The significance of addressing system dynamics explanations

Author information

Camilo Olaya
Organization: University of St. Gallen - Switzerland.
Postal Address : Dufourstrasse 72 - 9000. St. Gallen, Switzerland.
Phone : (+41) 71 224 2379
Email addresses **:** colaya@uniandes.edu.co
camilo_olaya@hotmail.com

Abstract

In a previous work the philosophical concept of Mechanism was proposed in order to characterize the kind of scientific explanations provided by the system dynamics approach. That earlier paper positioned such idea epistemologically contrasting it with the traditional view used by mainstream management research and developed a different ontological ground based on the structuralist approach of Bertrand Russell. However, it seems to be needed an emphasis on the epistemological nature of the Mechanism thesis because of its common association with reductionism and the view of mechanistic thinking as supposedly opposed to holism and emergentism. This paper constitutes a second part; it underlines the epistemic status of Mechanism which explains why it is in no way opposed to ideas like holism or emergentism, on the contrary it is consistent with such worldviews. Based on this condition the paper explores the repercussions of such characterization for philosophy of science and for system dynamics.

***Key Words**: philosophy of science, epistemology, methodology, explanation, mechanism, ontology.*

1. Introduction

Why the epistemological issue of explanation can be particularly relevant for the field of system dynamics? Two natural answers come immediately to mind: first, system dynamics aims to answer 'why' questions, which is also recognized as the main target of any explanation, that is, a core goal for the discipline should be *to provide understanding*. But, what does this mean? How do we know if the explanations are getting better? What types of criteria can be developed to assess this? The second answer is that scientists, in general, judge their works [theories, concepts, models] in terms of their power to explain; therefore the concept of explanation becomes a major yardstick for any field in order to evaluate its progress as scientific programme, which in turn is even more critical for a developing discipline as system dynamics. But, in spite of these inherent reasons, the issue of *explanation in system dynamics* is yet to be explored; there are previous works on important related topics, many of them placed in the realms of epistemology and methodology, but a direct approach is lacking.

A preceding work exposed in the system dynamics conference of 2004 presented the fundamental models of explanation and introduced the concept of *Mechanism* as a characterization of system dynamics explanations (___ 2004); this account included its deep difference with the standard notion of explanation that supports mainstream management research, namely causality, and it also developed a coherent ontological ground based on process and structuralist philosophies. In the reception of that previous work it was noticed the still prevalent and mistaken view of mechanism as opposed to holism and emergentism; this seemingly widespread view of mechanistic thinking, labelling it as inadequate and opposed to systems principles, makes difficult to recognize the epistemic status of Mechanism which should be understood mainly as a kind of explanation and as such belonging to the epistemological realm without pretending to insinuate or infer anything about ontic aspects of reality. One goal of this article is to refine this issue. In addition, and as a major aim, this paper delineates a research agenda that hopefully shows the significance of the relationship between the explanation inquiry and system dynamics. Thus, the paper can be seen as divided in two big parts. In the first one there is a clarification about the epistemic status of mechanism (which is the central theme of the next section). The second part, third and fourth sections, develops such notion and underlines its relevance for practice and research suggesting various topics for constructing a research agenda. A brief conclusion closes the exposition.

