Emergence and auto-organisation: revising our concepts of growth, development and evolution toward a science of sustainability

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Abstract

Our actual understanding of biodiversity and sustainability, hence our capacity to address and reverse adverse effects, is still limited. I would like to argue that this insufficiency is not (only) quantitative (learning through cumulative steps) but rather qualitative (raising adequate cognitive faculties). The common interpretation of biodiversity in terms of "genetic resources" is based on a mechanistic scientific liberal worldview. But machines are not self-sustained as they rely on external principles for their coming into being and functioning. In fact, organisms have internal formative principles that are sufficient to both specify their kind and allow new emerging forms to arise from them. Metamorphosis (shaping oneself through becoming an other) is an inherent property of living processes. Without variation, there would simply be no growth, no development, no evolution. Metamorphosis involves non linear changes resulting in emergence and auto-organisation. New theoretical frameworks do exist to analyse such processes. Yet, non linearity is still a challenge for our common sense. To think emergence, auto-organisation and individuality in life sciences we need to extend our cognitive faculties. Cognition is a value system and here the notion of paradigm shift takes all its importance as it links science and ethics in a new vision of the common good. I will discuss how changing our value system can impact on knowledge and call for a revision of the current theory of development and evolution. There is not only a need for new concepts but novel cognitive approaches must also be developed to address sustainability values.

Keywords: auto-organisation, biodiversity, cognitive values, emergence, genetic resources

Introduction

It is now widely recognised that biodiversity, meaning biological diversity for short, is a value under threat and that it should be protected. It is also clear that our human activity contributes to a large extent to its erosion. This concerns both the wild and the domesticate, i.e. the part of diversity that humans have created through domestication, acclimatisation and breeding and that constitutes a major source for our food supply. Obviously, conservation in national monuments and seed libraries can only offer a partial answer to the problems. The main challenge is to ensure that agricultural and technological practices are sustainable, i.e. able to maintain diversity "in process" through continuous enhancement and dynamic management.

So what has gone wrong ? Have we been merely foolish and vain in overlooking the consequences of our human activities ("we should have known") or was the "state of the art" insufficient ("we simply did not know") ? The answer to these questions - moral responsibility vs cognitive mastery - depends on the way we view and value biodiversity and the type of knowledge we consider appropriate to address it. Here, I would like to argue that sustainability is an intrinsic property of living systems. For this reason, raising adequate understanding of the nature of life processes is not only a cognitive issue but also a moral one. My approach will consist in examining the implicit values incorporated in current concepts and interpretations used in biosciences. I will discuss some conceptual and ethical implications with respect to a science of sustainability.

The liberal scientific value system: revolving around machines

Every world view relies on a specific value system that conveys meaning in our relationship to the world. This value system is a religion, taken here in the widest, etymological sense, i.e. a mediation between principles anchored in a representation of the world and our activities. Principles cannot be demonstrated. They are "given" so to speak, or revealed through intuitive perception (Pouteau, 2004). Within a given principle framework, deliberative rationality provides specific internal coherence for a global cognition system. Knowledge proceeds not only through cumulative steps but also through qualitative changes in our representations of the world. Every value system allows to explore and describe a specific angle of the wider reality. Part of this reality is hidden - a precondition for any cognitive endeavour: to uncover the hidden is the purpose of science. Yet, in different value systems the ultimate source of moral intuitions and cause of phenomena - usually figured by god(s) and/or divinities - are thought to remain beyond our reach, making these systems to some extent compatible with each other.

The liberal scientific value system, however, establishes a unique metaphysical institution. First, its specific principles of method - in particular: objectification, empiricism and reductionism - lock the process of mediation itself (both moral and cognitive) by disqualifying intuitive perception and inner evaluation (Pouteau, 2004). Second, it postulates the existence of an entirely self explanatory, universal system based on causal necessity. The leading representation in this value system is rather simplistic: the reality is a clock, a machine (or a computer). The hidden parts, provisionally beyond our reach, are constituents that can be analytically identified and eventually deciphered. Of course, this representation remains inherently creationist: machines are not self-informed, they rely on external formative principles for their coming into being. Chance, selection and evolution must take over the ancient role of the divine architect or engineer to explain how the machines function (Kupiec and Sonigo, 2003). Most importantly, machines are not self-sustained. They are intrinsically dependent for their maintenance, prone to failure and decay and eventually perishable. Finally, machines are not ends-in-themselves but contingent devices to satisfy others' needs and expectations.

Genetic determinism and resources: the qualification of biodiversity under liberal scientific values

The entire living world spread over the earth can be addressed with the notions of "biosphere" coined by Teilhard de Chardin (1955), and biodiversity. The two notions embrace distinctive features of the living world, the wholeness of life as a unifying essence endowed with intrinsic teleological value, and its expression through a wealth of different particular manifestations in individuals and phyla, wild and domestic relatives. These notions are usually evaluated with an analytic, quantitative rationale based on collection and classification strategies: knowing species by their names, traits, locations, frequencies and degrees of kinship or phylogenetic relationships. The qualification of biodiversity in terms of "genetic resources" is very revealing of the cognitive and ethical values that are implicitly applied in evaluation approaches.

