From the revolution of the complex to complexity thinking

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A first version of this book was published on line in French in march 2016 (*la révolution du complexe: sciences, dialectique et rationalité* www.revolutionducomplexe.fr). The present version is suite renewed and increased.

The translation of the present version does not include the glossary. The citations are given in French, and I did translate them in foot notes (so it may happen that I had to translate into English a text from a French translation from English).

This second version owes a lot to the numerous discussions that took place around the lecturesI have been givingsince the first version, with a special mention to Anne Frédérique Paul and Véronique Thomas-Vaslin and Michel Thellier.

Introduction

Notre tâche consistera à appliquer la méthode du matérialisme dialectique et la conception du processus historique créées par Marx, à une analyse de la genèse et du développement de l'œuvre de Newton en relation avec l'époque à laquelle il vivait et travaillait (Boris Hessen[1])

For several years I have been wondering about recent developments in science in the fields of the complex. I am challenged by the difficulties encountered by concepts related to the complexity to be disseminated in the various scientific disciplines despite their innovative scope, as well as by the difficulties that even some of the actors in these developments have in realizing that they lead to a change in the way of thinking, in science as in everyday life. Indeed, since the 1970s, authors have published books for researchers and the general public, emphasizing the importance of these developments, which can be described as a scientific revolution, and their influence on mindset. In vain, it seems! The obstacles must be significant and multiple. The approach developed by Boris Hessen seemed to me likely to answer my questions, by placing these scientific evolutions in the various contexts where they developed. What is it about?

On the morning of Saturday, July 4, 1931, in a room at the London Science Museum, an additional session of the Second International Congress on the History of Science was devoted to the ten presentations of the important Soviet delegation. Devoted is an understatement for everything was done for these presentations to be sloppy, little listened to, and perturbed. It was thanks to the help of the English communist scientists that they were translated hastily into English and published a few days after the session in a book entitled *Science at the Crossroad*. Yet at least one of them, *the social and economic roots of the Principia of Newton*, presented by the Soviet physicist and philosopher of science Boris Hessen[2], was to have a broad and lasting repercussion. It has been translated, commented, and published in French recently.

In the introduction to this edition Serge Guérout distinguishes three theses in Boris Hessen's presentation the first of which was to be selected and developed later, mainly by historians of science. It stipulates that the evolution of the sciences is profoundly linked to the structure of the productive forces, and therefore to the economic context in which they are practiced. Thus, the great Newton owes less to the apple than to the questions raised by the rising bourgeoisie, questions accumulated through the practices essential to the development of trade and nascent industry: all of them beeing mechanical problems. « *Ce bref compte rendu des « Principia » montre la coïncidence*

1 Boris Hessen, *Les racines sociales et économiques des principia de Newton*, translation and comments by Serge Guérout, Vuibert, 2006, p73. *Our task will consist in applying the method of dialectical materialism and the conception of the historical process created by Marx to an analysis of the genesis and development of Newton's work in relation to the period in which he lived and worked*

2 Boris Mikhailovich Hessen (1893-1936), interrupted his scientific studies to join the Red Army, then resumed them later and became head of the Physics Section of the Communist Academy of Sciences while having an intense activity in what we would now call Popular education. But political struggles tore Soviet physicists, mixing Stalinist science, career and ideology, and Hessen suspected of his attachment to modern physics theory was arrested and sentenced to death in December 1936 at the end of a "trial" where he was accused of being a member of a terrorist organization affiliated with the fascist gestapo.

parfaite entre les thèmes de la physique étudiés à cette époque, nés des besoins de l'économie et de la technique, et le contenu principal des « Principia »[3] This thesis is in keeping with the Marxian tradition set out in l'idéologie allemande: *" « Mais où seraient les science de la nature sans l'industrie ni le commerce ? Car même ces sciences "pures" répondent à un objectif que leur assigne le commerce, l'industrie, l'activité matérielle des hommes, et elles en reçoivent leurs matériaux»*[4]

The second thesis deals with the importance of the ideological context. The ideology of the scientists, in relation to times and social conditions, plays an important part in their discoveries. Newton's ideology, "*typical representative of the rising bourgeoisie*" in the England mid-seventeenth century, was the result of a religious and political compromise between the former feudal proprietors and this rising bourgeoisie, resulting in a constitutional monarchy, and some religious tolerance. This compromise has a philosophical translation, obvious in Newton's case, between materialism and idealism, a philosophical translation that has a direct bearing on its scientific theories. « *Cette caractérisation idéologique de Newton, qui était un enfant de sa classe, explique pourquoi les germes matérialistes cachés dans les Principia ne se développèrent pas chez lui en une structure pleinement formée de matérialisme mécaniste analogue à la physique de Descartes, mais se mêlèrent à ses croyances idéalistes et théologiques au point de reléguer au second plan, lorsqu'il était question de philosophie,...les éléments matériels de sa physique* [5]*»*. For Newton, it was the hand of God that was necessary to the movement of matter, unlike Descartes, who puts mechanical motion among the properties of the matter. *« Cette « division du travail » entre Dieu et la causalité, unique en son genre dans le gouvernement de l'univers, était caractéristique, chez les philosophes anglais, de l'imbrication des dogmes religieux et des principes matérialistes de causalité mécanique* [6]*»*. This thesis contains both an analysis of the influence of his class on Newton's ideology and an analysis of the philosophical positions of this scholar in the context of the opposition between materialism and idealism in his time.

