Boundaries of a Complex World

The philosopher Constantin Noica described three types of human adversities: the absolute adversity (one disappears), the relative adversity (one wins, both finish) and the complex adversity (nobody wins, a new criterion develops). Similarly, there are three main procedures towards understanding complex systems. One is to begin with a particular complex system and addresses a variety of questions coming from that particular domain and its points of view. The other approach eliminates the deterministic point of view and hosts statistical theories which are fundamental to complex systems in general: random matrices, systems theory, artificial intelligence and super-computer simulations. The third approach cuts across particular domains such as the earth and life sciences, economics, physical sciences, biology, the social sciences and the sciences of the artificial.

The first two approaches lead to domain-specific interdisciplinary fields such as cognitive science. The third approach represents a new type of interdisciplinary approach, by starting from fundamental general questions relevant to all domains, and searching for rigorous methods to solve the open questions. All these approaches are complementary and interdependent: any advance in one makes a contribution to the other.

In this book we review the modern approaches   in the science of complex systems. Usual models (based on non-linear differential equations, dynamic systems, graph theory, cellular automata, stochastic processes, or information theory) are well adapted to study local problems. However they cannot simultaneously take into account these different multiplicities, nor explain how the system can have both robustness and flexibility. Thus new approaches seem necessary, in particular to treat the following challenging problems: correlation between phenomena at different levels, self-organization, robustness and flexibility of the system, memory evolutionary systems, and growing of supplementary structures.

The topic is wide and a sort of modern “hic sunt leones” area. This book debates rather on the importance of free (dynamical) boundaries in the evolution of complex systems. It is written at graduate level, mainly useful for science students and interdisciplinary researchers who cross domains with large differences in their conceptual or formal approach. In that, we tried to write the book having in mind to fit different ways of thinking about complex systems. The readers do not need to be skilled experts in different fields of science to benefit from the whole content and applications of the book.

The book has a unitary mathematical point of view and language, but in order to cover as much as possible all fields of science benefits of generous endorsing from different experts for different chapters. Chapter … on data mining was reviewed by …, chapter … on biological systems was reviewed by …, chapter … on economic theories was endorsed by …, and chapter … on system theory was supervised by ….

The readers do not need special mathematical preparation to cover the book. The mathematical level is maintained to Calculus I, basic elements of algebra, Euclidean geometry and system theory. In order to avoid trading rigor over simplicity we introduce more sophisticated and counter-intuitive concepts in a self-explanatory manner, rather in words and pictures than formulas. Formulas and equations, main theorems and proofs are always provided as supplement, as well as accompanying intuitive examples.

The book has an uniform and integrated structure. Uniform by following the same major theme: to what extent the structure of the free boundaries of a system controls the evolution of the whole system. It has an integrated structure by following this theme along three orthogonal types of thinking: **mathematical** (constructing a model based on physical laws, and quantizing fish behavior in terms of their local interaction towards obtaining collective mode solution), **social constructivist** (fish schools can be built only in specific hydrodynamic conditions, their formation involves interactions of members with each other and with the environment, and it's dynamics is controlled by learning processes of the fish), and **morphological analysis** (considering the fish biology and behavior, the water and swimming dynamics, the surrounding eco-systems tries to explain the existence and necessity of fish schools backwards from their kinematics and dynamics towards the fish local interactions).

PART A: GENERAL IDEAS

1. Introduction and motivations to Part A

In this chapter we explain the motivations for postulating the approach of "boundary controlled" complex systems analysis. We develop the principles which form the core of the book and guide the reader throughout the consequences, applications and predictions.

2. Mathematical formalism

We introduce only those mathematical absolutely necessary to fully develop all theories presented in the book. We mention about other sophisticated mathematical methods through motivational examples, and we provide full references.

3. Systems with free boundaries I: Limitations of the inner dynamics controlled by the boundaries.

- Canonical complex systems
- Drops, bubbles and shells
- Pattern formation
- Biological morphogenesis. The immune system

4. Systems with free boundaries II: Coupling of boundary modes with internal modes.

These complex systems are multi-scale in several ways: hierarchy of components of various complexity levels, multiplicity of internal regulatory subsystems operating with different temporalities and different logics. In order to maintain a global coherence, in addition to a certain degree of internal flexibility) their dynamics is strongly influenced by their boundaries. This happens through the need for learning and adaptation to changes in the environment. A review of the applications in biology and in socio-economic areas.

- Chaos, turbulence, vortices and their organization.
- Multi-scale complex systems with free boundaries.
- Evolutionary dynamics
- Axonemal swimming
- Neuronal networks

5. Systems with boundaries III: Superposition of free boundary systems in interaction

In the software-sorted communities the topology structure has been displaced from public space into the topologies of the technologies, the architecture, and the code that drives them. Motions in this domains relates to the virtual space of flows of databases and networks. Topology in the pure mathematical sense resolves the shape invariant properties. Topology in the computer technology space refers to the physical pattern of connectivity within a computer network or between processors, memories, and peripherals. Between these two overlapped topologies on the same socio-geographic space, the boundaries are differentially permeable interchanging during time virtual and material space elements.

- The evolution of cooperation.
- Evolutionary economics. (Nicolis, 2007)
- Permeability of free boundaries to different mechanisms: speed and access, privatisation, social polarisation and the development of a risk-society. The increased tendency towards technological lock-in and division of societies into high-speed, high-mobility, connected and low-speed, low-mobility, disconnected, classes. Increasingly coded or software-sorted society with highly differentiated mobility: corridors of high mobility and easy access for some, and slow travel and difficult, expensive and blocked access for the majority.

