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Surprise of Complexity and Complexity of Surprise: What Happened to Predictability? Limits and New Possibilities of Complexity for Physical, Psychological and Social Sciences

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Abstract

Complexity, as emergent self-organization, is indicative of the end of a science which has always rooted its own aims, its own reasons, its own meaning in the most exalting project: making the uncertain certain, knowing order so to predict and control the future, what is unknown. Emergence, with its burden of surprise and unpredictability, and non-linearity meet at all levels, in physical, inorganic and material, systems as well as in living, human and mental systems. At this point, some question could be raised: if this is true, if everything is emergent, surprising, unpredictable, where does this acknowledgment lead us? What is the sense of Science? What are its objectives? Does Complexity 'promises' and 'permits' us to better understand nature and the real behaviour of systems, or are emergence, surprise, and unpredictability really *sic et simpliciter* only alibis to hide our scientific failures? Are we at the end of Science? Complexity, as "essential unpredictability" opens up problems which all Sciences must face. And certainly, puts to the test our ability to redefine the way of conceiving Science and its objectives, of viewing and doing Science. This paper faces this issue. Innovating in respect to the concept of classical science, the study of Complexity and Chaos, although it cannot articulate on forecasting purposes, revolves around the imperative of taking into account underlying mechanisms governing real phenomena and structuring and generating stability and emergence, by modelling deterministic nonlinear interaction structure in physical and human systems. In Physics, Chemistry, Geology, Biology, Medicine, Neuroscience as well as in Sociology, Psychology and Psychotherapy, Economy, Politics and International Relationships, nonlinear modelling can introduce a new way of conceiving predictability.

Keywords: Newtonian metaphor; Complexity; Emergence and non-linearity; Self-organization; Predictability issue; Nonlinear models

Beyond the "Newtonian Metaphor" and Afterward?

In 1997, Prigogine, Nobel for dissipative structures, publishes a well-known essay with a very evocative title. The End of certainty [1] highlights how modern science celebrates, through the complexity concept as emergent self-organization, the dialectic synthesis of the opposition between two categories, scientifically and culturally conceived as mutually excluding one another: order-disorder, determinism-probability, being-becoming, necessity-freedom, determination-unpredictability, and constraint-possibility. This dialectical synthesis (expressed even by the concept of deterministic chaos) characterizes the current scientific and cultural revolution, by revising the epistemological meaning of unpredictability and uncertainty, which are now converted into structural elements, that is, into inherent elements to the generator mechanism of real phenomena even if it is a deterministic mechanism.

This is the end of Classic Science, the end of a science able to forecast, which sees systems as stable system, characterized by linear interaction relationships among its components, namely proportionality constants between input and output, by a linear determinism which is guarantee of predictability and controllability of events. From Aristotle to Décartes, from Newton to Einstein, uncertainty was considered the daughter of ignorance. The Newtonian-Laplacian Weltanschauung gives us an image of the world which is conceived like a gigantic clock, a gigantic 'accurate' mechanism. As only a machine can be, it is endowed with perfection, reliability and working predictability. A deterministic working mechanism, therefore, governs and makes system evolution predictable and even ensures the control over future events. As we said, the general assumption is that of a necessary structuring of phenomena as linear system, that is, governed by causal relationships of constant proportionality over time, and, therefore, stable, regular, incapable of any surprising and unexpected behaviour, predictable in their future manifestations. No wonder that, under the bounds of these natural rules, irregularities as well as atmospheric "disorder", fluid turbulence, running faucets, falling leaves, stones rolling down a cliff, oscillations of magnetic waves and plant and animal population dynamics, heart beats, the diffusion of nervous impulses and so on, were considered brain teasers or, at worst, monstrosities by classic science [2]. And no wonder that the o'clock metaphor generated the belief that the order could be grasped and the lack of forecast and control was the result of the lack of knowledge of the Law that generated events. Hence, the Positivism and Enlightenment confidence - the Cartesian, Newtonian, Laplacian confidence - in the ability of reason 'to light up the darkness', to tear away the dark curtain of the unknown, to conquer with the light of reason what was obscure, to reclaim terrains of ever growing ignorance, came, affirming the realm of certainty, in other words, the realm of predictability and control over events.

In the current, new epistemological panorama of complexity this trust is gone, by acknowledging the non-linearity and emergence of reality.

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In open systems, like those strange mixtures of chemical substances, kept in a state of agitation, which Prigogine studied in his laboratories, the increase of entropy, imposed by the second law of thermodynamics, does not necessarily create disorder, but ever new, surprising, configurations. Whereas in the framework of the classic paradigm the whole dynamic of evolution tends to stabilize, with no place for surprise, which is absorbed into the limbo of randomness, Complexity science refers to systems as unstable systems, living and transforming in a continuous process, adapting to environmental perturbations by self-organizing, by generating spontaneously (from inner guidelines rather than the imposition of form from the outside) organization and evolving irreversibly towards ever new interaction structures, an ever new, emergent, surprising, unexpected, unpredictable, order, as a result of nonlinearity of interactions and positive feedback among system components. In this sense, Prigogine does not see degradation in thermodynamic processes and in entropy, but an increase of complexity; in dissipative structures, he sees the place of a combination of order and disorder, and in arrow of time, he sees creation and not dissipation [3].

