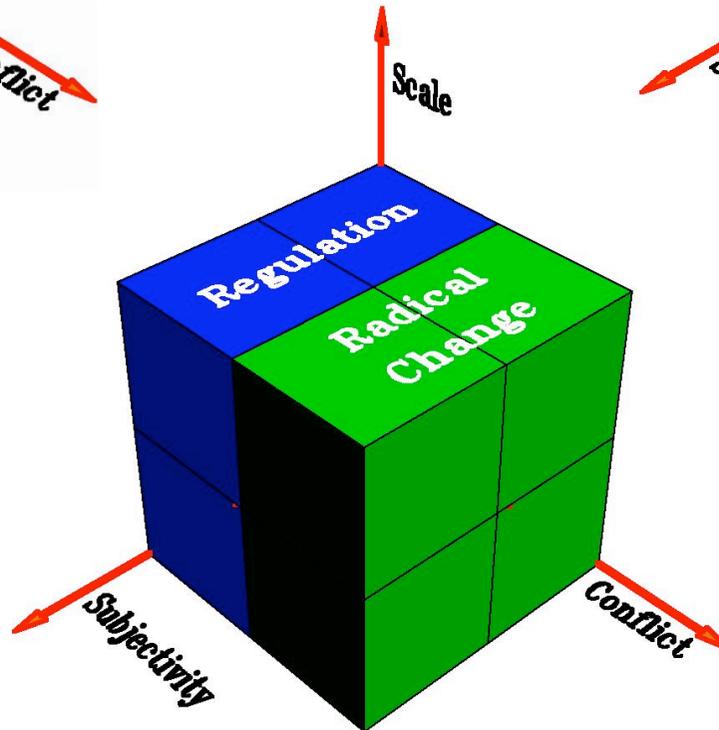
# A Mechanical Engineer's View of Social Science



But we are trying to develop a *SUSTAINABLE* process of socio-economic development catalysed by ICTs...

