Review of
"*Mondes Mosaïques: Astres, Villes, Vivant et Robots*"
by Jean Audouze, Georges Chapouthier, Denis Laming, et Pierre-Yves Oudeyer
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Nature confronts us with structures on many scales. From the largest, with the super-clusters and clusters of galaxies, the galaxies, the planetary systems, planets structured by their geology, to the smallest with biological systems, cells, molecules, atoms to elementary particles. One of the goals of science is to describe these structures but first of all to understand why the laws on nature allow for the existence of such diversity and the complexity that comes with it. This is a difficult question, very lively debated and controversial, mostly because it goes beyond the boundaries and scopes of each discipline. The reductionist view tries to find the properties of any object in those of its constituents. While it had some successes, in particular in fundamental physics and the dream of a «final theory», it was understood that the existence of emergent phenomena sets a strong limit to such a thesis.

The quartet of authors of the book «Le Monde mosaïque» addresses the question of complexity and diversity through the thesis of the Mosaic proposed by Georges Chapouthier. They focus on four systems. The universe is described by Jean Audouze, astrophysicist and former director of the Institut d'Astrophysique de Paris. The structure and dynamics of cities is described the architect Denis Laming. The biologist and philosopher Georges Chapouthier introduces us to the properties of complexity of the living world and animals. This is echoed by the description of how machine can generate their own complexity by Pierre-Yves Oudeyer, a world specialist in robotics and artificial intelligence working for Inria. The four parts of the books compare the structure and the complexity of the universe, cities, animals and robots. Their dialog echoes to highlight similar structures in these systems which, a priori, may appear very different. This is indeed one of the goals of science to discover mechanisms that are universal enough to apply to many different systems.

An astrophysicist, as illustrated by Jean Audouze, would like to understand how the structure of the universe appeared during the history of the universe, since a fraction of second after the big-bang the universe was in a structureless state of a hot and dense, almost homogeneous, gas containing only protons, neutrons, electrons, neutrinos and photons. No structure can form since it would be immediately destroyed. The first nuclei are synthetized only a couple of minutes later and the first atoms about 400.000 years later. At that stage, no complex molecules, no possible life and obviously no consciousness. Information, life and conscience are emergent phenomena that we cannot relate to the laws of fundamental physics and of the state of the early universe.

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A physicist, as myself, would like to understand why the fundamental laws of physics allows for the existence of complexity, why they contain it in their space of possibilities. One can trivially observe that our knowledge about nature is structured in fields: physics, chemistry biology, physiology, sociology, economy, politics to name a few. Each of them focuses on a part of reality. They have been developed independently with some interactions with close fields. It follows that each has developed its own ontology. The fact that we can understand the world has a deep implication: these theories form a hierarchical structure organized in modules in interaction but that decouple enough so that they can be studied independently. For instance, describing a proton, one has two levels of description, one microscopic that is needed to understand its internal structure and a more macroscopic one in which the microphysics can be forgotten. This separation of scales is crucial. For instance, the properties and our understanding of DNA do not rely on our ability to understand the structure of neutrons and protons. This is fortunate since otherwise it would have been impossible to start biology before having understood nuclear physics!

The relations between the different theoretical layers are in itself very complex and this is a reason why reductionism cannot be defended. It exist emergent phenomena that cannot be reduced to properties of lower (more fundamental) levels. They simply do not exist in these levels of description; think about temperature and pressure of a single particle! More important, higher (more complex) levels can act on lower levels by changing the environment and context. Physics rely on the idea of isolated systems, which do not exist in the real world. One thus needs to understand the dynamics of one level of complexity in terms of itself but also in terms of lower and higher levels. This enriched all the discussion on causality. For a reductionist, causality is bottom-up: what happens in a higher level can, in principle, be described by what happens in a more fundamental level. But, when one takes into account the effects of the higher levels, one needs to include top-down action such as algorithmic causality, action by non-adaptative information control (e.g. a thermostat), action by adaptative selection (e.g. Darwinian evolution), action by adaptative selection of information (e.g. Pavlovian conditioning), intelligent action.