The DNA machine in a gene order

According to scientific values, living organisms are sophisticated machines determined by their genetic blueprint. The current interpretation is that genetic programs control every aspect of the functioning of the machines: ontogenetic development, interaction with the environment, creation of variation available for further selection etc. DNA, a quasi-mineral substrate, is supposed to contain all the instructions of the program. This "book of life" is thus granted special value and is meant to represent the very essence of living organisms. Genes, in spite of the difficulty in circumscribing their specific identity as DNA entities, remain the main actors in this instructionist worldview.

Resources: a commodity in a consumption model

According to liberal, utilitarian values, living organisms represent a commodity, a "resource" to respond to our needs for consumption whether in the short term or in the distant future. Conservation and preservation of biodiversity are aimed at maintaining living organisms as a resource potential for us and future generations but not for their own good. As a commodity, they fall under the commercial regulation applicable to any other good, hence their eligibility for patenting. In this context, the inherent worth or intrinsic value of living organisms is not acknowledged.

Life auto-organisation and emergence: valuing autonomy and integrity

We all know that the essence of a book is not in the paper nor in the ink but in the spirit or intelligence which conceived its content. In fact, any cognitive endeavour must first postulate that the world is intelligible. Eventually, the essence of the living machine has to be found elsewhere than in DNA, in non material principles that constitute a form of "intelligence". So, who wrote the "book of life" ? The synthetic theory of evolution tells us that the intelligence is the sum total of failures (mutations) and contingency (chance and selection), i.e. external principles. But can we think of internal principles that are not eventually external ? What are the processes involved in the material manifestation of this internal intelligence, its emergence into a global coherence: an organisation (organism) ? To answer theses questions, a shift from mechanistic thinking ("the parts explain the whole") to emergence (systemic) thinking ("the whole explains the parts") is necessary. It is supported by formal methodological approaches and experimental data from the science of complexity. It leads to a conception in which processes can only be autonomous, with no need for genetic programs or instructions to govern them, i.e. auto-organised processes (Pouteau, 2007).

Non linear dynamic systems

The notion of auto-organisation encompasses the properties of non linear dynamic systems. All living processes are not only material (i.e. spatial) but also dynamic (i.e. temporal). The principles of these systems are based on the notion of attractors, or basins of attraction and the possible occurrence of alternative states depending on the initial conditions and history of the system. This theoretical framework can explain the emergence of spatio-temporal structures (organisations) that are "dissipative", i.e. that allow a creation of order out of disorder (also called dissipation of entropy).

Most - if not all - biological processes are non-linear: the fact that A implies B is only a superficial observation, a mechanistic illusion. The determinist interpretation is correct at the macroscopic level but erroneous at the microscopic level, supposed to be causal for the macroscopic level. For instance, the cell cycle is a determinist process that leads to partition of one cell into two daughter cells; but every independent step in this cycle is reversible (Novak and Tyson, 2003). Bistability is probably the most common example of non-linearity. But it usually passes unnoticed because it can only be detected by applying very specific experimental methodologies. The emblematic example is the lactose operon (Laurent, Charvin and Guespin-Michel, 2005). Ironically, this was initially described as the model for genetic linear determinism by Jacob and Monod. Prion is another example (Kellershohn and Laurent, 2001) illustrating how epistemological and ethical issues can eventually merge together. Indeed, sporadic cases of BSE in cow herds were probably not due to infection but to occasional threshold overriding in a slow non-linear transconformation of healthy into pathogenic prion protein. In the light of this epidemiological analysis it may be inferred that herd slaughter was most probably unnecessary.

Variation: the essence of life

If information is thought to be instructional, then variation must be interpreted as a failure, a mistake in proper transmission and effective realisation of a program. In this case, inter-individual variability is merely a "noise" that blurs true biological reality and must be buffered with appropriate statistical tools. In fact, variation cannot be eliminated because it is constitutive of living phenomena. Without permanent disequilibrium and fluctuations between stationary states and unstable states, growth - hence morphogenesis, development, and evolution - could not take place. Qualitative modifications associated to changes in variability and correlations lead to emergent events and global re-organisations. Some developmental phases prove more sensitive than others to external perturbations. This may lead to multiple alternative states as in the case of salt adaptation in sorghum (Amzallag, 1999). Variability thus needs to be addressed as a specific biological property that provides specific information on the state of the system. This is necessary to qualify biodiversity in terms of process - relying on plasticity and polymorphism - and not only of the products (species) resulting from this process.

Material distributiveness and integrity

Information cannot be equated to a material substrate (DNA or RNA). Yet, its manifestation is material and involves actual physico-chemical interactions. In-formation is physico-chemically and materially distributed over all possible factors, endogenous and exogenous: an integrity. From a biophysicist's point of view, the biological matter is comparable to a growing viscous "paste" and can be studied by hydrodynamics. This "paste" is ruled by physico-chemical properties that are self-explanatory and do not require additional putative instructions. In other words, the "paste" is self-instructed by its inherent constitution - its structural, material constitution and its dynamics. Because of this constitution, it folds, unfolds, is creased etc. So, finally, the development of a tetrapod embryo appears to be entirely spontaneous (Fleury, 2006). One does not need genes to make legs and arms: these are auto-catalytically organised due to the inherent material properties of the living "paste". Of course, genes come into action as parameters in the equations of growth since proteins, especially enzymes, are essential material factors that set these parameters (viscosity, elasticity etc.).