This theoretical perspective, where the emergence concept is central, sets aside reductionism, the tendency to treat a system as reducible to its parts, to seek the key explanation at ever smaller units (i.e. agents in social theory, genes in biological science, etc…): the new, emergent, order is the macro result of nonlinear micro interactions, with properties which are properties of the "whole" and not reducible to the sum of behaviours of each single system component (from an anti-reductionist perspective, the whole is greater than the sum of its parts). This is to say that the general scheme of evolutionary systems is not understandable and predictable through individual interactions among its components, considered one by one. We are facing a new, *bottom–up* and *up-down* determination of causal relationships between parts and whole. On one hand, the system influences the parts/components, *connecting* and mixing them up in a super ordered whole and not simply uniting them in an aggregate, on the other hand, every element can act upon the whole and can modify it (*bottom-up process*), into a new, unexpected structure, which in turn connects the parts into a new form, re-binds them into a new whole (*up-down process*) which will be maintained until a new disturbance directs it toward a new evolutionary direction. Or else, the system can flow into *chaos* and eventually destroy itself.

Self-organization (order for free or supervenience- development of a superordinate structure), emergence, novelty and surprise are the words used today to describe the new patterns of relationships, the new high-level properties of the system generated by collective dynamics of its components or by nonlinear interactions among its constituent parts [4,5]. Change or self-organization output is no proportional to inputs. Large inputs can produce small results, and small inputs can produce unexpected or dramatic results.

So, Complexity, as emergent self-organization, has required for the interpretation of system working and evolution mechanism a new model based on the assumption of distance from the edge of chaos as the preferential state, just as Prigogine suggested for dissipative structures. Complex systems are far from equilibrium systems (in a thermodynamic sense, namely maximum disorder or entropy), at the edge of chaos or intermediate between complete order and complete disorder, between complete differentiation and complete connection (neither too regular nor predictable, like crystal molecules, nor too random and chaotic, like molecules of a gas tending toward entropy), and able, just because they are in this intermediate state, to self-organize and evolve. Systems survive just because they operate at the edge of chaos, and should maintain a balance between flexibility and stability to avoid falling over the edge.

This phenomenon of far-from-equilibrium self-organization has been described by Dissipative Structures Theory and by all other approaches, which on the whole constitute Complexity Theory: Complex Adaptive Systems Theory (the Santa Fé School) [6], even though it is interpreted in light of 'learning and selection' terms and co-evolution between system and environment and Autopoietic Systems Theory [7]. In particular, Maturana and Varela include the self-organizing process in the framework of a system evolution process which is not determined but only suggested by the environment. Complex autopoietic systems, self-organize and self-reproduce their own elements, by working as a non-banal machine, adapting by autonomy to environmental perturbations (operational closure), transforming without losing their identity.

System's working and change mechanisms have been, therefore, re-specified. The New Science dissolves the association between linearism, determinism and predictability, celebrated in Newtonian and Laplacian universe, and makes visible the word as it is, unpredictable and uncertain, though deterministic. This is the novelty of Complexity. Order and disorder are linked within the same framework. Complexity is essential unpredictability. It is the property of systems to show possible but not predetermined behaviours, though deterministic [8]. The new configurations occurring on the edge of chaos are the expression of an implicit order, which originates inside the same system. At the edge of chaos, the system continues to be deterministic, constrained by order-generating rules, and nevertheless it is unpredictable in its dynamic. It follows that uncertainty is no longer, *sic et simpliciter*, a condition based on ignorance, nor as a condition depending on chance, in a huge cosmic lottery which assigns to events mere probability of occurrence. Instead, it seems intrinsic to the system. It springs from the law itself that structures the event, due to sensitivity of the system to initial condition changes and nonlinearity. Non-linearity amplifies even small changes in initial conditions of the system, so as to produce disproportionate, unexpected outcomes, escaping the capacity of prevision (sensitive dependence on initial conditions or butterfly effect). So, at bifurcation points, the choice of one or other branch of the evolutionary process remains unpredictable, considering it impossible to master, control, and precisely define the system state, that is, its initial conditions and the very small changes in initial conditions to which the system continuously reacts. Even for complex systems consisting of few elements, system evolution, beyond a certain time horizon, remains unpredictable. Therefore, emergence, surprise, uncertainty, and unpredictability can be regarded as unavoidable conditions, which cannot be eliminated from the most intimate working mechanism of the system. Ignorance can regress, generating laws and mechanisms can be discovered, but all these cannot eliminate unpredictability, which remains inextricably linked to the orderly determinism of occurrences and of their non-linear cause and effect relationships. Prigogine, with its studies, shows us complexity as "essential unpredictability". He has no doubt: surprise and uncertainty are 'essential', inextricably part of human destiny, of nature and of human history [8]. This applies, therefore, to Physical Sciences as well as to Social Sciences, to Physics, Meteorology, Biology, Chemistry, Geology as well as to Psychology, Sociology, Economy and Political Sciences. Today, Physicists and Biologists recognize *eternal turmoil* as a constant reality in nature. Nevertheless, social scientists like Courtney Brown, author of a rigorous application of non-linear dynamics in the field of electoral volatility [9], does not hesitate to declare that there is no place in human existence where we cannot see emergence, where complex non-linear dynamics operating and where the measure of our ability to predict and control is not seriously put into question.

It is the End of certainty, in its most tragically disarming meaning for scientific undertakings which have always rooted their own aims, their own reasons, their own meaning in the most exalting project: making the uncertain certain, knowing order, to foresee and control the future, and the unknown.

At this point, some question could be raised: if this is true, if everything is unpredictable, emerging, surprising, where does this acknowledgment lead us? What is the sense of Science? What are its objectives? Does unpredictability of the system's evolution expresses in itself the non-scientific nature of its studies? Does Complexity promises and permits us to better understand nature and the real behaviour of systems, physical, inorganic and material, systems, including living, human, mental, psychological and social systems [10], or are emergence, surprise, and unpredictability really *sic et simpliceter* only alibis behind which we can hide our scientific failures? Are we truly at the end of Science?

Complexity, as "essential unpredictability", therefore, opens a problem which all Sciences must to face. And, certainly, it puts to the test our ability to redefine the way to conceive Science and its objectives.