2. Mechanism is a kind of explanation

It is not difficult to find discussions where systems thinkers and academics alike criticize what they call reductionism; usually when elaborating their arguments our systems friends will hoist the flags of holism and emergentism. Although all of these terms are widespread used it is hard to say that they carry everywhere the same meaning or the same idea behind. Because of this situation any serious discussion around such subjects becomes problematic, however, a basic ground will be suggested in order to clarify and to make the central argument natural to grasp. Basically the doctrine known as holism maintains that all levels of organization are of equal value and that at the level of the whole there are features that cannot be reduced to features of its parts (Healey 1991); this idea is usually identified with the familiar sentence that "the whole *is* more than the sum of its parts". The point that must be emphasized here is that such sentence is an ontological assertion, i.e. an affirmation about the nature of reality, and it should be taken in this sense (e.g. Brandon 1984). Naturally, the idea of holism has a broad scope for different spheres; for example semantic holism refers to "the doctrine that all of the inferential properties of an expression constitute its meaning" (Devitt 1993, p. 281). In ethics the holism of Aristotle is worth of mentioning with its important notion of assessing lives as wholes (Price 1980). Maybe here the conflicting connotation would be its epistemological cousin, a sort of methodological or explanatory holism which asserts that "a satisfactory explanation of the behaviour of an object of some type cannot be given by analyzing that object into its components parts and appealing to the laws that hold of these parts" (Healey 1991, p. 397)[1] and therefore the idea behind is that it should be necessary to direct the study to the level of the whole[2]. Yet, what must be emphasized here is the nature of holism as an affirmation referring to things/objects of reality and their properties and thus alluding to ontological premises. Closely connected is the also popular idea of emergence, the view that "at each higher level of organization new and irreducible properties appear (emerge) which are not possessed by their component parts, neither when taken separately nor when put together in other partial combination" (Looijen 1998, p. 33). This is also fundamentally an ontological or even metaphysical assertion; for example already Pepper underlined in 1926: "Accurately speaking, we must first observe, laws can not emerge. Emergence is supposed to be a cosmic affair and laws are descriptions" (1926, p. 242)[3]. Thus, so far, it should be unmistakable that holism and emergentism are essentially ontological theses referring to assumptions about the character of reality. Their opposites must be ontological theses also, namely a sort of ontological reductionism, i.e. all higher level entities and processes are nothing more than certain combinations of lower base level entities and processes (Brandon 1984) or even the extreme form of atomism, i.e. the entities of the lowest level of organization have ontological higher value over higher level entities (Looijen 1998).

The earlier exposition is important because reductionism and its related concept known as mechanism are commonly opposed to holism[4]. It is frequent to find darts from holists or emergentists advocates against what is labelled as mechanistic thinking and associating it tightly with 'evil' reductionism of reality. However, to notice that usually mechanism and reductionism refer to epistemological issues but are apparently taken as assumptions about reality may shed light on the debate, as already Lancelot Hogben put it in 1930:

> *In any discussion between the two [mechanist and holist or vitalist], the combatants are generally at cross purposes. The mechanist is primarily concerned with an epistemological issue. His critic has always an ontological axe to grind. The mechanist is concerned with how to proceed to a construction which will represent as much about the universe as human beings with their limited range of receptor organs can agree to accept. The vitalist or holist has an incorrigible urge to get behind the limitations of our receptor organs and discover what the universe is really like* (1930, p. 100, as cited in Brandon 1984, p. 347).

Concerning reductionism it is worth of noticing that fundamentally all kind of reduction refers to a kind of explanation and therefore it has to do with logical relations between statements or ideas, and as such it is not about ontologically reducing wholes or emergent properties; specifically, in its extreme form denotes the claim that it is possible "to reduce all the concepts, laws and theories that have been developed for a certain higher level of organization to concepts or theories that have been developed for (a) lower level(s) of organization" (Looijen 1998, p. 29). This is closely related to methodological reductionism, i.e. the assumptions about the ways of approaching to knowledge, in this case suggesting that "the best way to understand phenomena at the level of the whole is to study causal mechanisms at the level of its constituent parts" (Looijen 1998, p.35). The connected explanatory notion of mechanism is well underlined by Grene: "Let us look for a mechanism which might underlie the phenomena we hope to understand, seeking wherever we may relevant sources from which to derive… an analogue of a possible mechanism… Such an explanation is of value because it tells us *how in fact those phenomena are produced*." (as cited in Brandon 1984, p. 346). It is easy to see the natural association between reduction and mechanism but their scope is not so extreme as to *imply* a reductionist ontology. Both notions refer to kinds of explanations; the latter one can suggest for now an explanation of a whole in terms of its parts; such account is developed in the third section of this article.