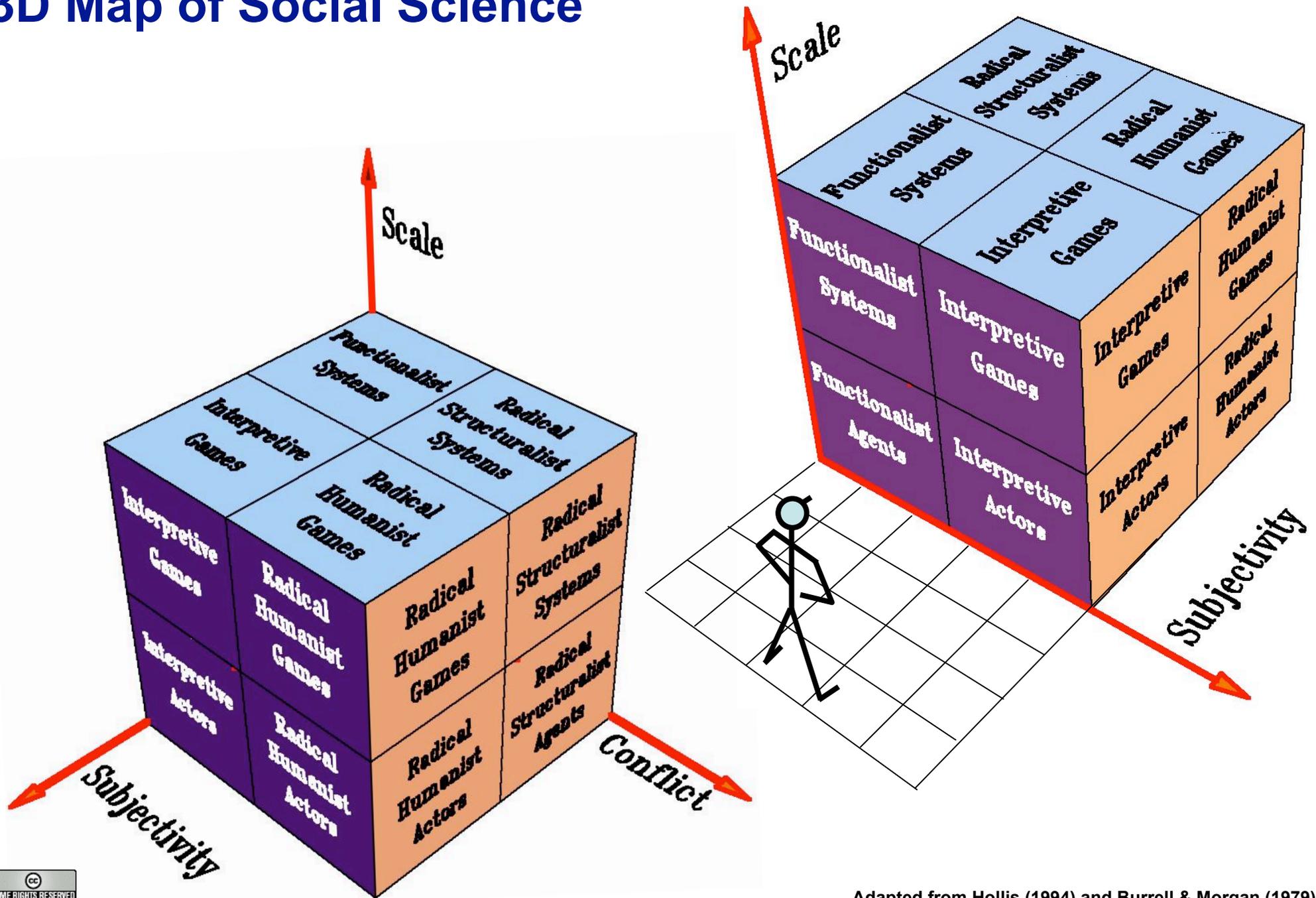


We can't ignore conflict

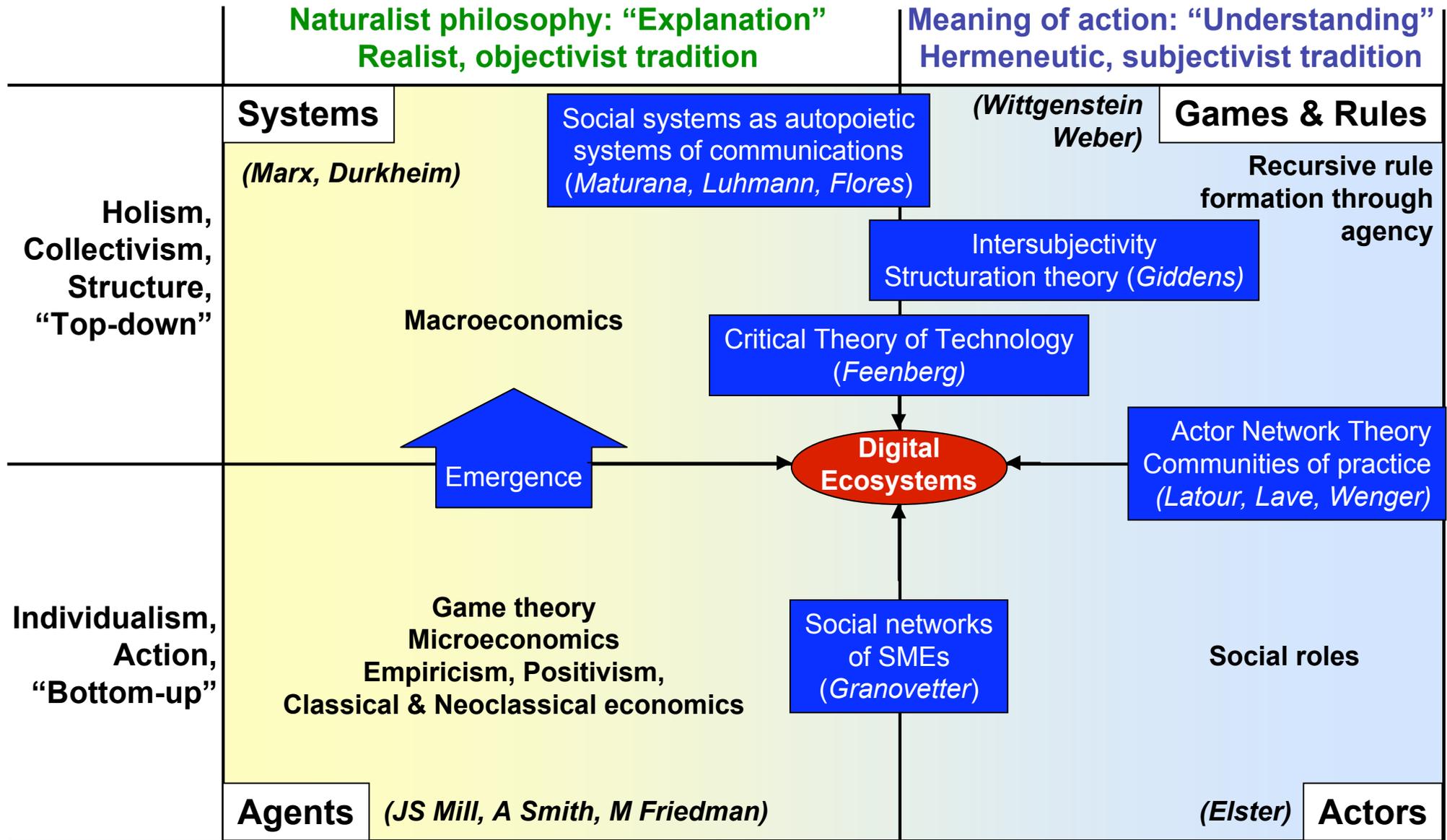


Hence we can't help aiming for a view informed by the sociology of regulation

# 3D Map of Social Science



# Spaces of Debate



# Associative

Based on association  
Conducive to association  
Dependent on association  
Enabling association

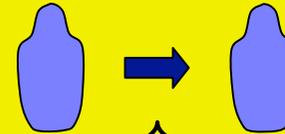
Recursive, reflexive,

# Autopoietic



*Autopoietic*

Capable of generating itself with the ability to reproduce itself recursively



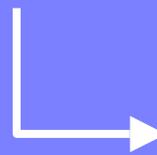
Capable of generating itself with the ability to reproduce itself

Self-generating  
Self-producing  
Self-organising



Capable of generating itself

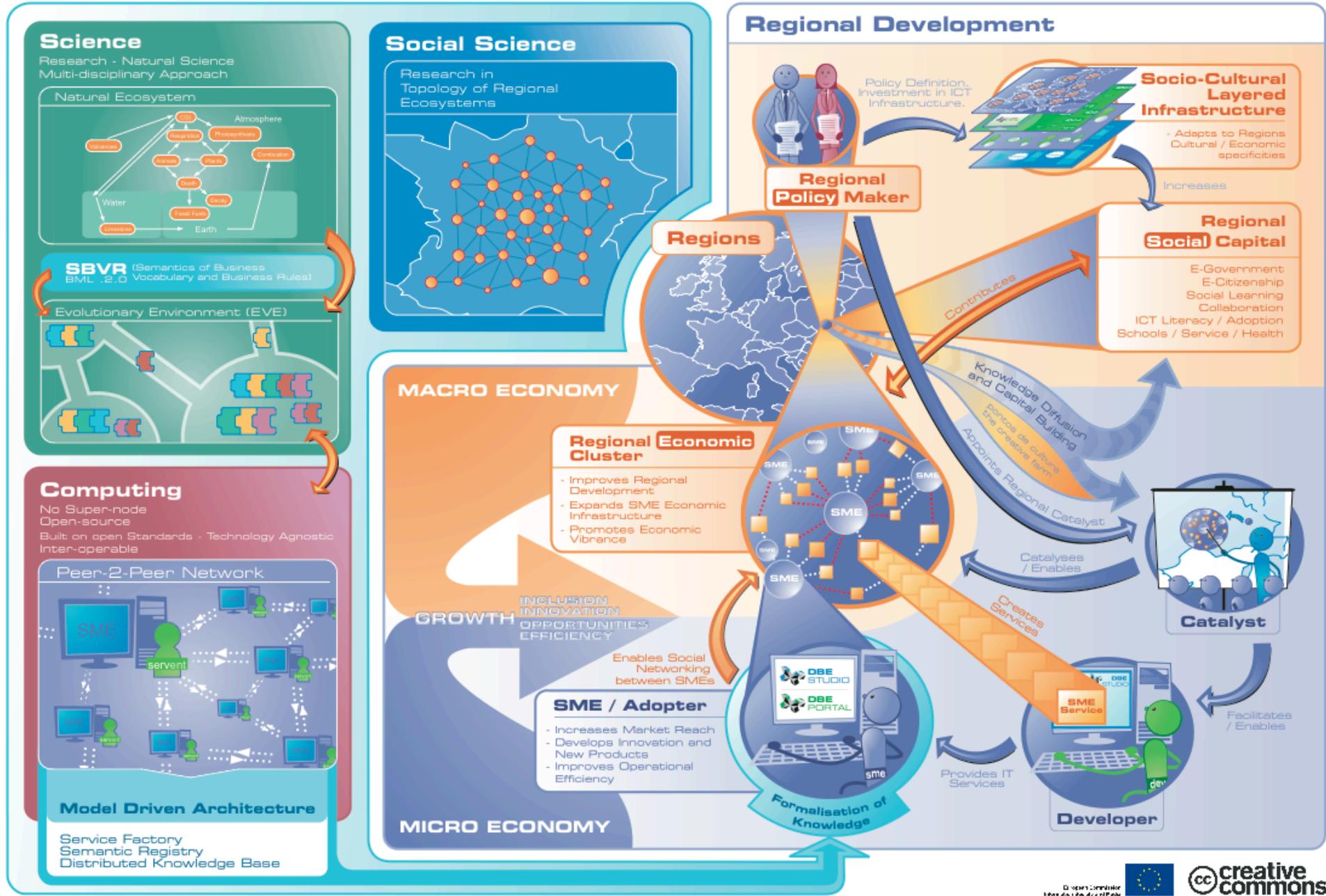
self-reinforcing community building process