Redefining the Way to View and Doing Science

What is the solution to these theoretical dilemmas? As we said, Complexity as essential unpredictability or emergent self-organization and deterministic chaos concept synthesize the union between order and disorder. On the one hand, the mechanistic image of the universe is definitively deflagrated. On the other hand, complexity even manages to shake up the vision of the universe as a gigantic cosmic lottery. Chaos has nothing to do with chance. It is the result of the system's ability to evolve toward that critical state where its sensibility to initial conditions change is such that these changes, albeit extremely insignificant, inevitably push the system to a state of disorder. And, however, the randomness and a-causality of system behavior is only apparent, having been generated by the same mechanism which is also at the basis of the same system's stability states. Thus, the old issue of incompatibility between randomness and law's determinism is become obsolete and a new metaphor has been coined in the Social Science fields to confirm just how interdisciplinary Complexity Science really is. It refers to a world where, like an immense desert, phenomena leave traces very much like those left by serpents on the sand [11]. But the traces left behind are only apparently erratic, discontinuous, random. They, in fact, obey specific laws of structure and evolution.

The first implication of this new acquisition for scientific research is clear: complex and chaotic systems can be understood, even if not predictable. On one hand, research has to reassess its ambitions regarding predictability, yet it can and must focus on discovering mechanisms and laws which structure and generate discontinuity (i.e., basic equation governing system's behavior). From this perspective, the Santa Fe School researchers have entrusted to Nonlinear Mathematical Modelling the progress in the study of complex systems.

Techniques of mathematical modelling (models of nonlinear equations, simulation models, such as genetic algorithms, artificial life, etc.) have been developed to analyze systems evolving in a discontinuous and sudden way, trying to model order, the deterministic nonlinear law, underpinning to emergence and disorder.

It is true that some questions are still highly debated questions. as the ability to construct a unified theory of complex systems that applies to physical, chemical, biological, immune, neurological, weather, social, psychological, population, economic and political systems. The question divides the same Santa Fe researchers.

Complexity researchers such as Bak [12], Holland [13], Langton [14] and Kauffman [15] are confident in this possibility. Bak, for example, considers self-organized criticality as the common mechanism at the basis of all complex systems (Geological, Biological and Socio-Economical) and therefore the foundation of a unified theory of complexity. On the contrary, other researchers deny this possibility. Some have insisted on the fact that, in reality, the power law, on which the theory of self-organized criticality is based, has not shown the degree of generality desired by Bak. Some other authors even doubt that Science can achieve a unified theory of complex systems able to go beyond some general principles, considering it a reductio ad absurdum [16]. According to Anderson [16], for example, reality has a hierarchical structure, where each level is in some degree independent and separate from the one above and below it: "Psychology is not applied Biology and Biology is not applied Chemistry". In a released interview to Horgan [17], Prigogine himself considered with caution the acquisition of a unified theory encompassing Politics, Economy, immune systems, Physics and Chemistry. Indeed, progress in the field of chemical reactions far-from-entropy (equilibrium) cannot provide us with the key for the study of Politics. Nevertheless, research on Dissipative Systems has introduced a unifying component in the self-organization, bifurcation, irreversibility and emergence concepts.

Beyond this question, the commitment to modeling the nonlinear interaction structure among system components remains valid. By innovating, in respect to the concept of classical science, a science that defines itself as such in relationship to its ability to discover laws governing systems and to foresee phenomena change, predictability is no longer a test bench for assessing the scientific nature of research. The extraordinary discovery, that deterministic laws can produce emergence and that disorder can spring from order, in a view that does not separate them irreparably, celebrates a new ideal of science, a new scientific awareness that if, on one hand, understands it can no longer to be articulated on forecasting purposes for its own self-definition, on the other hand, it models itself on the imperative of accounting for mechanisms and laws which structure and generate stability and instability/emergence in physical systems as well as in living, social and mental systems. As was said above, is not by chance that the increasing success of Complexity Science lies on new non-linear mathematical modelling techniques, which have shown us how intellectual linearism, inspired by Newton's mechanics, has ended up by naively narrowing our view of nature and society. The real 'novelty' now is that today we find ourselves in a more fortunate situation compared to Poincaré's and, before him, to Maxwell's situation. Due to ever more refined mathematical instruments (Topology studies, Ergodicity theory and Non-linear differential equations) and computational instruments (ever more powerful electronic computers able to manage complex non-linear analysis programs and simulation software) we have at our disposal what was denied to the greatest minds of the past: that is, a theory that incorporates the possibility of controlling its theoretical assumptions. Put more simply, today, we can formulate assertions on discontinuity of a certain phenomenon and chaos, and ensure strict empirical control over these assertions. Extraordinary achievements have been recorded in the physical *lato sensu* sciences. Likewise, today, within the Social Sciences we are witnessing numerous applications in various fields of research (Psychology and Psychotherapy, Sociology, Economy, International Relations, Political Science, Demographics), showing how surpassing a purely metaphorical use of the concept of chaos and complexity can finally be possible and actually workable.

As we shall see below, all the above introduces us to a new way of thinking to predictability. In conclusion, we are not at the End of Science. We are at the End of Classic Science and at the start of a new science, of a new way of viewing and doing science in the field of Physics, Psychological and Social Sciences.

Surprise in Living Systems: Building a New Science for Social and Psychological Systems

Thinking in complexity in Human Sciences means to emphasize emergence and non-linearity of psychological systems and social reality. In the social sciences "we are familiar with such holist readings" [18]. Prigogine's the idea of far-from equilibrium systems appears to be a promising reference point for contemporary analysis of cognitive and social systems, linking physical sciences and human sciences [19. p.7].