With the last basis established the next issue is to consider a little bit more the idea of explanation itself, a notion that has proven to be complicated to address. The general inquiry about [scientific] explanation has to do with "learning how the process of doing science facilitates understanding, and what type(s) of understanding science provides" (Berger 1998, p. 307). In a very intuitive way, a first approach to explanation might be associated plainly with removing puzzlement (Benjamin 1941). It is also common to affirm that an explanation aims to answer queries of *why* in order to provide understanding (Salmon 1992). Yet, to characterize such idea is a major and open unresolved question in philosophy of science[5]; the failure to typify the concept of explanation is pictured by Newton-Smith (2000):

> *The current situation is an embarrassment for the philosophy of science. Indeed, one might go so far as to say that it is the sort of scandal to philosophy of science that Kant thought skepticism was to epistemology. While we have insightful studies of explanation, we are a very long way from having this single unifying theory of explanation…We would like to be able to explain what it is that leads us to count different explanations as explanatory. This task is made all the more pressing as most philosophers of science hold that a main task, if not the main task, of science is to provide explanation, whatever that may be.* (p. 132).

Thus, to say that a mechanism is a kind of explanation does not seem to be very advantageous. Precisely one of the aspects that this paper wants to highlight is the potential contribution of system dynamics in order to advance in the theory of explanation; this will be done in the rest of the paper. For now, beyond a matter of words or labels, this section emphasized the status of mechanism, an idea that is easily mistaken because it is ascribed with assumptions about reality which are out of the question because of its epistemological *in essence* character[6]. In the previous paper various accounts for explanation were introduced highlighting the prominent idea of causality as the way to explain things. In this context, mechanism was labelled as a different way to explain phenomena and also as the type of explanation that fits system dynamics. In the next section this concept is developed in order to show what this kind of explanation is about, a requirement in order to elucidate its benefits for system dynamics and for the philosophy of science.

3. What is a mechanism?

Even such an intuitive notion like a mechanism, i.e. resembling a machine, has not been easy to characterize. The fact that it is a kind of explanation is only the beginning. A traditional view is to associate it with regularities (usually expressed in laws) and causal relations that are accountable for the thing to be explained. For example, in 1927 Krikorian summarized that a "mechanical explanation of a given phenomenon is its subsumption under laws which employ only causal relations" (Krikorian 1927, p. 16). By the mid of the past century Benjamin synthesized diverse positions: "*Mechanism* (materialism, mathematical rationalism of a type) emphasizes quantitative description as over qualitative, analytic as over against synthetic modes, and explanation by causes as over against explanation by effects; the general tendency is to explain by *earlier* events and by *parts*." (1941, p. 492, emphases original). A further addition to these definitions is the idea of process. Brandon characterizes mechanism asserting that "to model a process is to offer a more or less plausible hypothesis concerning the mechanism underlying the process. Thus any process capable of being modelled is a mechanistic process" (1984, p. 346). In spite of the long tradition on the subject there is still no agreement about what a mechanism is and how it appears to succeed in science as a way to provide understanding; recently, this topic has gained special attention in philosophy of science; this late debate will be summarized here in order to picture the up to date image that we have about mechanisms.

Stuart Glennan advocates the position that emphasizes the nature of *complex system*[7] for a mechanism where the role of parts and its interactions is indispensable. His position replies to the conventional view of a mechanism as merely the interactions between causal processes as the essential *explanans*, the traditional approach aligned with the customary notion of causality as the way to explain phenomena. Glennan stresses: “A mechanism for a behaviour is a complex system that produces that behaviour by the interaction of a number of parts, where the interactions between parts can be characterized by direct, invariant, change-relating generalizations” (2002, p. 344). Several distinctions must be noticed here: a first one, already mentioned, is the suggestion that a mechanism is a type of complex system. A second one is that it accounts *for* behaviours. A third one is the notion of interaction of parts taken here as occasions on which a “property change in one part brings about a property change in another part” (p. 344) by virtue of the first part capability to do so. Glennan clarifies also that he avoids using the term "causal-law" and instead uses "change-relating generalizations" because these relations are not exception-less as traditionally a law is understood. In addition, he emphasizes the very different character of such account that is in opposition to the traditional causal view in which mechanisms are sequences or chains of events leading up to a particular event - which is often associated in systems theory literature with "linear thinking".