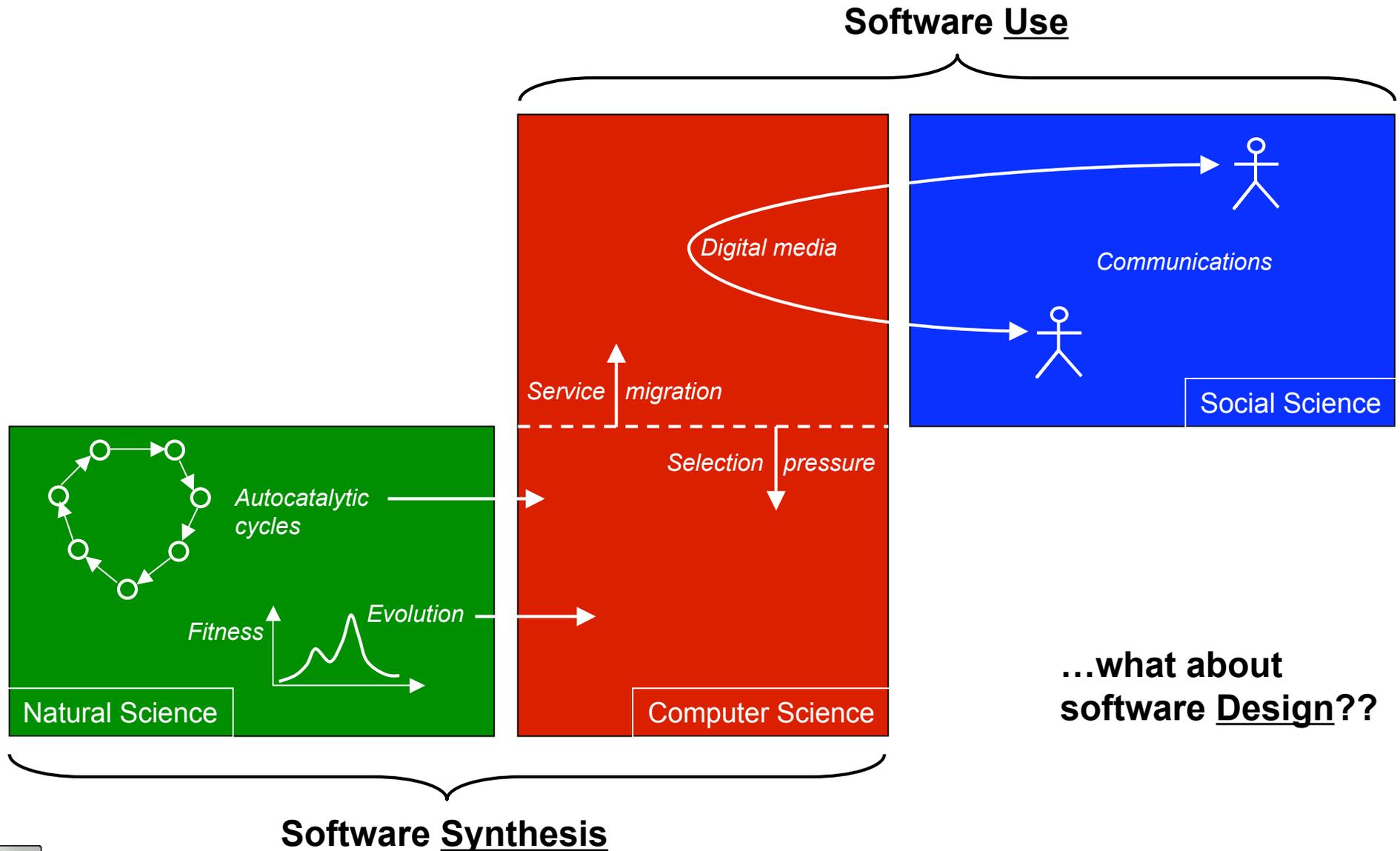
Socio-economic systems



Software?

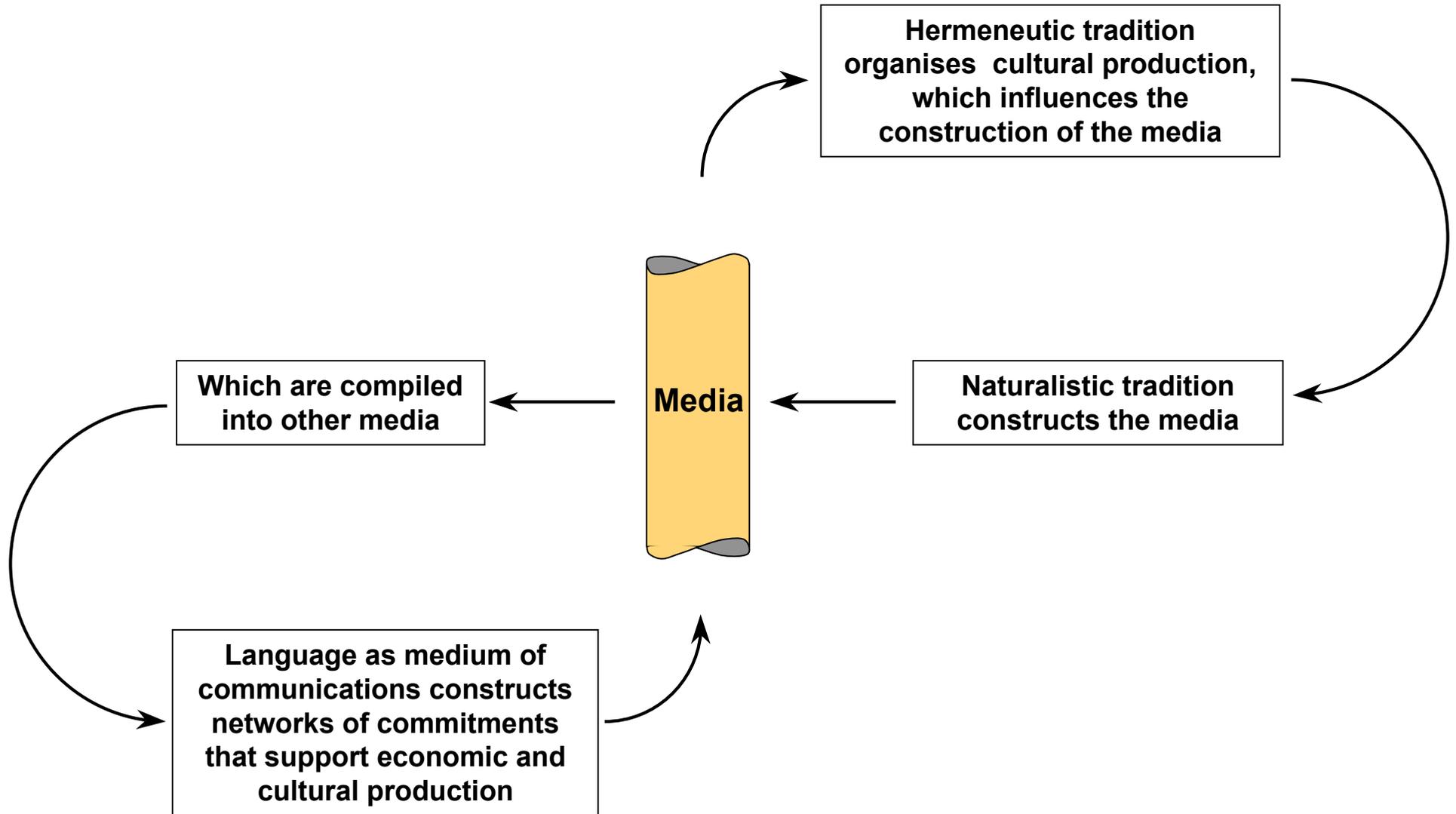


# How can the 3 disciplinary domains coexist?



...what about **software Design**??

# Autopoiesis of Media



# Shift of Paradigm

Engineering “problem solving” approach:

Isolate problem, identify variables, make a plan ...

