Methodology in Complexity and Emergence

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Over the past decade, our understanding of complex adaptive systems and the phenomenon of emergence has greatly increased[1]. This is owing to the progress in developmental science, along with technological advances which allow us to extract more information from the objects of our studies. This article is an exploration on methodology for research in the area of complex systems and emergence. In this paper, I will be beginning with a short introduction to complex systems and the notion of emergence, covering a discussion on order and level (Part 1). This is followed by examining the metaphysics which underlies the notion of level (Part 2). In Part 3, I will be outlining the epistemology which can support such an understanding of the world. In Part 4, there will be a delineation of a heuristic methodology to be applied which following the aforementioned epistemology. The main purpose of this paper is to outline the methodology that can be followed in carrying out a research study in the field of complex systems approach and emergence.

PART 1: COMPLEX SYSTEMS AND EMERGENCE

What are complex systems? || Notion of emergence || Order & Level

Complex systems refers to structured arrangement of components which non-linearly interact with one another and self-organize to effectively respond to the internal and external changes in the environment. Prior to formation of the system, the components act as individual members of a larger system or as members of other sub-systems within the larger whole[2](Frémond 2017, 80). Under a certain set of conditions[3], components (say, C_1, C_2, C_3.....C_n) interact with one another[4] and arrange themselves in a structured manner. That they

[1] (Stephan 1992; Bedau and Humphreys 2008)

[2] A whole with properties of stability, cohesion and coherence is considered a system.

[3] What are these conditions? The kind of conditions which incline behaviour of the components will depend on their complexity. For instance:

- **A. In case of magnetization, the set of conditions is a reduction in the temperature which results in the magnetic spins to orient in one direction. They self-organize themselves into a magnetic field.**
- **B. In case of the Benard rolls, the condition is increase in the temperature of water which allows the molecules to self-organize in certain ways.**

When the conditions which arise allow the self-organization to be a way for reaching stable equilibrium, then we can witness the coming together of components in a structured manner. The arising of such conditions is arbitrary and cannot be predicted.

[4] Prior to formation of the system, the components will be named differently, depending on their position within other systems.

are structured implies that there is no central or mother component within the system which governs its behavior[5]. Behaviour of the system manifests global structure which arises from the local interactions between the components[6]. This spontaneous emergence of global structure from local interactions refers to self-organization (Frémond 2017). This global structure refers to the organization that emerges to ensure the stability, cohesion and coherence[7] of the system. The stable equilibrium of this structure will govern behaviour of the whole.

Emergence refers to the process of development of novel properties/wholes form the self-organization of components within a system. Novel properties are those properties which are not shared by any of the components and thus, allow to identify the system as a qualitatively distinct individual (and not just a sum of its components alone). Up to a certain level of complexity, we witness novel properties. Such novel properties are unencountered in the components but are subservient to the stable equilibrium of the system from which they emerge. Once a threshold of complexity is passed, emergent wholes arise. Such wholes have causal power[8] which affects the behaviour of its components.

A constant endeavor in understanding complexity and emergence is to wonder what this level of complexity must be. That is, how do we know how complex a system must get before we encounter novel properties or before an emergent whole emerges? Complexity broadly refers to the number, type and interrelations between the components in a system. One cannot predict the degree of complexity passing which novel properties or emergent wholes will arise. A certain novel property/emergent whole arises because under the certain conditions, such a development allows the components (sub-systems and others) to negotiate its survival in the environment better (that is, the novel property contributes towards stability of the whole and an emergent whole has causal power which symbiotically creates space for the stable survival of its

[5] There can be sub-systems where each has a function, whose contribution to the system's movement towards stable-equilibrium can be variant.

[6] These local interactions are non-linear. Non-linearity refers to the phenomena where the effect is not proportional to the cause. There are two types of non-linear interactions: positive feedback and negative feedback. In case of positive feedback, the effect is amplified- like in case of an infection turning into an epidemic. In case of a negative feedback, the effect is diminished- like in case of ripples of a stone thrown into water which gradually fade away. The constant series of positive and negative feedback allow the system to respond to changes in its environment and restore stability.

[7] Stability is the ability to restore the equilibrium after a disturbance in a system. Cohesion refers to one of the forms of stability, spatiotemporal integrity which emerges within a system through self-organization and non-linearity. Coherence refers to the capacity of system to place itself within its environment and thus, to situate every action in continuation of its past activities and future expectations.