Non-linearities clearly abound in social phenomena, where a yawn, a desire for an automobile with fins, or a life-style can spread contagiously throughout a population; where a judicious investment can trigger an explosive growth; and where a steady increase in traffic density provokes, at some critical value, a sudden decrease in the speed of vehicles. We see that, in general terms, the systems which interest us are large, nonlinear systems operating far from thermodynamic equilibrium. It is precisely in such systems that coherent self-organization phenomena can occur, characterized by some macroscopic organization or pattern, on a scale much larger than that of the individual elements in interaction. It is a structure whose characteristics are a property of the collectivity and cannot be inferred from a study of the individual elements in isolation. We may say that reductionism, long a strongly criticized attitude in the social sciences, is found to be inadequate even in the physical sciences. The whole is more than the sum of its parts for such systems.

Therefore, if Complexity epistemological paradigm, today, enjoys wide diffusion in Human Sciences, this is due to its usefulness to describe traits which appear peculiar to cognitive and social systems as well as physical ones (far from equilibrium self-organization, emergence, evolution for adaptation, instability and change unpredictability), unable, in this case as well, to be comprehended by traditional approaches based on the reductionist, deterministic linear Newtonian-Laplacian paradigm.

In Social and Psychological Sciences the consideration of living systems as complex systems has not triggered resistance.

In Sociology, the arguments used in favor of such an attribution are based on the logical and sociological inadmissibility of the possibility of social systems coinciding fully, on one hand, with the maximum differentiation state, - a structure interaction processes that does not refer to institutionalized regulation criteria, to shared symbolic codes (maximum disorder) and, on the other hand, with the state of maximum connection - a rigid interaction process structure, pre-codified by rules and formal regulation criteria (maximum order). In fact, the opposite would mean decreeing, on the one hand, the absence of the conditions necessary for the process of interaction and, consequently, the impossibility of a sociological discourse in virtue of the evanescence of its object, i.e., the social system, and, on the other hand, by the perfect homologation of interactions and loss of the source of internal variety and the ability to redefine meanings in the face of external perturbations, the inability of social systems to adapt to environment, inevitably doomed to entropy [20]. As in all open systems, systems exchanging information and energy with external environment (as social systems are and even we ourselves are, from a biological standpoint and in our cognitive processes), strong social systems' emergent self-organization capacity, drive us toward a conception of social systems as complex systems, requiring even for the interpretation of social systems' working and evolution mechanisms the same models based on distance from equilibrium (Entropy) as the preferential state that Prigogine suggested for physical ones. In this regard, it is interesting to note that Prigogine himself [3] considered Durkheim a forerunner of the dissipative structure concept in the social field, by interpreting the labor division process and emergence of modern society as proof of social system spontaneous self-organization process in response to society's moral and material density increase.

In this sense, contemporary macro-sociological approach has no difficulty in recognizing social systems as dissipative structures [21-23] or adaptive and autopoietic complex system [24-26]. Non-linearity, self-organization, emergence, surprise, self-reproduction, operative closure, co-evolution, fitness landscape concepts have entered into sociological language, structuring a new way of thinking about social systems as unstable systems, transforming in a continuous process, by adapting to environmental perturbations by self-organizing and evolving into a new interaction structure, new pattern of meanings or social expectations, new emergent, surprising, unexpected, unpredictable order patterns and new communication through communication. As a result of nonlinearity of interactions and positive feedback among system inter-agents and non-passive adaptation (simply suggested and not determined, operational closure) to the disorder produced by loss of stability triggered by environmental disturbance. Into more specific sociological terms, inputs enter the inter-exchange network of meanings and is processed by inter-agents, being able to activate nonlinear, non-proportional to causal inputs, signification processes, and, consequently, equally disproportionate and unpredictable behavioral effects, beyond the very intentions of the individual inter-agents.

So, Classic issues of Sociology have thus been readdressed. The new paradigm, with its emergence concept and the burden of surprise and unpredictability which emergence implies, has encouraged going beyond Parsons' functionalism without relinquishing a macro-sociological analysis of society as a whole. Although Parson's definition of social system as ordered, stabilized, and embedded in social structures' interweaving of interactions, continues to be accepted and recognized as indispensable for Sociology, reflection today, starting from Bailey's assessment of Parson's functionalism [27-29] rejects the properties of equilibrium as tendency toward system stability, self-maintenance of order if disturbed, while it is in favour of self-organization process analysis of systems at the edge of chaos. On this same track, Luhmann [24] who has constructed his theory of modern society on complexity – focuses on sociological transposition of Maturana and Varela's [7] concepts of autopoiesis and operational closure, in the light of which environment does not determine but only suggests self-organization. Luhmann's definition of social systems as emergent, self-reproducing, operationally closed communication systems, underlines the autonomy and 'non banality' of social systems. The convergence and stabilization of meaning in social interactions, which is indispensable to form a social system and which is made difficult because of double contingency, emerges spontaneously by selection among many possible meanings. In the face of complexity as multiplicity of possibilities and selection among them, social system emerge and serve to reduces complexity, emergence. Produced Laws, money, power, love allows social actors to reduce complexity in different contexts of social interactions. The capacity of social systems to produce by itself its own elements, by reproducing communications through communications, is rooted on the theoretical assumption of a system that, responding to environmental disturbance entering into the autopoietic communication network, decides whether and how to react, whether and how to change, according to its structure, without losing its own identity (operational closure), increasing its own internal level of differentiation and cohesion, and producing *emergence* - therefore, difficult to predict new social structures, new self-organizing outcomes.

Having re-specified the relationship between system and environment in terms of a relationship of dependence and independence at the same time, emergence is, therefore, an intrinsic property to the system: social systems change, transform in a sudden and unpredictable way, far from the asymptotic stability of linearism.