Economy as machine

Complexity, Ecosystemic approach:

- From building a machine → nurturing a garden
- From “engineering approach” → “ecosystemic approach” (multi-stakeholder)
- From making a plan → creating the conditions

Economy as ecosystem

Open-source Digital Ecosystem:

- Embeddedness of economic action in social structure
- “Toll-free” medium of business communications and interactions
- Knowledge formalisation, community building through shared languages
- *Evolutionary and self-optimising service-oriented architecture*

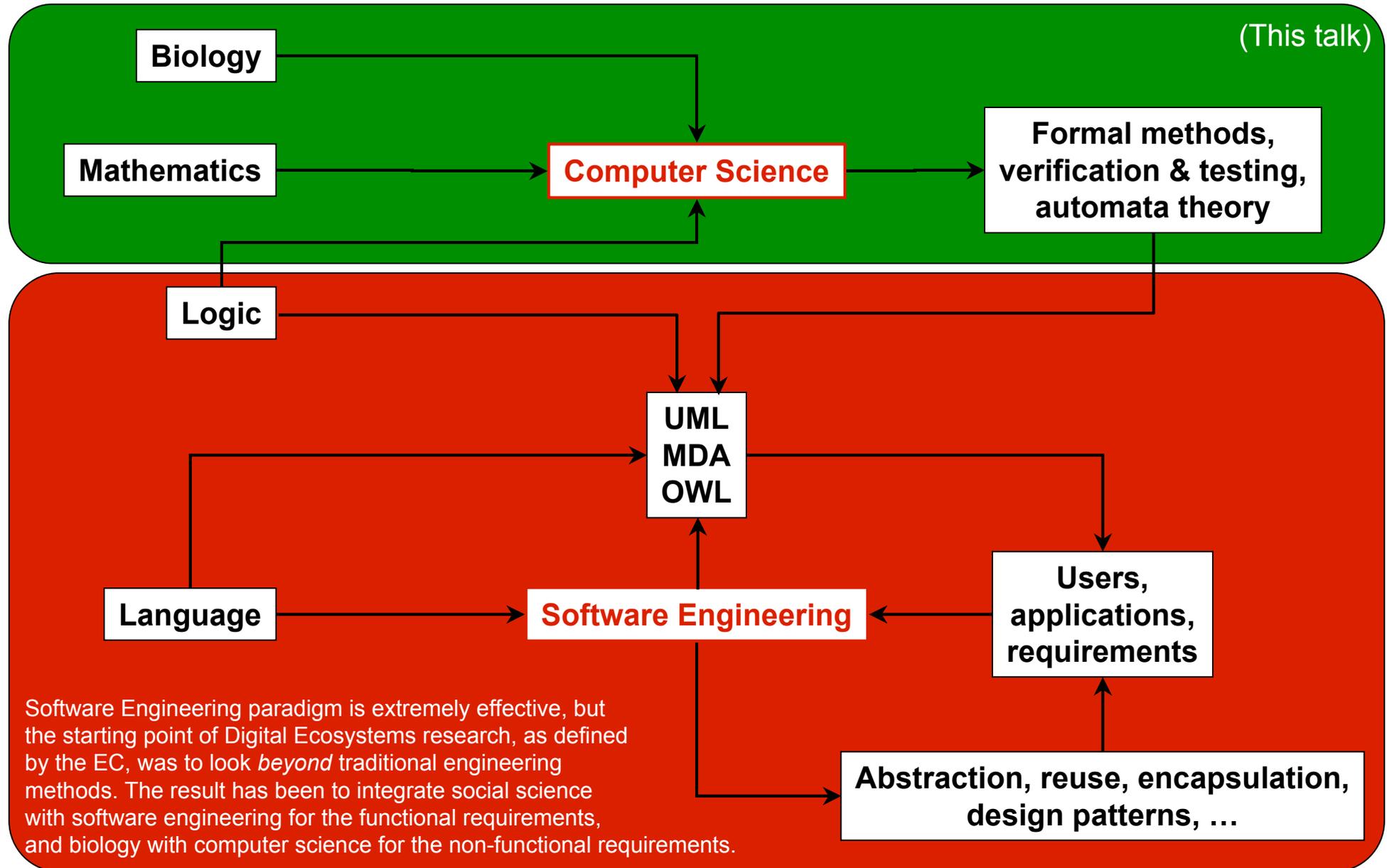
Sustainable socio-economic development

# Computer Science

**“Turing Machines cannot compute all problems,  
nor can they do everything real computers can do”**

**Golding and Wegner (2005)**

# Some Inputs and Outputs



# Interactive Foundations of Computing

- In the mid-60s Milner and others started to realise that deterministic finite automata (DFAs) were not adequate to model interaction between processes, and that something closer to Mealy automata, which generate an output for every state change triggered by an input, would be preferable.
- The result was the Calculus of Communicating Systems (CCS) in the 70s and the  $\pi$ -calculus by 1990. In parallel, Multiset Rewriting was developed as a model for chemical systems.
- Over the last 30 years the theory of concurrent processes combined with networking, the Internet, and OO programming has gradually given form to a de facto alternative to the model of computation based on the Turing Machine. This was not proclaimed too loudly though!
- It probably seemed too much to challenge *both* the Church-Turing thesis *and* the Chomsky hierarchy of formal languages.
- Wegner and Golding's papers show how Turing Machines were never intended to provide a model of computation for distributed and interactive computing, but were ascribed that role through a series of conceptual adjustments (misinterpretations) of the original theory motivated by practical concerns.

# A More Precise Rephrasing of the Church-Turing Thesis\*

## Accepted wisdom:

**Claim 1.** (Mathematical worldview) All computable problems are function-based.

**Claim 2.** (Focus on algorithms) All computable problems can be described by an algorithm.

**Claim 3.** (Practical approach) Algorithms are what computers do.

**Claim 4.** (Nature of computers) TMs serve as a general model for computers.

**Claim 5.** (Universality corollary) TMs can simulate any computer.

**Corrected Claim 1.** All algorithmic problems are function-based.

**Corrected Claim 2.** All function-based problems can be described by an algorithm.

**Corrected Claim 3.** Algorithms are what early computers used to do.

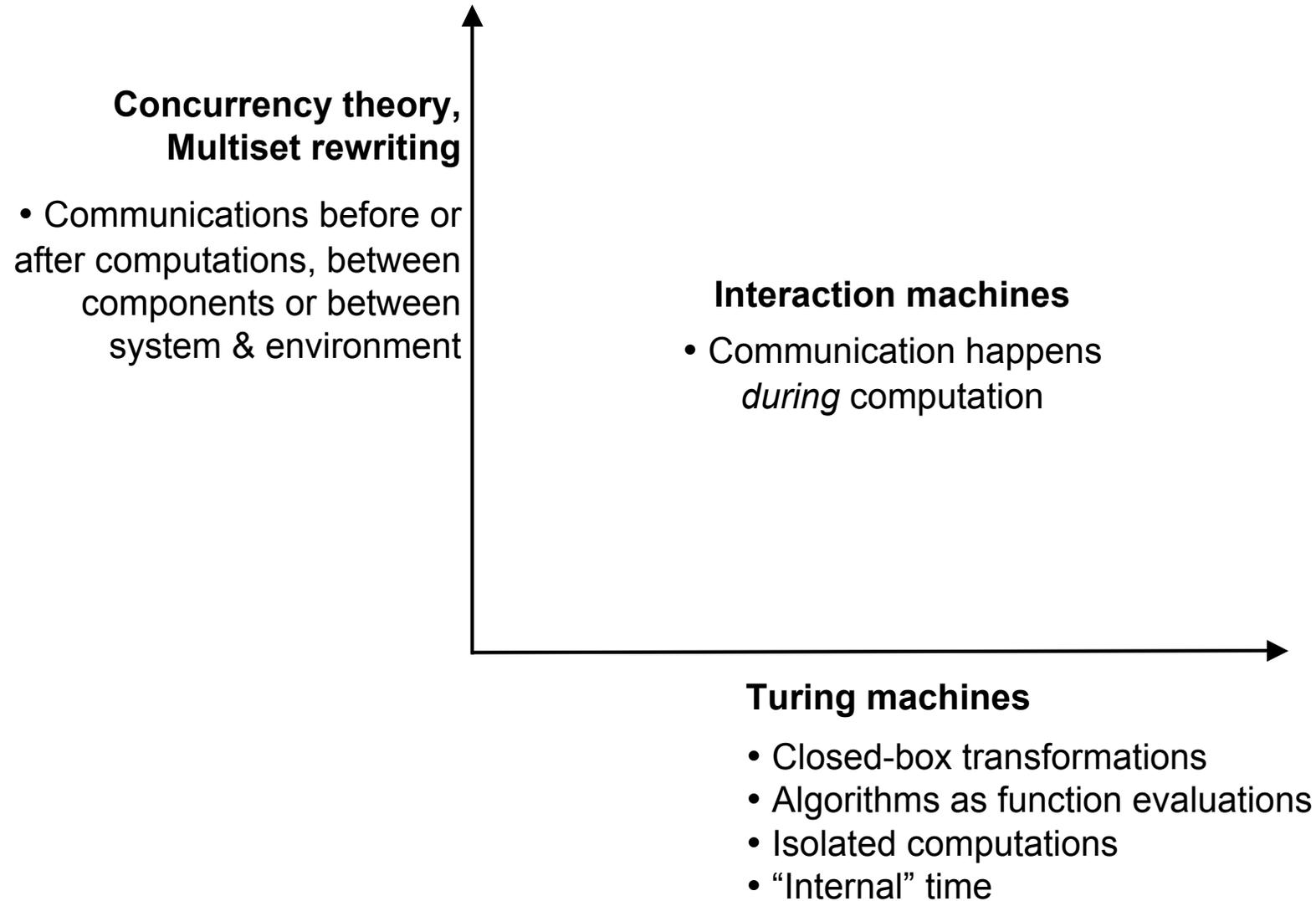
**Corrected Claim 4.** TMs serve as a general model for early computers.