Evolution and metamorphosis: valuing process and plasticity

Growth, transformation and evolution are key words to qualify processes both in the natural world and in cultural society. Civilisations have emerged, culminated in some form of culture, then declined and disappeared. Biological phyla have their hour of glory to later become extinct and replaced by new successful forms of organisation. We, occidentals of the last four centuries, have taken these processes very seriously by placing faith in progress right in the centre of all our affairs. Evolution itself has become an icon of modernity. But nostalgia for the ancient created cosmos and the need for permanence is still perceptible in some concepts, even in the theory of evolution itself.

The synthetic theory of evolution

With the metaphor of the living machine determined by a central causal system (genetic program), it is necessary to invoke some form of external intelligence (selection) to explain how something "intelligent"/ organised/ complex/ etc. can arise in the course of evolution out of a succession of failures and mistakes (mutations, noise). The instructionist or synthetic theory of evolution (neo Darwinism) still relies on the notion of fixed categories, once created and then perpetuated through reproduction. It defines their identity as an external property based on the criterion of sameness established by intellectual construction. In this context, plasticity, i.e. the capacity to express different phenotypes depending on the environmental conditions - and polymorphism, i.e. the capacity to express different features in a given environment - are seen as hindrances for proper identification of specimen.

Metamorphosis: a concept for growth, development and evolution

A major effort in evolving our concept of evolution is needed to keep up with most recent scientific advances. According to Jablonka and Lamb's analysis (2005), modern epigenetics is calling for an evolution of neo-Darwinism and the authors make a plea for a darwinism that would accommodate some of Lamarck's principles. New biophysical research is also prompting us to revise our variation-selection over-simplistic interpretation. The work by Fleury (2006) reveals that the inherent dynamic and physico-chemical properties of biological matter are sufficient to explain the spontaneous auto-organisation and "at once-formation" of embryos.

With a distributed in-formation system developing through spontaneous organisation, variation in any constituent can affect the whole make-up through feed-back effects and lead to new unpredictable, yet deterministic organisations. Epigenetic effects (independent from alterations in the DNA sequence) exemplify how the environment can impact on genetic expression and lead to heritable phenotypic changes. Categories are plastic natures, they are continuously remodelled through interactions, communications and exchanges with the wider context. Their identity is dynamic, established in a permanent "becoming-an-other". Metamorphosis, the term used by Goethe in 1799 to describe the gradual transformation of plant appendages into one another, seems an appropriate concept to qualify this evolution "in process" as a continuous flow of transformation relying on growth and developmental emergence of novel organisations (Pouteau, 2006).

Sustainability: toward an agro-ecological scientific value system

Sustaining... what... and how?

Sustainability is not a static but a dynamic concept. It needs to be thought of in terms of process, autonomy and self-propagation. The current scientific paradigm relying on the metaphor of the living machine is intrinsically unable to address these properties, hence the issue of sustainability whether this concerns biodiversity as illustrated in this paper or human activities and society. The hypothetico-deductive approach mainly used in current biosciences, especially in biotechnology, is locked in a mechanistic mode of investigation, prediction, and action. To step beyond this contradiction, the following issue must be addressed: how can we think of internal formative principles able to create a global coherence in living organisms in the same way as the intelligence of a machine inventor ?

Seeing integrity and process transformation: a cognitive sense for metamorphosis

Integrity is not an integrality, the sum total of constituents in interaction. It is an emergence, a novel property emerging from underlying levels of organisation as a specific global coherence with its own intrinsic worth (Pouteau, 2006). This coherence, or intelligence, is an entelechy in Goethe's words (2003): a force that draws itself into existence out of itself. The notion of "Urorgan" or "Urpflanze" - translated as primordial organ/plant, archetype or type - is not a simple mental concept: the idea of organism is the entity of the entelechy itself. To comprehend living organisms, percept and concept must merge together in what may be called a phenomenology or epistemology of intuition. This requires a recognition and enhancement of inductive approaches in scientific investigation, i.e. the integration of the notions of process, dynamics and evolution within the cognitive endeavour and practice.

The issue of sustainability is not just one more research subject on the agenda. It is a call for an epistemological revision. Agro-ecology is not just one more disciplinary field. It is a new scientific value system. Part of the challenge is to gain new access to the process of moral and cognitive mediation through intuitive perception and inner evaluation. De-automation of world representations currently locked in the scientific liberal value system must be achieved by raising new faculties, both individual and social. At the individual level, process learning may be educated by specifically training a vision of phenomena that is temporal, non spatial and non linear, for instance by developing a scientific methodology inspired from Goethe (Bortoft, 2001). At the social level, process learning is embedded in participatory research confronting different sources of knowledge through partnership between scientists and communities to reach agro-ecological goals (Warner, 1997). Finding new ways of knowing should become an integral part of policy research on sustainability.

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