Machamer, Darden and Craver (2000) join the discussion adding that mechanisms are not only inter-connected entities but also activities producing regular changes from initial to finish conditions; they call themselves dualists since for them both notions - entities and activities - are necessary to constitute a mechanism: "The organization of these entities and activities determines the ways in which they produce the phenomenon. Entities often must be appropriately located, structured, and oriented, and the activities in which they engage must have a temporal order, rate, and duration" (p. 3). It is important to underline their critique to Glennan’s view arguing that the concept of *activity* is fundamental to understand the changes produced [because of the activities] through the process and not only as the black-box view of change of states or change of properties of the inter-connected entities, they picture it clearly with the following statement: "it is not the penicillin that causes the pneumonia to disappear, but what the penicillin does” (p. 6). Furthermore, in order to account for a mechanism they emphasize three distinctions: set-up conditions (as *part* of the mechanism, not as a sort of input; this includes relevant entities and their properties and initial states), intermediate activities (including also relevant entities, properties, and an intelligible account of the activities that link them) and termination conditions (such as privileged endpoints, equilibrium states or the final stage of some unitary integral process). They also draw attention to the fact that mechanisms take place in nested multi-level hierarchies and that they usually are not full pictures but truncated abstract accounts - *a mechanism schema* - depending on the required level of detail or aggregation.

Noticing the contributions of both approaches Tabery (2004) proposes to integrate these complementary points of view in order to understand what a mechanism is, underlining that both features, i.e. the interactions among several parts and the activities associated with these interactions, are necessary in any mechanism-based explanation. It can be safely said that these accounts encompass most of the current views when attempting to characterize a mechanism.

In order to categorize system dynamics explanations the earlier paper introduced mechanism as a natural option. A short description of a customary modelling process it may be useful to understand why. A core premise of system dynamics has always been to provide understanding (Forrester 1987) although this aim does not seem to be seen as indispensable by all practitioners[8]; nevertheless, it is central that the model should be able to account for some problematic behaviour which is explained in terms of the structure of the model; here the term "structure" refers to the stock and flow organization, the feedback loops and the rules of interaction (Sterman 2000). This is known as a dynamic hypothesis and is the core concept in order to provide *understanding* from a system dynamics point of view; its endogenous character is the chief feature that makes intelligible this kind of explanation; for instance: "One key task in this search for insightful, system level understanding is the telling of 'system stories'—coherent, dynamically correct explanations of how influential pieces of system structure give rise to important patterns of system behaviour" (Mojtahedzadeh, Andersen & Richardson 2004, p. 1) a task that still is one of the more pressing research lines for the field (Richardson 1996). The previous paper detailed the description of system dynamics structures as explanatory mechanisms. In short, concerning explanations in system dynamics, the problematic behaviour is the *explanandum*, i.e. that which is explained, and the structure is the *explanans*, i.e. that which does the explaining. The point underlined in the previous paper is that the structure characterizes the exposed account of mechanism which is the kind of explanation in system dynamics, that is, the reliable identification of the influential structure will be the relevant information for having a meaningful explanation.

Thus, although there is no agreement about the essential character of a mechanism, its relevant aspects and potentials for explanatory accounts can be clearly distinguished in the previous discussion and in its role in system dynamics. Furthermore, the suggestion of characterizing system dynamics explanations as mechanisms renders several lines of inquiry which will be developed next.

4. The relevance of the discussion: a research agenda

So far this paper has presented a difference between some concepts (holism, emergence, reductionism, mechanism) as a plain and long misunderstanding based on a very basic thing, i.e. ontology vs. epistemology, in order to assert that *Mechanism* is a kind of explanation. The other outcome has been the partial characterization of such notion. The reader might still be wondering what is the point [or the relevance] of these clarifications beyond an interesting philosophical debate. In this section the significance of this discussion will be developed highlighting important implications for theory and practice.

Studies of complexity using computer simulation seem to have taken philosophers of science by surprise, and within this sphere the issue of [scientific] explanation is no exception. The notion of causality has traditionally played a central part in characterizing what an explanation is. In fact it has been common, particularly in the second half of the past century, to identify explanation with the search for causes, a doctrine which is fully pictured in the title of the book of one of its main advocates, Wesley Salmon: "Scientific Explanation and the Causal Structure of the World". In the previous paper it was shown how this vision has pervaded most of management research where theory development and explanation are understood essentially as causes. However, there are several authors agreeing in that many types of explanations are not based on causal relations. For instance we can explain things by identification, with models and with analogies. It has been suggested also that non causal explanations might be based on formal linguistics, laws of association, laws of co-existence, variational principles and structural laws (see Ruben 1990). The supporters of these accounts argue that they are non causal explanations regardless of having sometimes causal factors involved because the real explanatory work is not based on these singular aspects but on other essential explanans

(Hesse 2000; Newton-Smith 2000). In recent times the use of computer models and computer simulation has arisen as a provocative way to impulse and enrich the debates. This issue will be introduced.