**Corrected Claim 5.** TMs can simulate any algorithmic computing device.

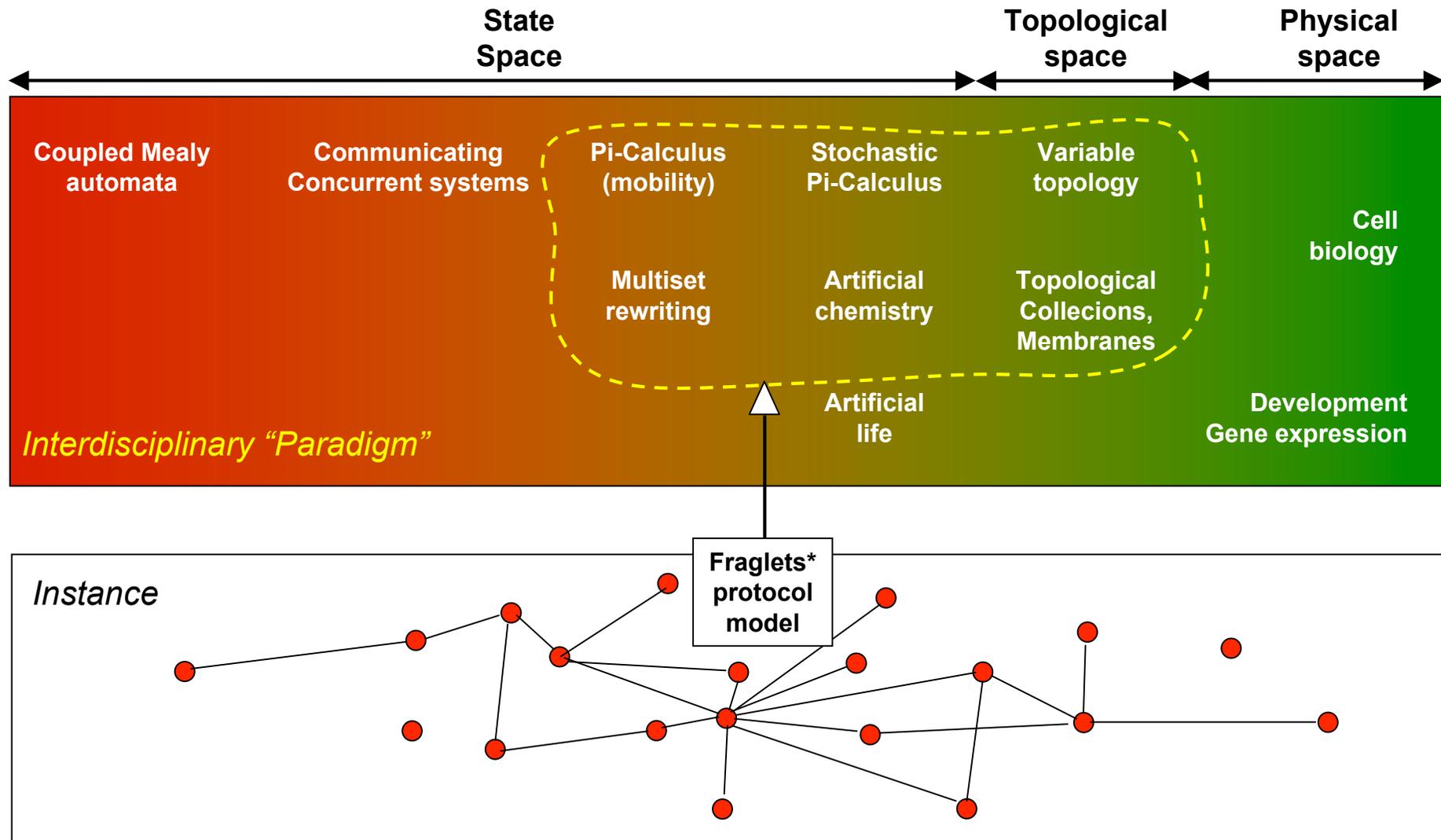
Furthermore, the following claim is also correct:

**Claim 6:** TMs cannot compute all problems,  
nor can they do everything real computers can do.

# The 3 Main Models of Computation



# Emerging Mathematical Framework for Biocomputing



# Natural Science

**“Darwin’s answer to the sources of the order we see all around us is overwhelmingly an appeal to a single singular force: natural selection.**

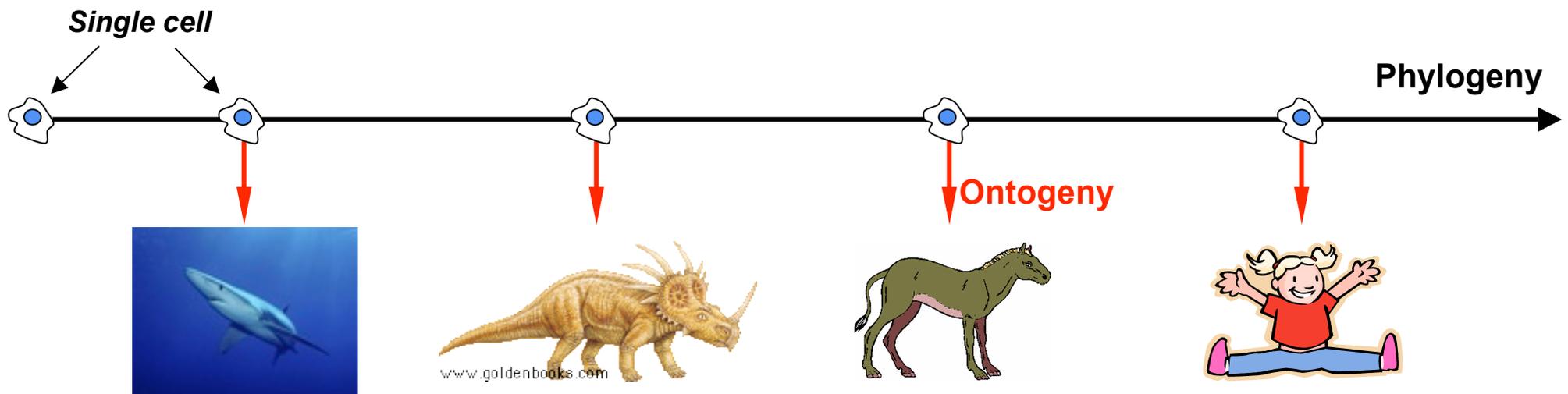
**It is this single-force view which I believe to be inadequate, for it fails to notice, fails to stress, fails to incorporate the possibility that simple and complex systems exhibit order spontaneously”**

