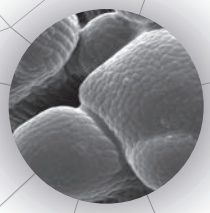
les dossiers
d'AGROPOLIS
INTERNATIONAL
Expertise of the scientific community in the Occitanie area (France)

COMPLEX SYSTEMS
From biology to landscapes



Number 23
February 2019

Foreword

Complex systems have emerged as a focus of cross-disciplinary research over the past 30 years. In the wake of the pioneering work of the Santa Fe Institute in the United States and the research centre headed by Ilya Prigogine in Brussels in the 1980s, centres conducting research on complex systems have emerged in Italy, Spain, UK, Poland, Hungary and France. Meanwhile, researchers have also founded an international association (Complex Systems Society[1]), specialized journals, and international conferences are held regularly. The field is especially well organized in France, including regional centres (Paris-Île-de-France, Rhône-Alpes, Toulouse, Rennes and Normandy) and thematic networks, all of which are embedded in the French National Network for Complex Systems (RNSC), which fosters coordination and brainstorming on the topic. Within the scope of Agropolis International, we felt it was essential to draw up a comprehensive inventory of research on complex systems in Occitanie region (France), focusing on topics ranging from living organisms to the environment and land management, with emphasis on biology, ecology, geology, hydrology, agronomy, human and social sciences. The approaches often involve modelling, while also relying on both quantitative and qualitative data.

But what do we understand by complex systems? An article published in *Natures Sciences Sociétés*[2] refers to Laplace's Demon, as described in his Philosophical Essay in 1814[3], as being, "An intellect which at a certain moment would know all forces that set nature in motion, and all positions of all items of which nature is composed….it would embrace in a single formula the movements of the greatest bodies of the universe and those of the tiniest atom; for such an intellect nothing would be uncertain and the future just like the past would be present before its eyes." This implies knowing the initial situation of all beings in the universe—a data issue—while also recognizing all the laws of nature—a dynamics issue. Contemporary science has shattered this dream of such a demon, indeed: quantum physics has introduced absolute uncertainty, which makes it impossible to ascertain the state of the universe at any given time; chaos theory implies that a very slight initial difference can spawn completely different novel behaviours (*Does the flap of a butterfly's wings in Brazil set off a tornado in Texas?*); and the scale-dependence of dynamic interactions often makes it impossible to deduce the overarching behaviour of a process solely on the basis of the elementary component properties—this is called emergence. Understanding contemporary challenges, particularly those concerning adaptation to global change and territorial management, and then intervening in these major systems with their multiscale interaction dynamics, cascading, feedback and emergence phenomena, requires the development of new tools at the crossroads of various disciplines and Big Data, all pooled under the moniker 'complex systems science'. These tools cannot rely solely on one scientific discipline, they require more integrated expertise and practices that combine field experiments and models. All of these features presently characterizing complexity are addressed through new methods developed

1. http://cssociety.org
2. Deffuant Guillaume, Banos Arnaud, Chavalarias David, Bertelle Cyrille, Brodu Nicolas, Jensen Pablo, Lesne Annick, Müller Jean Pierre, Perrier Edith, Varenne Franck. Visions de la complexité : le démon de Laplace dans tous ses états. 2015. *Natures Sciences Sociétés*, 23 (1): 42-53.
3. Laplace P.S., 1995. *Philosophical Essay on Probabilities*: Translated from the fifth French edition of 1825 with notes by the translator (A.L. Dale), Springer Verlag New York.

by our research laboratories, and our aim in this *Dossier* was to present a snapshot of them (even partial). We thus opted to structure this document in three main parts to showcase the research under way:

The first part deals with the data—sometimes available in very high volumes—which is essential to gain insight into the state of the systems being studied. Never have there been so many sensors available at all scales, ranging from microscopic to those that produce satellite images, while also serving to track our movements and social network exchanges. This has generated a huge amount of often heterogeneous information that must be collected, processed, integrated and interpreted by assimilating it into our operating models. Infrastructures are emerging in France and Europe to supply, store and process these data.

In turn, the second part focuses on how systems operate, since the thrust is not only to describe (first part) but also to understand how complex systems work. Therefore we organized the contributions according to the scales of the systems studied, ranging from intracellular mechanisms to the functioning of geoecosystems and territories (i.e. 'anthropized spaces', or even better, 'socioecosystems'), including individuals (plants or animals), populations and ecosystems (approached without human input, but is this still conceivable?). Many methods have been developed to account for these complex operations based on differential equations, networks, or individual-centric models—sometimes combined—according to the analysis scales.

Finally, the third part deals with application of the complex systems approach to meet contemporary challenges. Our review spans from technical and social organization to systems monitoring via so-called observatories, while discussing—from many standpoints—participatory management initiatives that take a multitude of issues into account, as well as decision-support systems.

Nicolas Arnaud (UMR GM),
Bertrand Jouve (XSYS)
and Jean-Pierre Müller (UPR GREEN)