PART B: PARTICULAR TYPES OF SYSTEMS

6. Introduction and motivations to Part B

In this chapter we explain why we have selected these particular examples for part B. The guiding line in choosing the examples was to find complex systems whose relation with the environment is not-trivial. We also chose examples of systems whose self-organization is strongly determined by the geometry, kinematics or dynamics of their boundaries, and systems characterized by a strong feed-back towards the environment, through their boundaries (deformation vs. transformation). Some of these examples were chosen because they are framed pretty compendiously in literature. Few other examples were selected because they represent still tangled theories and rather open issues, or counterintuitive exceptions.

7. Physical sciences

Solving integro-partial-differential equations in a domain, a part of whose boundary is unknown in advance (free boundary). In addition to the standard Cauchy boundary conditions needed in order to solve the equations, additional conditions must be imposed at the free boundary in order to determine both the free boundary and the solution of the equations (Friedman, September 2000). Sections:

- 7.1. Obstacle problem type (variational problems)
- 7.2. Stefan types of problems (phase change)
- 7.3. Surface depositions
- 7.4. Coating flows
- 7.5. Tumor growth
- 7.6. Fractal boundaries for chaotic Hamiltonian systems (S. Bleher, 1988)
- 7.7. Nonlinear dynamics in free bounded systems

8. Free boundary problems in mathematics

- 8.1. The Gauss-Green Theorem for fractal boundaries
- 8.2. Fractal boundaries and super-localization of the waves (B. Sapoval, 1991)
- 8.3. Wavelet analysis of fractal boundaries
- 8.4. Time-distance maps (distance defined by different means of transportation) (Ludu, 2012)
- 8.5. Non-manifold architectures with mixed dimensions (rip currents, tides, bacterial swimming)
- 8.6. Some boundary related unsolved problems in theoretical fluid dynamics (tornadoes impact with structures and buildings, for example)

9. Social networks and economics

- Introduction: New socio-economic theories.
- Neoclassical economics: migration and immigration over boundaries.
- Societies with imposed boundaries: the socio-economic impact of climate change.
- The role of interface cooperation in evolutionary economics.
- Artificial societies, computational experiments, and parallel systems: computational models for complex socio-economic systems
- Industrial ecology and eco-industrial areas
- Surveillance and boundaries stability
- Nonlineart. Wavelets and musical interpretation; Flat vs. curved spaces in painting and the importance of the frames.
- Permeability of boundaries through differentiate mobility (Graham, 2004)
- Influence of the economic organization boundaries on capital formation and economic systems. Capital (economic, social, academic) represents a complex system possesses a multi-scale structure (micro, meso, macro) always in the process of transformation. The scales interact with the social and economic organization boundaries and are interdependent and interactive.

10. Systems theory and neuroscience

- Memory models: solitons v.s. ion channels: importance of axon membrane in the brain functioning.
- Mathematical models of the human perception: mathematics of olfaction and memory.
- Boundary of complex networks, i.e. nodes at distance larger than the mean distance from a given node in the network). Applications to scale-free model networks, fractal boundaries and power law probability density functions.
- Random walk in spaces with free boundary.
- The method of generalized inverses for Markov chains and applications for the analysis of urban structures, evolution of languages, and musical compositions. We also discuss a generalization of Levy flights over large complex networks and study the interplay between the nonlinearity of diffusion process and the topological structure of the network (Ph. Blanchard, 2010)

11. Biological systems with free boundaries

- Fish schools
- Self-organization of hydrostatic skeleton invertebrates
- Ant colonies

12. Climate

- Effects of the urban areas (surface roughness) on the boundary-layer airflow, clouds and precipitation anomalies.
- Internal changes in societies with imposed variable boundaries: shore and ice contour change. Integrating socio-economic and climate change scenarios.

13. The battle for scales

Societies evolved historically in space, time and basic needs (Glaser's Choice Theory principles). The interrelations developed specific metrics with range in the human scales: weapons, tools, houses. Time was initially measured in terms of human time scale: natural cycles, life and death. The social relations were initially topological, locally connected and compact (family, tribe). Later on, societies tried to extend the scales in terms of space, time, and human activity: the battle for large space scale (traveling, discovery, astronomy, cosmology). Development from houses to churches, castles, cities, empires. Simultaneously, another battle developed: for smaller scales: medicine and pharmacy, clocks, miniature art, atoms, molecular biology, and elementary particles. In space and time society advanced towards moving faster (ultrafast photography, relativity) or moving slower (cosmological time, life quality). In another direction, the social communication scale, initially defined by human senses (distance for talking, range for signaling) also expanded by electromagnetism to telephone networks, radio networks, TV programs and the internet. In order to try to predict the future directions of social expansions we may need to comprehend what other dimensions need to be introduced in addition to space, time, behavioral needs, and communications. Most importantly, what coordinates could describe such new dimensions, and what will be the equivalent in these dimensions of the human battle for "larger, smaller, faster, slower". We will conclude by enumerating the presently known natural limitations that can bring delimitations to these new battles: what is the largest possible intelligent memory, what is the maximum possible computation (storage) speed no matter of the medium used for storage, what is the most general theory, etc.

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