**Stuart Kauffman (1993)**

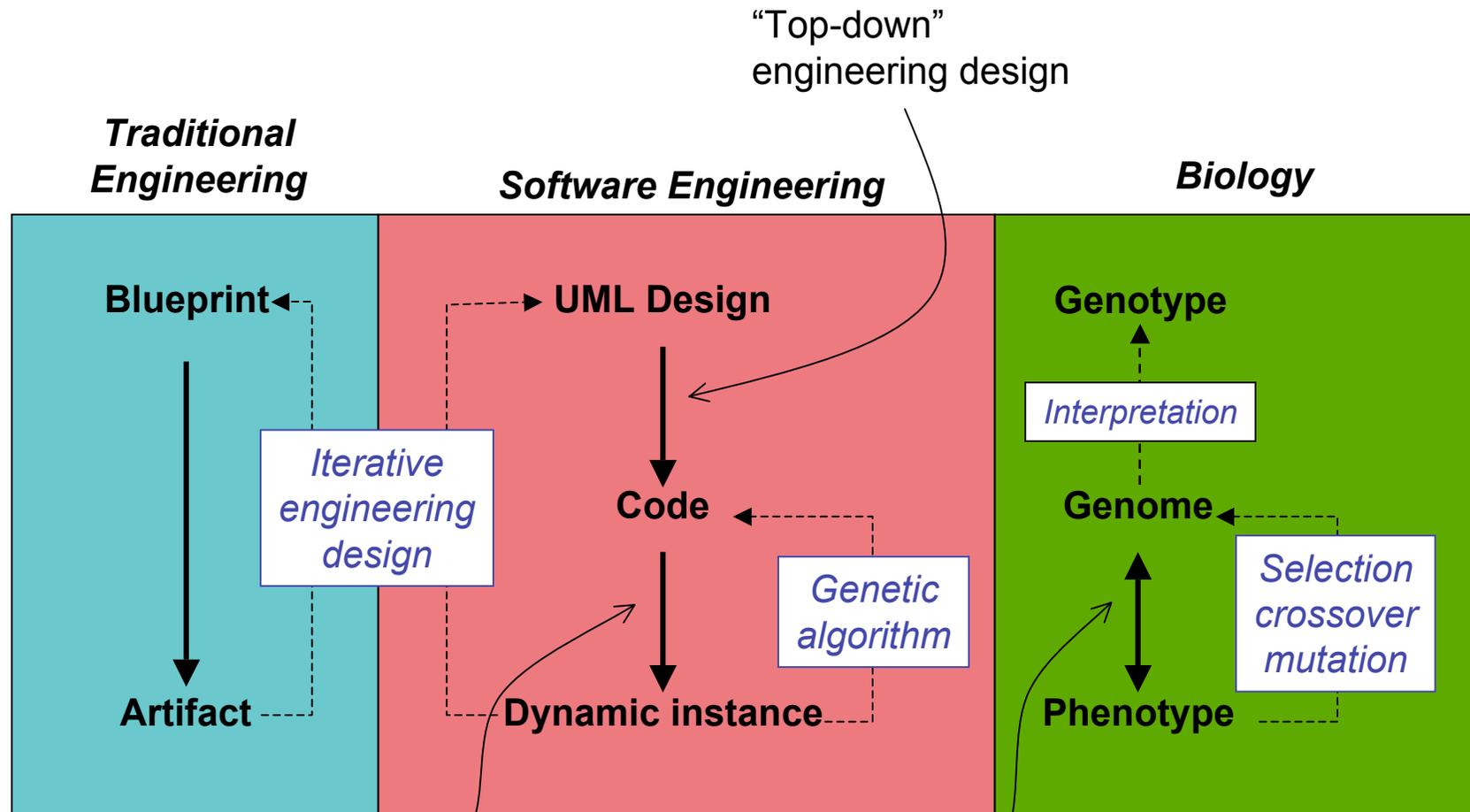
# Objective

- **Natural Science Digital Ecosystems research is concerned with discovering how biological self-organisation can be applied to software.**
- **However, since we do not quite understand biological self-organisation, yet, we need to involve biochemists and physicists in a collaborative interdisciplinary effort so that *both* Biology and Computer Science can benefit in the end.**
- **Where do we start? We start by recognising two forms of biological self-organisation:**
  - **Darwinian Evolution**
  - **Development (embryogeny)**

# Evolution and Development



# Evolution, Development & Engineering



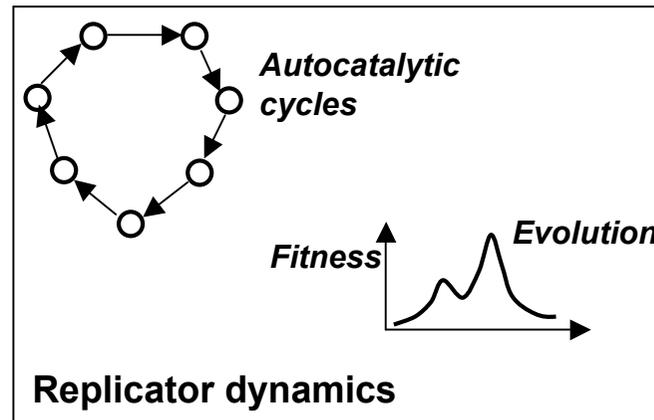
- Compilation and instantiation:
- mainly unidirectional
  - minimum context sensing
  - linear genotype-phenotype map

- Development, morphogenesis & gene expression:
- bi-directional
  - highly dependent on environment of DNA
  - highly non-linear genotype-phenotype map

# Origin of Life: Distributed Algorithm

- Before cell membranes formed the primordial soup was populated by free RNA replicators
- The replicators that were faster at replicating themselves were “fitter”
- At some point the replication rate of one species started to depend on the presence of another species
- The second species started to depend on a third, and the third on the first: the first autocatalytic cycle was born