Current approaches in order to focus on structures, relations, emergence and evolutionary processes use computer simulation as a way to deal with well known complexity features - e.g. emergence, non linearity, non equilibrium dynamics, feedback (Bar-Yam 1997; Sterman 2000; Georgantzas 2002). What is simulation? In a plain sense "simulation means driving a model of a system with suitable inputs and observing the corresponding outputs" (Axelrod 1997, p. 23). The application of this kind of approach is not new in social science[9]. Furthermore, and expanding the scope of computer simulation, it can be affirmed that it is a technique able to represent, communicate and test theoretical concepts (Liebrand 1998; Sterman 2000) and not only – in a narrow sense - a tool to solve structural abstract [mathematical] problems. Furthemore, it can be conceived as a natural way to study mechanisms underlying emergent properties of complex systems (Holland 1998). Moreover, this way of inquiry suggests a whole different research approach. Axelrod (1997) underlines the possibilities: "Simulation is a third way of doing science. Like deduction, it starts with a set of explicit assumptions. But unlike deduction, it does not prove theorems. Instead, a simulation generates data that can be analyzed inductively. Unlike typical induction, however, the simulated data comes from a rigorously specified set of rules rather than direct measurement of the real world." (p. 24). Likewise, Winsberg (2003) adds that "simulation represents an entirely new mode of scientific activity – one that lies between theory and experiment…a form of theory articulation or 'model building' (pp. 117, 119)[10]. The consequences of such affirmations are clearly pictured when addressing the question about explanation. Computer simulation and mathematical modelling in general are approaches capable of proposing explanations based on structural mechanisms in order to develop issues like theoretical-representations building, articulation and testing and, fundamentally, in order to provide understanding. Such kind of explanation represents a new challenge for philosophers of science. As Berger (1998) notices when attempting to characterize the explanations provided by nonlinear dynamical modelling:

> *Mathematical modelling [is recognized] as one of the central activities of science, and it is reasonable to say that modelling explanations dramatically increase our*

> *understanding of the world. But the modelling explanations found in contemporary scientific research show that the interesting claims of causal accounts are untenable…An adequate account of scientific explanation must accommodate modelling explanations, because they are simply too central to ignore"* (pp. 329, 330).

In this sense, system dynamics might offer significant contributions for the philosophical realm, e.g. can the ways in which system dynamicists work provide meaningful insights, or even concrete accounts, for the general unresolved issue of explanation? But also it goes the other way around, such debate enriches and gives guidelines for developing system dynamics as a solid research programme. Both paths are introduced next.

For philosophy of science there are several novelties to face. First of all there is the already mentioned challenge to the characterization of explanation as merely causal connections. The mechanism depicted in system dynamics proposes a kind of explanation that goes beyond the received view of causality account, that is, because of its endogenous character and because of its complexity account, i.e. multiple dynamic activities and processes, it confronts the usual position on causality based on exogenous and unidirectional influences on a system; and essentially, following Glymour: "Remains…a considerable bit of science that sounds very much like explaining, and which perhaps has causal implications, but which does not seem to derive its point, its force, or its interest from the fact that it has something to do with causal relations (or their absence)" (as cited in Ruben 1990, p. 212). A second major challenge is the question whether explanation must always follow a deductive path; in the previous paper the classic models of Hempel were introduced; these long-established models emphasized the condition of deduction and general laws for having an explanation; however, the explanation in system dynamics are not deductive schemas from universal covering laws, instead it can be understood as a sort of abductive reasoning based on the understanding of the dynamics of the model as a way to understand the actual behaviour it accounts for. A further interesting aspect is that in spite of the lack of this universality, i.e. no universal laws behind, these kinds of models aim to provide understanding for a diverse range of phenomena that might share relevant influential structures and similar behaviours associated to it, that is, it accounts for regularities in order to unify them in a certain kind of phenomenon[11] under the same essential explanation. This situation insinuates a flavour of paradox because of the traditional rigid association of universal laws with the explanation of regularities, in system dynamics there are no general laws but the aim is to explain general regularities[12]. A third challenge has to do with statistics given that mechanism is a non-statistical account of explanation, an affirmation that defies classic notions on explanation which postulate statistics as a major advance to provide understanding; in spite that statistics is used to gain confidence in the models it is not the *explanans*, that is, no system dynamicist provide understanding or base its account for behaviour on statistical relations *per se*[13]. Fourth, it also eliminates every reference to purpose in spite of the lack of universal rules; the previous paper suggested the distinction of structural laws in order to account for the mechanism (opposed to substantivalist rules which relate objects/properties); in this sense these mechanisms are not under universal-natural laws but nevertheless they do not imply teleological, i.e. purpose oriented, design as long as the behaviour of the system is understood as a consequence of the structure with no further specific function or goal in mind; this is also suspicious for the standard philosopher who instantly associates lack of purpose with [natural] laws (see for example Krikorian whose paper of 1927 can be used to track this long belief) but system dynamics suggests a kind of explanation that at the same time is ateleological and lawless.