And there is an interesting aspect in the Social emergence conception. The question of the relationship between structure/agency and micro-macro levels of analysis have been readdressed in the framework of a connectionist and anti-reductionist/emergent perspective, which overcomes the split between upward conflation or downwards conflation. This perspective rejects both reductionism and a holism that ignores individuals, synthesizing in the complex realism concept the tension between sociological critical realism and post-modern vitalism, between search for general theory and instances of contextual understandings. Sociological interpretations of society as complex dynamical systems, which expressly emphasized the connection between Complex Systems Theory and sociological realism, such as Byrne and Callaghan [30] and Reed and Harvey [18] did (about the integration of many of complexity theory's key ideas with ideas from critical realism [31,32]), resolve the social emergence issue in the sense of a spontaneous bottom-up self-organizing process, recognizing the self-reflexivity and rationality of social actors without losing the emergent character of social totality, being expressed by surprising, counter-intuitive, unintended effects, unexpected patterns of social expectations which are beyond the intentions of each agent and cannot be explained by reducing them to the properties of individual interactions since they constitute an "effect of the system" as a whole, as an organized and dynamic collective entity. From this perspective, the fact that rational actions are able to generate effects which contradict them becomes a intrinsic possibility to the logic of system, to its autonomy. Micro e macro are structured in inter-relational relationships where the macro emerges from non-linear micro local interactions and, in turn, this new emergent order connects the parts in a new whole which constrains and is able to re-orients social actions (causal up-down process) until a new self-organization and change process [33].

While Byrne and Callaghan [30] underscores the compatibility between complexity theory and realism, the idea of a stable order of sense in line with the conception of a deterministic world, with an intrinsic order and Cilliers [34] argues its compatibility with postmodernism, emphasizing the lack of stable sources of sense and rational teleology of history, the dismissal of the possibility of social causality and systematic social inquiry in favor of the uncertainty, unpredictability and surprise, Reed and Harvey's [18] theoretical position of complex realism grasps the potential of Complexity Theory of going beyond this dichotomous conception, linking determinism and unpredictability. It remains within the modernist programme of progressive thought and rejects at the same time the canons of reductionist positivism and postmodernism.

In other words, Complexity Theory, by its conceptualization of nonlinear determinism and emergence, has inspired a new way of thinking about the classic issue of inherent indeterminacy of human behaviour. On one hand, the Complexity approach has led to reaffirm this idea. On the other hand, however, it has led to re-specify this concept, acknowledging that it is far from meaning that any order or any structural explanation of social life cannot be found and that a dice toss is the fundamental engine driving social processes [35]. Complexity's insights have contributed to strengthen sensibility of social scientist for the analysis of the deterministic structure and logic underlying human behaviour "including the logic and structure of indeterminacy", being considered no longer a metaphysical element but a valuable conceptual tool in the analysis of social life.

Emphasizing social emergence means to support an emergentist conception of social change. Applying the concept of dissipative structure or complex adaptive system to the study of society means looking at social systems as inherently historical entities whose evolution "is driven as much by internal instability as by external perturbation" [21], using environmental feedback for learning and adaptation and self-organizing. And the same conditions of nonlinear interactions or sensitive dependence on initial conditions observed for natural systems have been acknowledged to be the foundation for their historicity. Human history may be described by a succession of bifurcations [8]. As Brown [11] highlighted, this emergentist conception of social change celebrates emergence, discontinuity, unpredictability and uncertainty of the process but, at the same time, recognizes that it is the result of non-linearity underpinning the deterministic mechanism of evolution.

As a result, the way of thinking about the aim of Social Sciences was influenced as well. Complexity Epistemological Paradigm has encouraged the sociological awareness that, although we cannot predict social phenomena, we must attempt to understand underlying mechanisms governing social phenomena by modelling nonlinear social interactions. Several studies have shown the profitable use of nonlinear dynamical models (non-linear equations) in formalizing human interdependences and describing discontinuous processes of social change (population's evolution and market instability, voting and electoral shifts, arms race, crime dynamics, non-compliance and coercion relationship, urban growth, spread of innovations, marital instability, authoritarian attitude; political revolutions, suicide behaviours [36-43]. Many of these studies found that social systems present a bounded development process. In this process, human interdependences are structured according to a non-linear logic of the *logistics* type, which expresses the interplay among factors that promote growth and factors that act as restraints. This simple non-linear differential model, which appeared to be the rule in social systems [44], contrasts the idea of a regular linear or exponential trend (expression of the cause-effect constant proportionality logic) and can result in unpredictable outcomes of social interaction relationships and irregular and instable trends of social change process (even chaotic processes). Its use in the Social Sciences is highly pervasive. Every time a social phenomenon has been studied from a possible non–linear perspective, the Logistic map – just because it is able to include regions of predictable behavior, regions of chaos and transitions between such regions - appeared to be the most suitable for modeling its behavior and for reconstructing its underlying governing mechanism. The discovery of this *regularity* is of relevant consequence for the Social Sciences. We can say that the Logistic map *is* the structure of a non-linearly oriented social phenomenon.