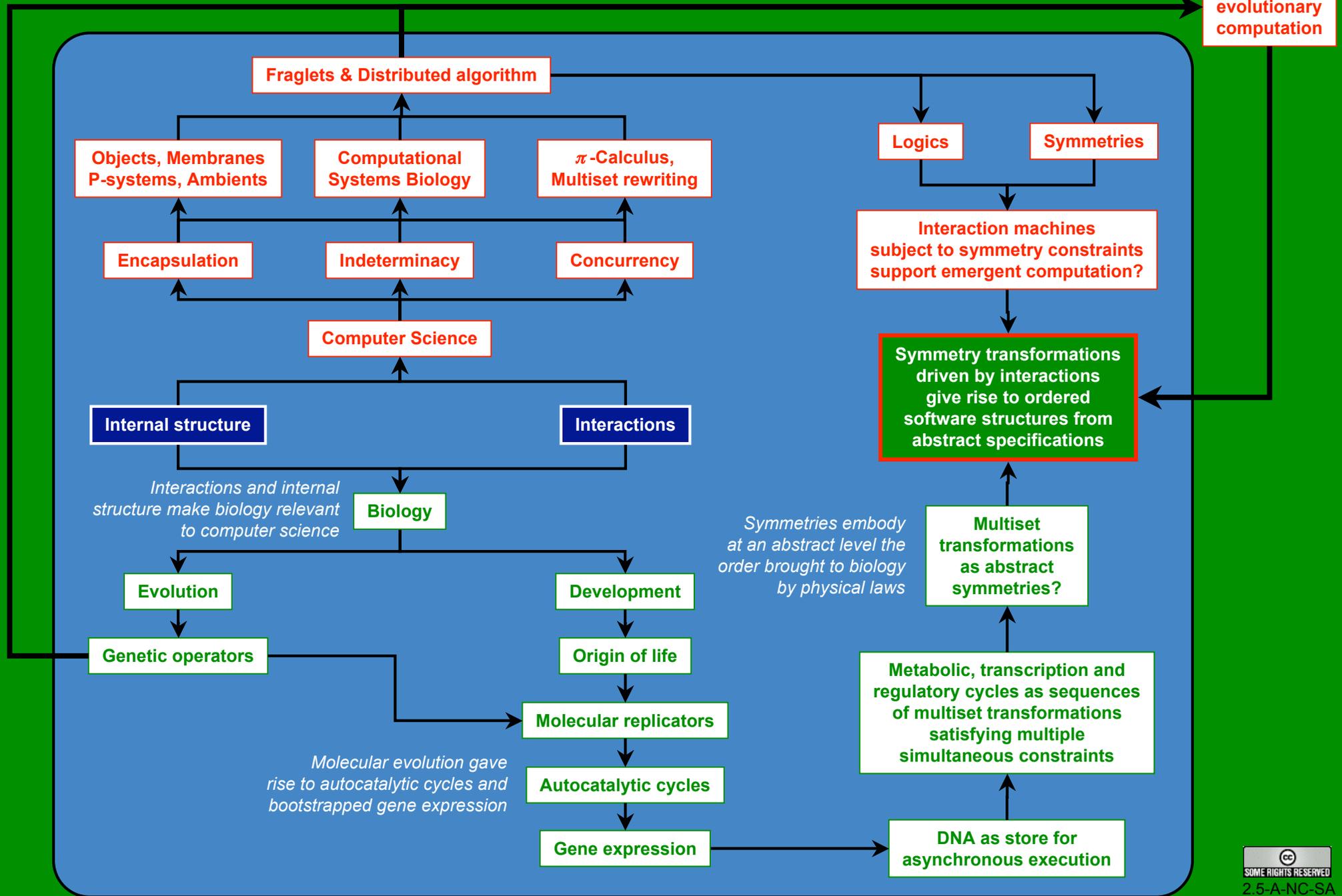
**Autocatalytic cycles**  
**are the origin of**  
**gene expression**



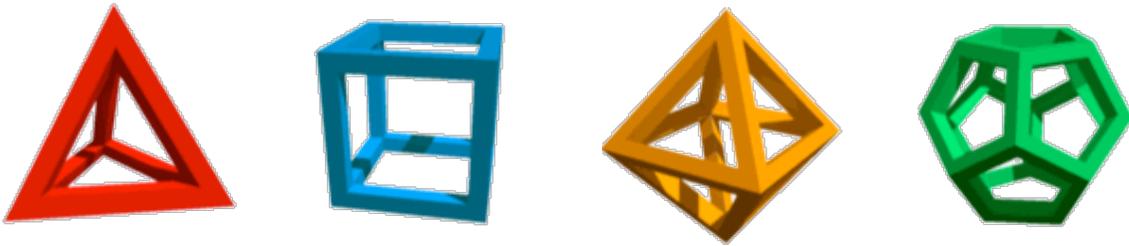
**Molecular evolution**  
**Is the origin of Darwinian**  
**Evolution based on**  
- mutation  
- crossover  
- natural selection

- Since the fitness of the autocatalytic cycles was greater, they took over the primordial soup
- Autocatalytic cycles and molecular evolution ratcheted off each other to generate ever greater complexity and diversity, bootstrapping an ecosystem
- Interdependence between molecular species leads to the concept of distributed algorithm

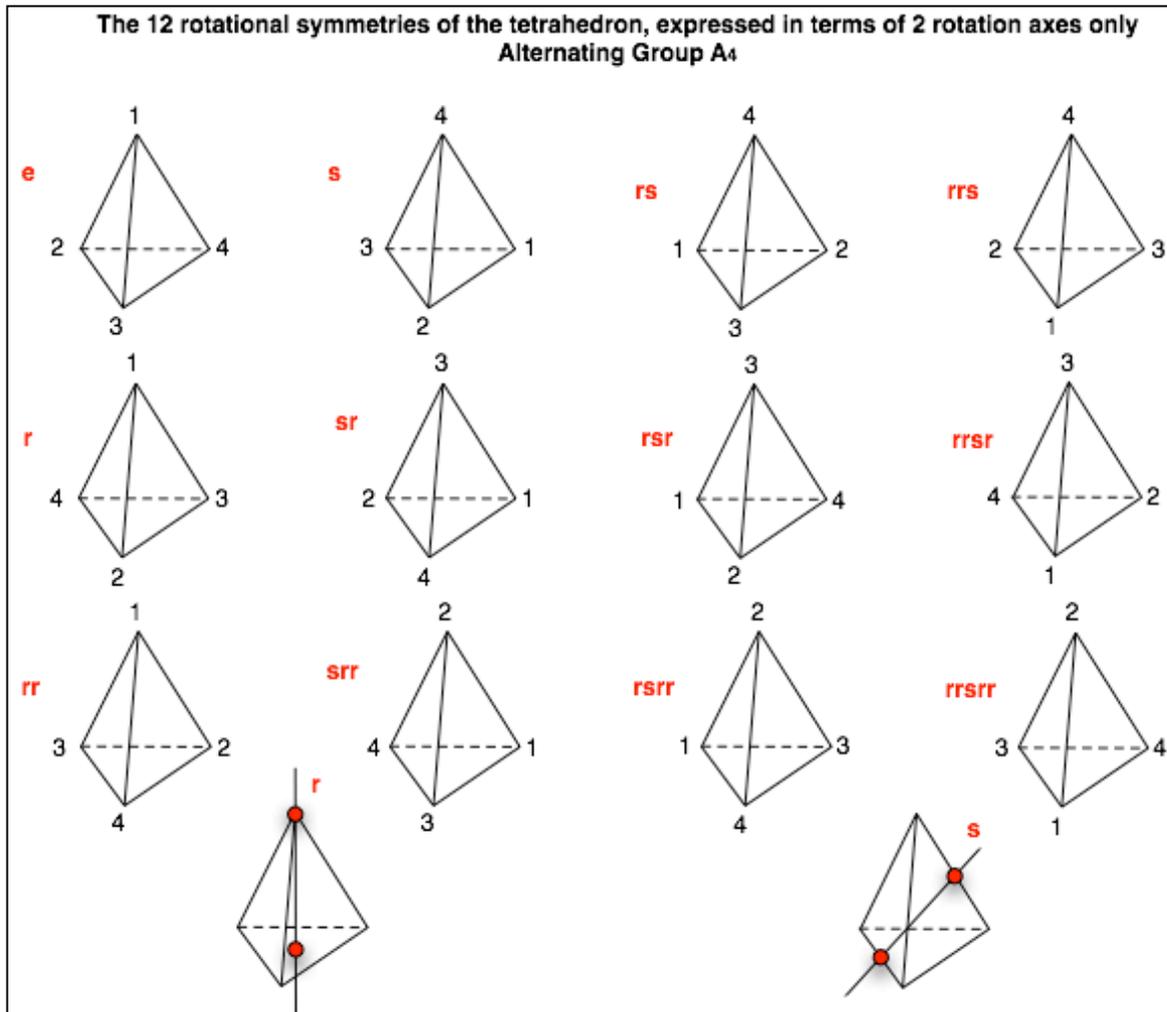
# Computational Biology and Biocomputing Integration Framework