It follows that the conditions for complexity, and the actual nature of this complexity, depends on (1) the space of possibility set by the lower level, (2) information selection and (3) modularity. This is what is examplified in the cases of cities, animals and robots. For instance, let us consider cities. To describe the structure of a city, one needs to take into considerations many levels. At a «fundamental» level, the architectural character is determined by the matter that can be used to build (wood, type of rocks and stone) but also by the environment (here the local geology and climate, whether it is in a plain, seaside or mountain). But indeed, that would be the reductionist explanation. One needs to take into account a series of explanations coming from higher levels: the population, its history, its myths and legends, which is sociology, psychology, history, economics, politics. The beliefs and ideas of people designing, financing and living in the town. A city is thus simply not a collection of buildings, monuments, streets and parks. Ignoring one of these dimensions, one would fail to understand the structure and dynamics of a city. Many beautiful examples are given by Denis Laming. It highlights why understanding the forces at stake in the structuration is crucial, in particular to act at a more political level to increase happiness of the inhabitants but also to better protect the en environment and biodiversity.

Georges Chapouthier describes how Darwinian evolution leads to a the (bio)diversity of the world. His description in terms of a mosaic is based on the fact that any (complex enough) living bodies have different levels of description: the genes, the cells, the organs, and the body. And indeed, Darwinian evolution takes place on each level with different time scales. It follows a description of an animal as a mosaic of these structures interacting together. Again, this illustrated the fact that the properties of the more fundamental objects (e.g. the genes) define the space of possibility of more complex structures but that these latter sets the context in which the dynamics of the former takes place. Georges Chapouthier then scales this up to address the question of the brain and consciousness, of language and of human populations. This offers a vertiginous description of the living.

When it comes to machine, we, as human, like to consider them as product of our intelligence, to think them as automata that can only execute rules and algorithms that we have thought and designed, indeed faster than our own brain could. But is it so? Or can machines crate their own forms or behaviors, beyond their own program. This is a crucial question in many respects. First, our world relies on computer and machines. The recent example of IBM Watson and its use of big data led to the idea of a «computer that can learn» and maybe have creativity. Second, the reductionist approach of the human brain project hopes to lead to a purely mechanistic understanding of the brain. Is there any chance it may work and reveal the nature of conscience? Or is it doomed to fail, as I personally think? And if machine can innovate, what is it to be human?

As you can see, this loops to the chapters on cities and animals. In all cases, we learn that one cannot explain a complex phenomenon by a reductive approach or by considering a single level. One needs a global approach. And if you doubt it, just ask yourself if you can explain the book in your hand from the fundamental laws of physics (the four fundamental interactions and all the elementary particles) and the initial conditions one microsecond after the big-bang. Clearly not! This just offers the possibility for such a book to exist not an explanation for the actual existence of this book, which requires to consider many top-down actions from higher levels of complexity, such as machines, living animals etc.

I may however have a point on which I tend not to agree with the authors and it concerns cosmology. Maybe this is just because I am more specialist of this field and thus more critical. Indeed, the universe has been demonstrated to have a history and to evolve in terms of the structures it can contain. Jean Audouze describes this beautifully. But in this evolution, in the formation of stars, galaxies and planets, no Darwinian selection is at work. There is even no top-down action from higher levels because they simply do not exist in these stages, and when they do causal limitations forbid them to do so (for instance, once one understands what fixes the lifetime of a start like the Sun, it is easy to increase it by homogenizing the fuel of the star. While easy on the paper, it turns out to be impossible in practice). The universe offers a large diversity (type of stars and galaxies) but it can be explained from the gravitational dynamics and variation in the initial conditions, which is a huge success of cosmology as a physical theory. While there is no complexity (at least like in the other systems), our universe offers the possibility for complexity to emerge. And that is surprising. In particular changing slightly the laws of nature, or the fundamental constants by a fraction of a percent, would result in a dull structureless universe. No stable nuclei, so no chemistry and no biology. In this sense the apparent fine-tuning of the universe, as a condition for complexity and life to exist, calls for an explanation. Among them, the idea of a multiverse with all possible universes with all possible laws of physics realized has been considered. There, one can identify a mechanism similar to Darwinian selection based on the anthropic principle. But this is highly speculative as I write. So I agree the structure of the universe can be described as a hierarchy, more than a mosaic, but it does not contain the same notion of complexity. It is lower important to understand its history as it sets the stage for complexity to develop.

In conclusion, if you think that the questions «why the nature allows for complexity?», «why is the world understandable?», «what is it to be human in such a universe?» then I think this book will give you matter, examples and thesis to think about. I recommend the reading of this book which explores science beyond its disciplinary boundaries. It casts some new light on common objects and shows that many connections and similarities exist between them. Some may reveal the fact that similar mechanisms are at work. Some may just be coincidences. I think the reader will have a good time trying to make his mind and disentangle the puzzle.