Sociology has shifted toward Complexity. Even Psychology has found in Complexity a valid support to reflection on classic issues such as micro-macro relationship and change issue. The affirmative answer to the question whether there are principles of cognition which cannot be reduced to the action of neurons within the brain has projected Psychology toward Complexity. Basic traits of complex adaptive system concept and Nonlinear Dynamical Systems – anti-reductionism, self-organization, sensitivity to initial conditions, entropy, attractors, bifurcation, deterministic chaos, catastrophes, balance between flexibility and stability, differentiation and connession at the edge of the chaos – are revealed far better equipped to face key questions that Psychology and Psychotherapy are concerned. *Synergetics (or Self-organization Theory*), the interdisciplinary field of research on nonlinear dynamics in interacting subsystems and, therefore, the study of how complex processes unfold over time, dealing with self-organization, has become a fruitful paradigm in Psychology and Psychotherapy [45]. The idea that order parameters characterize macro behavioural patterns that may undergo discontinuous and spontaneous changes or *phase transitions*, leading to new features such as synchronization (coordination) or chaos, has stimulated a broad variety of research on neural and mental processes, cognition and emotion, mind-body interaction, pain management, human resilience, synchronization, (coordination) and how to conceptualize psychotherapy. Psychological change processes have showed all important features of non-linear systems – self-organization, discontinuous and spontaneous change processes, non-stationary phase transitions, critical instabilities, emergence, and nonlinear coupling between patient and therapist and even deterministic chaos [46-48]. As Schiepek says, for dynamical phenomena as human development process, human change processes, learning, cognitive, perceptual, affective processes, the dynamics and prognosis of mental disorders, problems manifesting in social systems such as couples, families, teams, or the question of how psychotherapy works, "self-organization is ubiquitous" [46, p.131].

So, even Psychotherapy is shifted towards Complexity. In recent years, in the light of complexity of psychological change processes, research in psychotherapy point toward the nonlinearity of therapeutic processes as a complex system (discontinuous changes in psychotherapy instead of linear incremental gains), where small interventions can result in large effects and vice-versa. Both the classical idea that psychotherapeutic effects are ascribed merely to linear or damped proportionalities between interventions and outcome (linear input-output mechanism of therapeutic actions) and, consequently, the idea that input from the therapist should determine the client's output have been disputed in favour of a circular causality of psychotherapeutic self-organization [46, p.131], a nonlinear, emergent and spontaneous change process rather than a mere, linear, reaction to certain "interventions" from the outside. Today, Psychotherapy focuses on the interactional process between therapist and patient and acknowledges that they produce emergent qualities, unfolding in a dynamic and interactively ever-changing context. So, the new conceptualization of Psychotherapy in a framework of complexity configures as support to self-organizing process of bio-psycho-social systems, that is, a dynamical realization of conditions supporting for the patient's own self-organization processes. These processes underly the enhancement of capacities of patient and are interpreted as cascades of order-to-order transitions prepared by critical to instabilities (bifurcations) in temporal proximity of pattern transitions. The central assumption of Synergetic that spontaneous and discontinuous changes or pattern transitions are prepared by critical instabilities as well as the assumption that stable boundary conditions are prerequisites for such transitions have been empirically corroborated, confirming synergetic conceptualizations of how psychotherapy works. Indeed, studies concerning control or driving parameters of change in therapeutic processes to be supported by the therapist (factors such as emotional involvement, activation of resources, or working intensity) have found positive empirical evidence, as well as studies regarding the impact of a stable relationship between client and therapist on producing solid boundary conditions allowing for a destabilization (self-organized criticality) and a re-stabilization of processes [49].

Non-linearity and self-organization have enriched the conceptualization of psychological-psychotherapeutic changes. And new methodologies and technologies of analysis are continuously evolving.

Tools for nonlinear dynamic system analysis**,** measure of entropy, critical transitions, fractal structure, algorithms for the estimation of dimensional complexity and deterministic chaos (e.g. Kolmogorov-Sinai-Entropy, Lyapunov Exponents) are used in each of the specific topic areas of psychology, including clinical psychology and industrial-organizational psychology [48]. Villmann et al. [50] generated an entropy model of psycho-physiological variability detecting emotionally unstable phases during the therapy process which was related to the dramatic value of speech analysis according to the cycle model of Mergenthaler; Lichtwarck-Aschoff et al. [51] used the entropy markers in order to identify critical instabilities in therapeutic change processes of mother-child interaction dynamics.

Synergetic Navigation System, an Internet-based process monitoring for data acquisition and time series analysis, allows for visualization of the characteristics of nonlinear dynamics and therapeutic self-organization, identification of stable periods, attractors, bifurcations, self-organizations or phase-transitions associated with critical instabilities (i.e. the investigation of phase-transitions of brain activity and related subjective experiences of patients during their psychotherapy process; (e.g. [49]) by patients with obsessive-compulsive disorder in a hospital ward), the assessment interpersonal relations by a dynamic interaction matrix tool for dyads (e.g. in couples therapy), families, groups, teams or organizations.

Nonlinear Equation has been used to model cognitive processes and therapeutic processes. A variant cubic of logistic map (the gamma function) is the mathematical model that is central to the new nonlinear psychophysics. Mathematical Ginzberg-Landau model of phase transitions (a potential function for the cusp catastrophe model) is used in the perception area and has been useful for modelling the organization of motor response patterns and speech configurations in addition to strictly perceptual phenomena [52]. Learning processes are modelled by nonlinear curves, able to stabilize in a fixed point attractor if the self-organization process is complete and flows in chaos in the event that learning is incomplete [52]. Mushroom catastrophe is useful to explain the dynamics of creative production in problem solving groups [53]. In this regard, using nonlinear regression techniques for estimating the Lyapunov exponent, Guastello found high dimensionality and instability. According the author, as creative self-organized systems engender more instability, "it would follow that creative problem solving groups are systems operating at the edge of chaos" [53,54]. Based on assumptions of Synergetic, coupled dynamic consisting of a periodic driver and a chaotic slave model spontaneous process of creative production in problem solving groups [54]. Nonlinear equations model synchronization processes (e.g. synchronization of emotions and connection between group synchronization and work team performance [55] and therapeutic processes [48]. Several simulation studies are in progress. Recently, a model which integrates variables acting as order parameters of the state dynamics of patient (intensity of emotions, problem intensity, motivation to change, insight and new perspectives, therapeutic success) in a set of five coupled nonlinear difference equations has been simulated by drifting control parameters (working alliance and quality of therapeutic relationship, cognitive competencies of mentalization and emotion regulation, behavioural resources and skills for problem solving, and motivation to change), in order to identify critical instabilities and transition-points in psychotherapeutic self-organization process and compare model's emergent dynamics to observed clinical processes. The model has produced multiple types of dynamics, as fixed-point-behaviours, simple or more complex cyclical patterns,, and critical slowing down near transition-points [56].