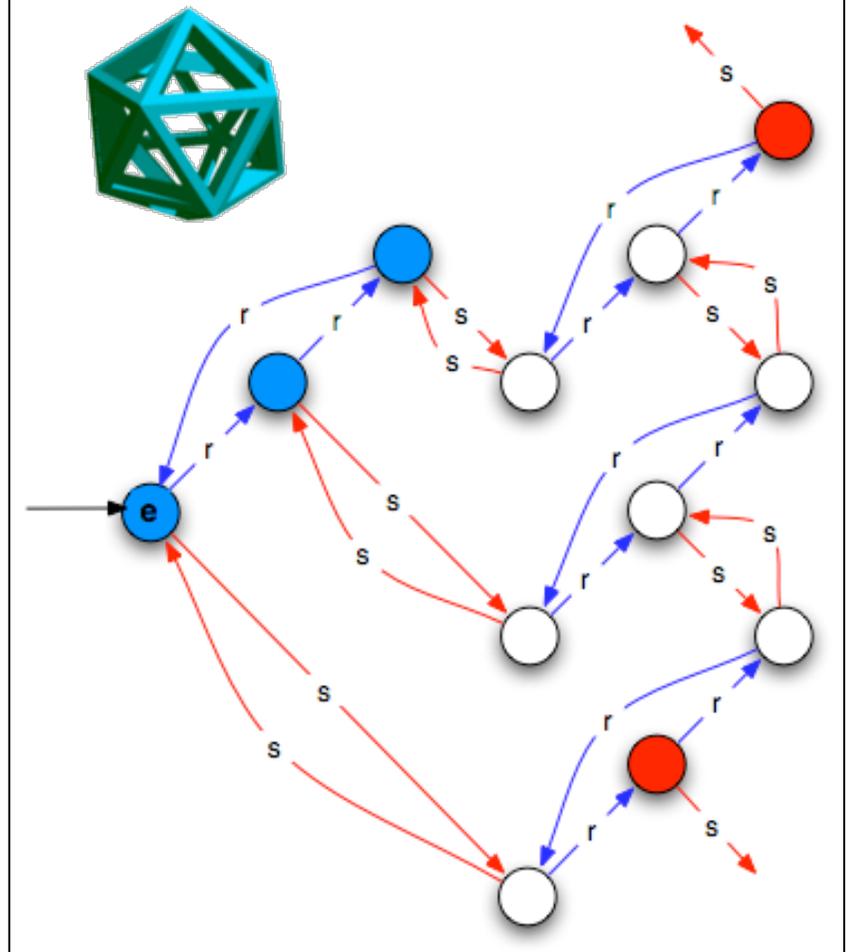
# Can symmetries provide useful constraints to enable emergent computation?



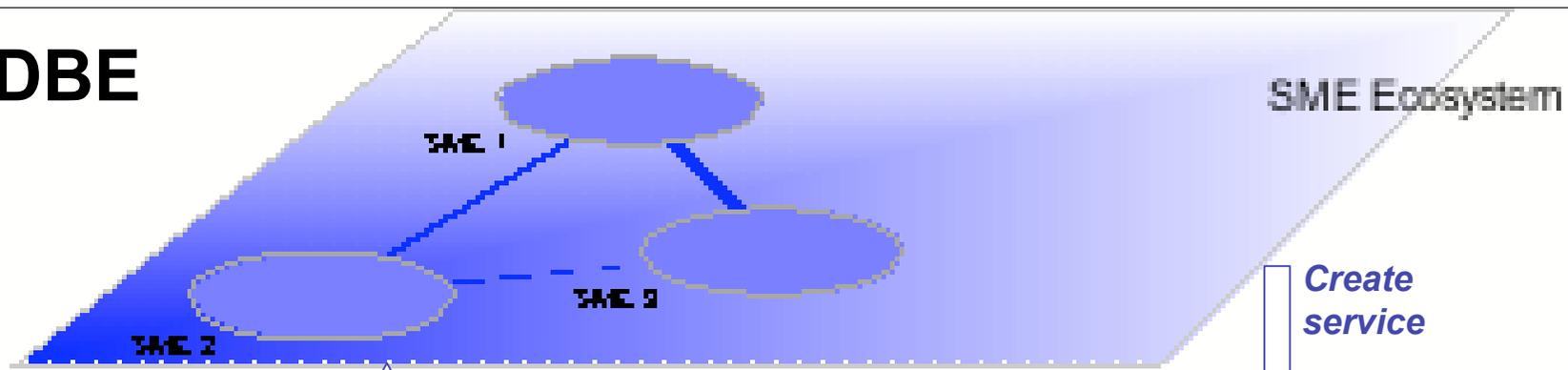
<http://math.about.com/od/geometry/ss/platonic.htm>



The 12 rotational symmetries of the tetrahedron can be seen as the 12 states of a Finite Deterministic Automaton whose language is given by any string of "r" and "s" symbols



# DBE



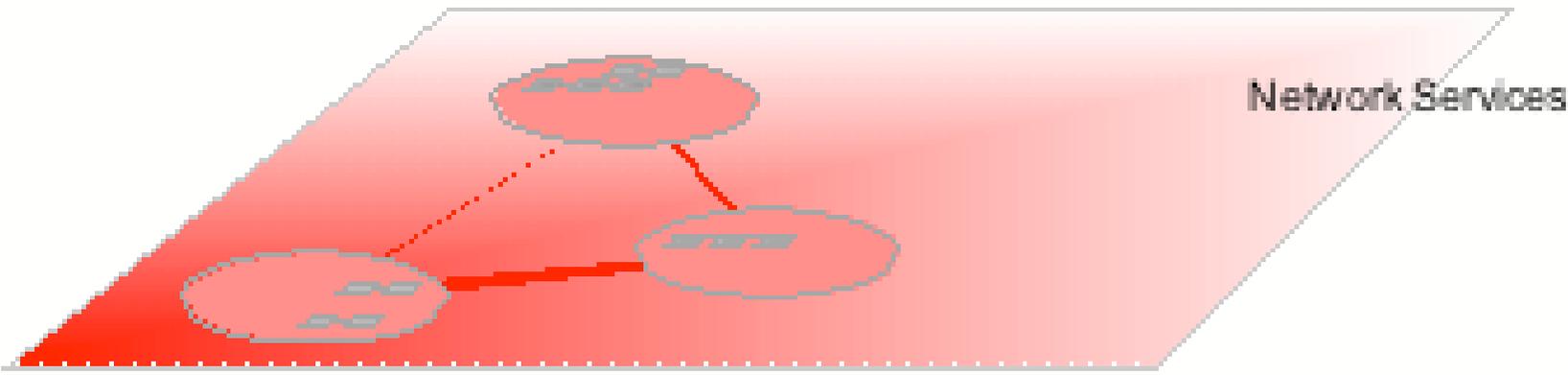
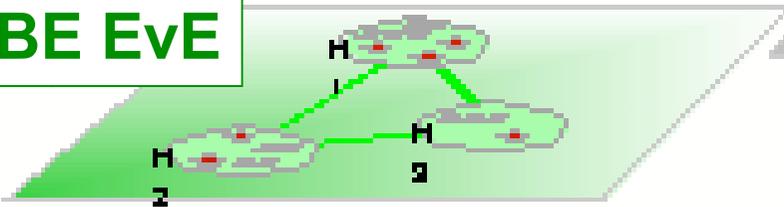
Create service

Consume service

DBE ExE

DBE Studio

## DBE EvE



SME 1..3 Small and Medium Enterprises  
H 1..3 Habitats