[8] The power to cause events/activities oriented towards its stable equilibrium. I considering *x* to be the cause of *y*, I imply that the ontological force for behaviour of *y* can be derived from understanding the powers of *x*.

components/sub-systems). Without complete knowledge of the components and the initial conditions of the system, there is low-to-negligible probability of predicting the degree of complexity after which we can witness novel properties. It is also contestable what it would mean to possess complete knowledge of components or of the initial conditions.

Not all complexity we encounter is unique. We can distinguish between living and nonliving things. We can identify qualitative differences in the existents in around us. Thus, we can broadly categorize the kind of beings we encounter, in the complex systems and emergence approach, through the concept of order. Order refers to the kind of causal power that an existent exercises, to negotiate its survival in its environment. We can identify order of an existent through the novel quality that distinguishes it. Broadly, on the basis of empirical findings[9], we can find the following three orders in our environment: material, sentient and phenomenal. Material order[10] refers to the order of being where the members are oriented towards thermal equilibrium alone[11]. The novel quality of material order is being- this means that *to be is to belong to the material order*. Members of sentient and phenomenal order possess a sense of self. Here, sense of self refers to the recognition of one's spatiotemporal integrity as whole, marked by boundary conditions[12]. This sense of self is indicative of the organizational closure of the existent: organizational closure refers to the manner in which components within a system are structured to allow the existent to exercise its capacities as a spatiotemporally integral whole. Sentient order refers to the order of being where the members have the capacity to sense and respond to the environment. Their novel quality of self-awareness or consciousness is defined as the ability to distinguish oneself from the environment. Here, the term *self* is used in the minimal sense to point that the system recognizes its boundary conditions and operates towards its stable equilibrium. Phenomenal order refers to the order of being which has the capacity to choose their source of stable equilibrium and to set up conditions for its fulfilment. Their novel quality is self-consciousness, which is the ability to *qualitatively* distinguish oneself from the environment. There is no appeal to hierarchy, that is, the idea that one category is *superior* or *inferior* to

[9] Which cover: behaviour, internal structure of organism, physiological monitoring and self-reports

[10] Here, material does not refer to "made up of bits of matter". It is merely a tentative labeling I have undertaken to refer to ontological category where the causal power arises from the self-organization of components. The use of word *physical* has been avoided since it might lead to the misconception that the other two orders are non-physical.

[11] Orientation does not imply agency. Check rock-on-top-and-bottom for understanding. Orientation simply points out that the subject has a set of preferences towards which, under favorable conditions, it will possess.

[12] The best way to understand this is to see the development of sense of self in infants. Initially, they cry when they see other babies crying- in the process of recognizing the boundaries of their embodied mind. Over time, they identify it and their actions are geared towards stable equilibrium of this embodied mind.

the other in such a categorization. It is a *structure*, not a *hierarchy.* The use of higher or lower is only for pointing out of the capacities that the existent has to negotiate its survival in the environment and does not imply any superiority or inferiority.

It is important to remember that such a categorization, at no level, intends to reduce the existent to the order. It only provides a framework within which we can contextualise the complexity of existents we encounter. There is no claim that a species *x* belongs to material/sentient/phenomenal order. While we can claim of human beings that they belong to the phenomenal order, it is important to bring to mind that though we might categorize a certain species *x* in an order, the gathering of more information about the species itself could render the categorization false and they might be shifted into phenomenal or material order.

There can be many existents that have varying degrees of complexity, without a change in the type of their causal power. To accommodate different degrees of complexity, we employ the notion of level. There can be many levels within an order, to account for the varying degrees of complexity.

Within the complex systems approach, members belonging to a singular order can be ontologically reduced and thus, epistemologically reduced to one another (that is, intra-level reduction is possible)[13]. However, it is not possible to ontologically and thus, epistemologically reduce the members of one order to another order because when we attempt to do this, we lose sight of the existent as a whole and encounter residue of the novel qualities belonging to order of the whole.

PART 2
Metaphysics of Emergence

Previously (in Part 1), I proposed that an order, in words of Bunge, "is an assembly of things of a definite kind i.e. a collection of systems characterised by a definite set of properties and laws…"(Bunge 2012, 161). In the complex systems approach, we follow the below metaphysical axioms:

1. Reality is a structure of orders where each existent belongs to at least one order in the structure. Reality is understood as a cohesive

[13] To say that a system *x* is ontologically irreducible to its components C_1, C_2, C_3….C_n is to claim that the causal power of x (exhibited through its behaviour) is not derived from the causal power of its components alone. This happens because when we consider causal power of the components alone, we cease to look at the whole, the system. The epistemological counterpart to this is to say that a system *x* is epistemologically irreducible to its components C_1, C_2, C_3….C_n is to claim that the explanation and prediction of behaviour of *x* cannot be carried out through theories which apply to the lower-level components.

organization of processes, in itself consisting of a non-linear interaction between diverse variety of its components which self-organize themselves to respond effectively to internal and external changes in the environment.