But also for system dynamics there are major and provocative issues to be developed around the question on explanation and its depiction as mechanism. Firstly, the long debate of qualitative and quantitative modelling; it has been a long time since Maloney (1993) threw a challenge to the system dynamics community wondering if this discipline is merely about providing insights; it is clear that the issue of explanation compels theorists and practitioners to ask themselves what is the kind of explanation they are providing and if such explanations are enough and satisfying; since this paper has been taken as an essential part of system dynamics the use of simulation and given that there is an important gap between giving insight and providing understanding, it is worthy to ask for qualitative modelling what kind of understanding it gives and how it can be characterized, in other words, to give an account of *explanans* and *explanandum* for such approaches. Second, concerning model testing as a traditionally hard to address issue[14] the hint looks simple: the criteria should be guided by the capability of the model to supply reliable understanding of the phenomenon in hands, that is, it rests on the capability to provide an explanation which in turn refers to the reliability of the mechanism in hands. What does reliability mean here? For instance, in order to identify a particular mechanism present in a model as the *explanans* for a precise *kind of phenomenon*, are there aspects of the characterization of a mechanism, e.g. the type of final state of an influential activity, that should be *necessary* conditions in order to give a reliable evaluation of that particular model? Or, what are the *essential* criteria for comparing different arranges or modes of organization in order to identifying them as belonging to the same type of mechanism? If the issue of explanation does not provide a solid ground for the field then the road to get a firm account for model testing might look rough. Third, the identification and search of mechanisms become a powerful heuristic for guiding the modelling process. Since the regularities of behaviour might be explained by similar structures (although also by different structures) the look for particular arrangements of entities and processes, i.e. mechanisms, constitutes a useful guide for building models. Furthermore, the issue of unification to provide understanding of diverse phenomena is a definitive step in the way to assert that the field progresses as long as broader range of phenomena may be explained with the same mechanism; the identification with what is known as 'generic structures' is straightforward as long as they are conceived for creating "a more general hypothesis about the structure and behaviour of a class of *settings of interest*" (Lane and Smart 1996, p. 110). Can these generic structures be epistemologically matched with mechanisms? Do these terms represent the same concept? Given this, and the long-established reductionist thread, is it possible to *reduce* a wide range of mechanisms to a core set? (See for instance Wolstenholme 2003). Given the account of what a mechanism stands for, i.e. behaviour, how should these archetypes be understood? E.g. essentially as communication devices (see for instance Wolstenholme 2004) or attached inherently to formal dynamics? These questions allow to recognize the fruitful relationship between on the one hand the demarcation of mechanism and on the other hand the development of broader explanations in system dynamics via unification, this is a connection that deserves to be further explored.

The ideas above introduce broad research agendas for philosophy of science and for system dynamics assuring a solid ground for discussion which benefits both. This field contributes to the quest for understanding 'explanation', e.g. challenging classical premises ascribed to it, which in turns adds value to system dynamics in its growth as research programme.