A New Way of Thinking about Predictability

Nonlinear dynamical analysis and nonlinear modeling for identification of critical threshold and transition points introduces a second implication, regarding predictability issue.

We might ask whether insisting on Complexity and Chaos is actually a waste of time: Is not 'losing' oneself on the study of non-linear analytical instruments, only to come to the conclusion that the phenomena is…unpredictable, vain? [17]. In reality, the study of complexity teaches us *a* new way of conceiving predictability. While it is true that we often are unable to forecast the evolution of a given phenomenon, the study of non-linear dynamics and chaos allows us to 'predict' what the conditions are in which a certain type of dynamic behaviour occurs. So, for example, we may not be able to accurately predict the evolution of a certain biological population, or the spread of a disease or the effects of an invention, the outcome of elections or social competitions, or the productivity of companies, however we may be able to know *at what conditions (at what parameter values)* a certain population becomes extinct, a disease disappears or reaches a stationary cycle or evolves in a completely random manner, a firm goes bankrupt, a political system becomes unstable, a war breaks out, or a group takes over another group. Now, this type of knowledge is very important for intervention policies (social or non) as much as the exact knowledge of future system evolution. In fact, an acquisition stating that natural or social systems are in a chaotic situation or in a transition zone, approaching chaos, by specifying the critical threshold where our possibility to control the event completely disappears, does not seem at all trivial. Having to avoid such a danger, knowing the critical threshold point at which a phenomenon goes into a chaotic regime is an absolutely precious information. By being aware of this threshold, it would be possible, for example, to plan eventual interventions so as to keep the system away from limit situations and as close to stable situations as possible. In other words, it is more important to know the level below which water pollution must be kept, avoiding fish population's erratic evolution until it becomes extinct, rather than knowing the exact number of fish in a lake.

Naturally, we are not implying that instability is always 'necessarily negative' nor that stability is always 'necessarily positive'. In medicine, for example, there are cases where chaotic instability and not stability, is the indicator of a healthy organism (heart beats, neuronal activity, etc.). Likewise, from a political point of view, stability is not always expression of a socially desirable situation, such as in the case of authoritarian regimes. We are saying that Complexity Theory, resolving order and disorder within the context of the same working deterministic mechanism, opens to the Natural and Social Sciences innovative perspectives. Concepts such as 'stable system', 'unstable system', 'return to stability', 'system crises', can finally be devoid of the metaphorical, intuitive meaning which they are usually used and find a way to possible empirical investigations. This possibility is just ensured by the parameter estimation of the non-linear deterministic mechanisms (equations), with which describe and explain the developments of given natural, social and psychological-psychotherapeutic phenomenology as aggregate results of local interactions: at certain values, each one analytically determined and determinable, we can verify empirically whether the system is steady or whether it is about to pass from order to chaos.

In conclusion, we cannot see any reason to consider the study of tools that allow us to achieve these above mentioned acquisitions a waste of time. Within the framework of the Social Sciences, for example, it is difficult not to agree with statements like those of Elliott and Kiel [57], according to which "by better understanding the confluence of chance and determinism in social system evolution we may we better learn when and how to direct policy responses".

For further clarification of this point, let us apply this argument to a social phenomenon like non-compliance-coercion relationships already quoted above, where the relationship is modeled according to prey-predator model a logistic structure. The study of this model tells us that at k values under 3.8-4 crime variability remains in a situation of possible controllability. In this situation any intervention aimed at influencing the system's current trend (in this specific case, assure a decrease in crime) can produce expected outcomes. Obviously, we need to avoid the situation from falling into a chaotic range and it is always the model which indicates that this can happen if the k value reaches 3.8-4. This value marks an alarming loss in predictability and therefore in control. It would be impossible, in fact, to predict what would happen in this case. Note, we are not saying that we would not know what to do in such a situation – or what line of intervention to take. We are saying something much different, namely that social phenomenon flowing into chaos produces absolutely unpredictable outcomes for any intervention adopted. It has been shown that if the crime rate reached this value, flowing into chaos, it would pull law enforcement agencies into chaos as well. In conclusion, the galloping, uncontrollable rise in crime would disorganize any form of intervention able to adapt the police force and their work to such an uncontrollable increase in crime. For instance, a law enforcement agency may increase the number of police officers but we have no idea what the outcome will be. Thus, measures taken to reduce crime might have a completely opposite outcome; they may produce even a rise in crime rates or an actual fall in these rates. The problem is that we are unable to predict what outcome will emerge. Priesmayer [36, p. 333] provides us with an exemplifying case, regarding cocaine use in the USA from 1985 to 1990. In his investigation, the Logistic equation fits cocaine use with a value k of 3.6, dangerously close to the critical threshold of 3.8, a value inducing the author to the following disarming conclusion:

Put simply, actions which decrease current use may contribute to higher future use or they may not; actions which contribute to higher current use may contribute to lowering use in the future or they may not. […] Does it suggest that […] attempts to lower cocaine use by aggressive intervention are far less certain? If cocaine use is not controllable in this way, what then is to be used to control cocaine use?

In brief, no one is able to define the terms of a scenario. Or rather, any type of scenario is equally possible. Possible scenarios might mirror films such as Escape from New York or on the contrary, film series where enforcement agencies become powerful managers of criminal enterprises. In an extreme case (not so extreme if we judge by current situations), crime agencies and police could form alliances creating strange symbiotic phenomena. This idea is suggested by the situation in Russia. The rise in the crime rate led to a rise in police enforcement, yet the reduction of crime was not forthcoming but there was more and better orchestrated collusion and corruption. In this scenario, it is not rhetorical to ask where crime control efforts will end up and what line of action to take against noncompliance.