2. As emergence occurs (that is, self-organization and non-linear interaction), there is a gain and loss of properties and correspondingly, laws which applied to the lost properties and were determined by them will also be lost.
3. Every order consists of any levels, each level pertains to a certain degree of complexity.
4. Every order involves capacities of the lower orders. The capacities of lower order are not eliminated, but subsumed in the behaviour of the higher order. However, these capacities are conditioned/affected by the capacities of higher order. Consider the capacity of material order: that of being oriented towards thermal equilibrium. Being oriented towards thermal equilibrium is the most primitive and essential property of any existent. However, thermal equilibrium is not the intended end for members of sentient and phenomenal order. In case of human beings, the presence of a sense of self conditions this primal property such that we can choose our own distinct source of stable equilibrium (in Hegel's terms "to be at home with oneself") and set up conditions to fulfill it. Thus, when I move towards what we consider to be my source of stable equilibrium, I do not tell myself I am seeking thermal equilibrium- it is that which involuntarily results from my being in stable equilibrium. Thus, the capacities of lower levels are involved in the capacities of higher order while being conditioned by them.
5. Every order has a certain extent of autonomy and stability, restricted by the complexity of its system. In a large enough system consisting of large number of components with strong interrelations, the elimination of few components does not affect stability of the whole. Their role can be compensated by that of other components. In this sense, that which the higher-order is oriented towards (autonomy), becomes the governing principle for the behaviour of the components ensuring that the stability of whole is maintained by non-linear feedback mechanism between the components. However, the system cannot perform actions which are not within the scope of complexity of the system. For instance, we cannot expect of a bird to talk human language (much like human beings' inability to talk through bird calls): birds use calls and sounds which are in

sync with the infrastructure of their bodies, as do human beings. The kind of capacities a system has will depend upon the complexity of its system. Thus, while human beings have the autonomy to choose their source of stable equilibrium (the autonomy), such autonomy can only be exercised within the purview of the degree of their complexity.

6. Behaviour is determined according to set of specific laws which belong to the order, to which the existent belongs and not through the lower-order laws. While I can use the laws of material order to explain the behaviour of components of a member of sentient order- the explanation will have to be contextualized within laws that apply to the sentient order itself. That is, my explanation of the cellular behaviour will have to be placed within the biological setup of an organism.

PART 3
Epistemology of Emergence

The previous section discussed the metaphysics that underlies emergent processes. If it is the case that emergence occurs as is explicated above, then there must be epistemological frameworks within which the behaviour of orders of being can be explained. However, one must not assume that the correspondence would be a simple one-to-one mirroring. That is, every level of complexity does not correspond to every level of science or vice versa. Different levels of science concern themselves with varying objects of study, which can lie in the relationship between levels, or in the nature of an order as a whole and so on. The following principles outline the complexity involved in such a mirroring:

1. The orders are knowable. Every order consists of various levels, corresponding to different degrees of complexity. These levels can also be known by employing instruments which study the behaviour of existent as a whole.
2. There are different levels of science (physics, chemistry, biology, psychology, sociology). A hierarchy is formed assuming that physics deals with the most fundamental entities (that which makes up every-thing: atoms, energy, forces, quarks). The hierarchy is formed on the increasing scale of spatiotemporal integrity. Every level of science selects its object of study and chooses the methodology (tools, instruments, way of approaching the object) suitable to the former's nature.

3. Every level of science has its scope and limitations. The scope of a science refers to the object (an existent/process) of its study in sync with the employed methodology. The limitation of a science refers to the kind of claims it can adequately support using its evidence. The limitation is largely dependent on the scope. It points out that every science is a primary source of information for that object which it considers, as a whole.

   The scope of a science is the object of its study. Consider the scope of physics: the fundamental processes of reality (where fundamental refers to that which is basic to every form of existence), biology which claims to understanding living beings, psychology which studies the mental structure of human beings and sociology which examines the society and processes within it. Every science uses those tools and methodologies that focus on their object as the basic unit: in biology, the basic unit is cells and cellular organisms, in psychology, the basic unit is the mental processes of an organism, basic unit of sociology is the society as as whole. The sciences will also explore the component within the object, however, such an exploration is carried out to understand the nature of object as a whole.