5. Conclusion

A brief commentary in order to close the discussion. Delorme (2001) summarizes that the task of science is the search for some explanation of some reality and put it to test; the issue becomes, thus, the numerous manners of understand explanation, reality and testing. A solid account of explanation is at the heart of any scientific activity in order to assess the development of any programme engaged in the process of growth of knowledge. This paper continued the introduction of such epistemic notion in system dynamics. Complementing the previous work it developed the significance of addressing this subject which means nothing less than to explore the possibilities of a broad research agenda. Possibly because it is a developing field and also because of its wide scope, this discipline has still a great deal of issues to demarcate in such topic. A number of them were presented. Furthermore, system dynamics represents several opportunities for philosophers of science too; it is unmistakable the natural framework and the stimulating ideas that system dynamics offers in order to address these inquiries. As an unresolved matter - like almost every issue in philosophy of science fortunately -, the inquiry on explanation aims to provide answers and the outcome is basically more questions, which is nothing less than a promising feedback loop in any scientific endeavour.

Notes

[1] To avoid confusion maybe is better to label methodological holism as 'phenomenological', as usually is taken, because of the emphasis on placing the study at the level of the whole and thus associating it with a descriptive or phenomenological method; however, another major confusion of names may arise with the *Verstehen* method of sociology (Looijen 1998).

[2] For instance Cooke and Rohleder (2004) stress the complementary nature of *methodological* holism and reductionism about how to study operations management.

[3] Over the years there has been a heated debate around the term "emergence" and the relevance of the idea behind it. For instance, to name a few, see Ablowitz (1939), Henle (1942), Lowry (1974). Recently Cunningham (2001) reviews its general uses.

[4] Or similarly mechanism is usually confronted (mistakenly) with vitalism which is also an ontological thesis (see for instance Krikorian 1927).

[5] In the previous paper the struggle to characterize the notion of explanation was introduced.

[6] It should be noticed that the isolation of epistemological, ontological and methodological issues in any philosophical discussion may not be the most adequate or clear strategy, after all they are not separated islands. But it is true also the other way, there has to be minimal criteria in order to avoid confusions on basic statements.

[7] The work of Bechtel and Richardson (1993) develops the association of mechanism and complex systems (in biology and psychology) and emphasizes the tasks of decomposition and localization as the heuristics in order to uncover mechanisms.

[8] For instance see the work of Vazquez, Liz and Aracil (1996) which had to emphasize the importance and implications of providing understanding with system dynamics modelling processes.

[9] The first formal models can be traced at least half a century ago with the arms race model of Richardson in 1948 and the ‘Models of Man’ of Simon in 1952, based on a formalization of the theory of Homans of interaction in social groups. The late 1950s witnessed the first computer simulation models (Troitzsch 1998).

[10] Although to illustrate the point clearer the discussion of Winsberg is oriented to natural science – and also specifically discrete simulation models – the assertion can hold for general scientific activities that use simulation because there are not specific intrinsic conditions or constraints related to that particular kind of models, his arguments are in terms of the general processes of building and using simulation models.

[11] The concept of "kind of phenomenon" was introduced already by Hayek when he identified explanation as modelling, however, its scope and proper consideration might gain new impulse with computer simulation. It is interesting to notice the range of his thought expressed half a century ago: "Any model defines a certain range of phenomena which can be produced by the type of situation which it represents. We may not be able directly to confirm that the causal mechanism determining the phenomenon in question is the same as that of the model. But we know that, if the mechanism is the same, the observed structures must be capable of showing some kinds of action and unable to show others… Our conclusions and predictions will also refer only to some properties of the resulting phenomenon, or, in other words, to a *kind of phenomenon* rather than to a particular event (Hayek 1955, p. 221).

[12] An important goal of the previous paper was to give a coherent account of this condition with structural and processes ontologies. This is a further line worth to be explored, that is, the scope of the assumption of system dynamics explanations with respect to ontic commitments.

[13] A similar kind of not statistical and not single causal explanation is what Thagard (1998) calls 'causal network instantiation' as a characterization of medical explanations for diseases. Furthermore, whether system dynamics explanations may fit the 'causal network instantiation' model is a suggestive query for future research.

[14] See for instance the summary discussion made by Barlas and Carpenter (1990) with respect to system dynamics; Sterman (2000) may be a starting point in order to explore the rationality behind this aspect in system dynamics.

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