To avoid similar dangers, I repeat that it is absolutely important to know and, therefore, to be able to *predict* the threshold of chaotic behavior for a social science researcher. Consequently, the study of models of nonlinear dynamical systems suitable for attaining this knowledge is also of prime importance.

Referring to Saperstein's studies [37], for example, by using a simple bilateral logistic model, the author estimated that it would be sufficient to have a parameter over to 1 in one of its equations for a transition into chaos or in other words the break out of war. It is evident that this knowledge can give a significant contribution to any peace oriented policy, by controlling that the arms build-up stays below the critical threshold level. Saperstein did not only limit himself to a 'theoretical' study, but provided empirical examples. He analyzed the arms race of different couples of European nations during 1936-37 and between the USA and the URSS in the 70s and 80s. It was ascertained that the relationship between Nazist Germany and the Soviet Union were within "a chaotic region" (a=1.34, b=0.0657): in fact, this case history has shown us the intrinsic uncertainty connected to a state of war. In US and URSS relations, the chaotic region was instead only touched.

In Psychology, Gottman et al.'s study on marital relations [40] is also relevant. It presents these relationship as a discontinuous process (both stable and prone to catastrophe), and analyzes this discontinuity applying a nonlinear model using difference equations. He used couples' perceptions about their marriages and each other to model marital stability or divorce. The model indicates the threshold beyond which a marriage is expected to break up.

Actually in Psychology and Psychotherapy converging methods for the identification of critical transitions seem to be available, in order to develop a deeper understanding of discontinuous and self–organizing dynamics in human systems.

Order transitions or critical instabilities can be measured and analyzed during on-going psychotherapy processes and used for an adequate placement of interventions, by controlling self-organization processes, that is, by generating together with the patient adequate boundary conditions and supporting spontaneous change dynamics [49]. Today, there are many studies have explicitly examined the nonlinear and non-stationary dynamics of a complex therapy system (for some of these, see previous citations). Entropy models have been generated to identify critical instabilities in therapeutic change processes. Recurrence Plots seem to be a very useful instrument for the visualization and quantification of critical instabilities and order transitions in human change processes. Transitions occur at a specific threshold of the control parameter value. Research work on control parameters and precursors of critical instabilities as well as on nonlinear equation modelling of interaction structure among order and control parameters allows for identification of critical threshold values of parameters driving self-organization processes. This analysis and the measurement of critical instabilities by local maximum of dynamic complexity during the therapy process are profitable for adaptive therapy planning. This is a very important aspect for psychotherapeutic treatment effectiveness monitoring as well as for prevention (e.g. suicide prevention [58]). And this can be considered a new type of predictability.

To conclude, from a heuristic point of view there is more than one valid reason to support the use of non-linear instruments in social system analysis.

Conclusion

Complexity challenges us about the nature of reality, about the real behaviour of systems, physical, inorganic systems as well as living, human, social and mental systems. It raises questions that cannot be liquidated merely by thinking that acquisition of concepts such as emergence, surprise, and unpredictability are really *sic et simpliceter* only alibis to hide our scientific failures. Dissipative structures have shown the *creative* role of time, and how instability, emergence, surprise and unpredictability are the rule and not the exception when we move away from equilibrium (entropy). This is the meaning of the *New Alliance* that Prigogine has handed down to us.

The *New Alliance* does not allude to the acquisition of a unified theory encompassing Politics, Economy, immune systems, Physics and Chemistry. For Prigogine, progress in the field of chemical reactions far-from-entropy (equilibrium) cannot provide us with the key of Psychology, Sociology, and Politics. Therefore, the New Alliance alludes to the bridge that the *new* science has built between the Natural Sciences, which have always described nature as a result of classic science deterministic laws, and humanistic disciplines, tending to underline man's freedom and the emergent, surprising historicity of its social realizations, thus ensuring the celebration of nature's re-enchantment. On this latter point, we might perhaps object to Prigogine [1], as does Horgan [17], that it is not easy to understand in what way the vision of an unpredictable, uncertain, even if re-enchanted, world is more comforting than the scientific vision of a predictable, timeless, deterministic world, However, if we separate judgments of fact from value judgments, the sense of the new alliance goes much deeper. On the level of judgment of fact, it defines the foundation of a new way of looking at and knowing the world, in light of criteria that constitutes a unifying element of our conception of the universe, even beyond its recognized systemic diversity. Self-organization and nonlinearity, bifurcations, irreversibility, evolution, historical dimension, emergence and surprise meet at all levels, are *ubiquitous* in physical, psychological, neural, mental, and social change processes, and provide the basis for a new way of thinking about systems. Today, Complexity and Chaos Theory shows the gap between physical science and social science to be highly artificial, redeeming the human sciences from being in a position of scientific minority, or, as Elliott and Kiel would say [59], in a position of scientific stepchild compared to the so called hard Sciences.

Thus, complexity poses a challenge for future research, projecting it in completely new theoretical and methodological areas, redefining the meaning of Science and its objectives, and introducing a new conception of predictability and control on events. Today, adopting complexity perspective means focusing on modelling nonlinear interaction structure in order to understand the interplay between order and disorder, and to predict and control *when* a system stabilizes, changes its state, passes in a new self-organization state, or falling into chaos. Borrowing Stewart's famous sentence [60], "God can play dice with the world and at the same time creates a universe totally dominated by laws and order". So, a new mathematical landscape emerges, where it no longer makes sense "to ask whether God is playing dice with the world but rather what the rules of His game are".

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