   The limitation of a level of science is that it cannot claim to provide conclusive findings on the nature of another object of study, unless only as a secondary discovery. The results that it comes upon only pertain conclusively to its object of study. For instance, consider the study of marriage as an institution in sociology. While sociology might use neurological readings to check the authenticity of participants' responses in a survey, any discoveries it makes about the neurons/their workings itself will only be secondary and question to the tools of neurology. In the same way, neuroscience can provide conclusive results on the workings of brain and its neurons but it cannot, but provide secondary findings, on the nature of subjectivity and mental states which belongs to the body-as-a-whole. The findings will have to be corroborated through science which studies the embodied mind as a whole (existentialism, phenomenology, psychology and others). "No single science embraces the whole of reality. This thesis contradicts reductionism, the epistemological partner of monism." (Bunge 1973, 164).
4. Understanding of an object of study in a science is affected by developments which occur in other sciences. However, there is no linear

form of development within the sciences and there can be different ways in which our understanding of the objects of study also progresses.

PART 4
Methodology of Emergence

In the previous two sections, we covered how there are orders in reality, there are levels in these orders and we can have knowledge of these layers, in a structured manner. In this section, we cover the methodological principles that can be followed to carry out a research that is founded on the aforementioned metaphysical and epistemological principles. These are largely inspired by Bunge's *Methodology of Levels* (Bunge 1973).

1. *Limit inquiry to one level. When this level is not adequate, scratch the surface to search for further levels:* this implies that one should exercise methodological reductionism[14] till it becomes clear that it is not possible to explain the nature of level via the behaviour of lower levels. It is important to differentiate between reduction and reductionism: reduction as it applies to levels and orders and reductionism as a research strategy in searching for explanations through analysis. The intention of this principle is *not* to prescribe to reductionism as an ontological principle but to avoid ontologically over-determining causal power of the level in the research, by taking account of previous knowledge available on the lower levels. The first step, therefore, is to attempt to explain behaviour occurring at a level through methodological reductionism[15].
2. *Confront emergence and move towards explaining it:* The research must begin "by attempting to explain the new in terms of the old. If this strategy does not succeed, meet the challenge: take the *nova* by their horns. Do not ignore emergence and do not regard it as beyond comprehension either, the way emergentists (e.g. Alexander) and intuitionists (e.g. Bergson) used to do.[16]" (Bunge 1973, 166).

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[14] Methodological reduction refers to the practice of attempting to explain behaviour of the whole through the behaviour of its components, indicated by the use of methods proper to the lower-level components.

[15] In response to the criticism put up by Wimsatt against methodological reductionism, that methodological reductionism tends to be wannabe-reductionism and "They claim that one should pursue reductionism, but never propose how.", it is adequate to point out that such a criticism is well-placed in consideration of history of reductionism- however, in our context, the presence of metaphysical and epistemological principles disallows a research without direction.

[16] The first step allows us to remove the possibility that the whole can be understood through the laws or theories applied to the lower-level components. From this stage on, it becomes clear that the systemic properties of the

3. *Carefully understand the lower levels in order to grasp the emergence occurring at a higher one:* No hurry should be made in claiming the novel causal powers of a level. The initial step should be to understand the working of emergence through the older levels. For instance, in trying to explain the origin of mind, one must understand the nature of networks in the brain and how they self-organize.
4. *Examine the set of facts on its own level and introduce new levels if required:* Always be sparing/judicious while introducing new levels since they might not provide more information to account for the causal powers and could also overload information causing hindrance for theoretical models. However, if the nature of information encountered in the lower levels turns out to be inadequate, explore higher levels and introduce new levels if need be.
5. *Always choose the level of science which grasps the object of study, as a whole and not in pieces:* The level of science you choose must be in sync with nature of the object. For instance, do not attempt to carry out the study of development of psyche (which is manifested through the behaviour of the individual in the world) of an individual through neuroscience, which deals with the study of brain and its workings (where brain is a component of the body and not reflective of the entire system). Move towards finding sources of information which consider the object as whole and cover as many factors as influencing the object: the environment, the genetic dispositions. Thus, while neuroscience could be a major contribution, it must not be the only-one.

In conclusion, the methodological principles applied during exploration of a complex system allow the extracting and gathering of information which will reveal nature of the object and not of the components alone. The metaphysics and epistemological principles support the methodological points explicated. Investigation of any complex system through the integrated matrix of the three sets of principles will allow holistic gathering of information about its nature, with particular emphasis on the emergent properties.

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