The third thesis, often forgotten or misunderstood, insists on the usefulness of the materialist dialectic to understand that matter can be fully conceived only in what Hessen designates as its

3 *ibid.* p116. *This brief account of the "Principia" shows the perfect coincidence between the themes of physics studied at that time, born of the needs of economics and technology, and the main content of the Principia*

4 Karl Marx, Friedrich Engels, *L'Idéologie allemande*, 1845. french translation.H.Hildenbrand, Nathan, 2008 p 49. *But where would the science of nature be without industry and commerce? For even these "pure" sciences respond to an objective assigned to them by commerce, industry and the material activity of men, and they receive their materials from them*

5 Hessen *op.cit.* p129. *This ideological characterization of Newton, who was a child of his class, explains why the materialistic seeds hidden in the Principia have not been developed by him in a structure fully formed of mechanistic materialism analogous to Descartes'physics, but were mingled with his idealistic and theological beliefs to the point of relegating to the background, when it was a question of philosophy, ... the material elements of its physics "*

6 *ibid.* p 130. *"This" division of labour" between God and causality, which is unique in the government of the universe, was characteristic among the English philosophers, as the interweaving of religious dogmas and the materialistic principles of mechanical causality.*

movements and which we would now call its transformations. In contrast to Newton, or even to Descartes, who thinks that "*toutes les variétés du mouvement se résument à la transposition mécanique […] le grand mérite d'Engels réside dans le fait qu'il considérait le processus du mouvement de la matière comme un éternel passage d'une forme de mouvement de la matière à une autre »*[7]. This thesis is based on the transformations of energy that is, for Friedrich Engels one of the keystones of the dialectics of nature. « *Le matérialisme dialectique considère que la tâche principale d'une science de la nature est l'étude des formes du mouvement de la matière dans leurs relations mutuelles, leurs correspondances et leur développement. »*[8]. The Principia appears here only as a thesis by default, (wrote S. Guérout) insofar as the state of development of the steam engines in Newton's time had not yet led physics to become conscious, therefore to seek to account for, the transformations of energy. The dialectical understanding of nature also requires a certain state of advancement in scientific techniques and knowledge, hence a certain economic and epistemological context. This thesis shows that a Soviet scientist has been able to rely on a dialectic of nature, not to impose a theory as Lysenkoism would do a dozen years later, but to give some sort of specification, a roadmap to science: "*study the forms of movement of matter*".This roadmap does not say anything about the value or truthfulness of the theory of relativity, but it legitimises the research that led to its discovery, giving some kind of palatability for this research. This was obviously very important for Hessen, who, being a proponent of quantum mechanics as well as of the Einstein's theories of relativity, had been exposed to the sarcasms of the Soviet mechanistic physicists of his time (who called him a dialectician, and were not evicted until 1929). But in 1931 he was already beginning to be mistrusted by the Stalinist ideologues, who accused him of Menshevist idealism and criticized him, among other things, for not using dialectic in a normative way.

In spite of the rather incredible conditions in which the communications of the Soviet delegation took place, Hessen's statement seems to have got an important and lasting echo, albeit mostly indirect, since Hessen himself, who was to be murdered in the Stalinist jails five years later, was relatively forgotten, at least in France, until this recent publication. This short text illustrates in a powerful way the contribution of a materialistic and dialectical way of thinking applied to the study of the multiple facets of the evolution of sciences.

Curiously, however, many of the texts on the history or epistemology of science, even from scientists or philosophers claiming to follow Marx's thought, have focused on only one of these three aspects. With exceptions of course. The French mathematician Paul Labérenne, best known

7 *ibid.* p137. *"all the varieties of movement are summed up in mechanical transposition ... the great merit of Engels lies in the fact that he considered the process of the movement of matter as an endless passage from one form of motion of matter to another "*

8 *ibid.* p147. "*dialectical materialism considers that the principal task of a science of nature is the study of the forms of the movement of matter in their mutual relations, their correspondence, and their development.* ".

for his work *L'origine des mondes* (1937), also wrote an article entitled *Les mathematiques et le Marxisme,* in which the three theses of Hessen seem to be present « *Sur la nécessité, pour les mathématiques, de conserver et de renouveler leurs contacts avec le réel. Le marxisme ne se contente pas de donner l'explication de l'évolution historique des mathématiques en fonction des conditions techniques, économiques et sociales dont elle dépend, il permet aussi d'analyser le mécanisme même du cheminement de la pensée scientifique par crises et synthèses successives, et d'orienter le sens de nos recherches»* [9]. More recently, Simone Mazauric studied *« l'émergence de la science moderne dans sa dimension purement théorique et dans sa relation, pour l'essentiel, avec l'histoire culturelle, politique et sociale de l'Europe »* [10] Marx himself, notwithstanding his great interest in the sciences of his time[11], has not written much on the subject, and has mostly considered science as far as its results are incorporated in the productive forces, in a specific manner « *...la condition préalable pour l'industrie est une science assez ancienne, la mécanique, alors que la condition préalable pour l'agriculture, ce sont des sciences tout à fait nouvelles : chimie, géologie, et physiologie*»[12]

More recently, the studies on the relations between science and society, corresponding to the first thesis of Hessen, were mainly carried out by historians of the sciences of the *externalist* school. However, they have become more interested in society in general, which operates as an overall explanatory factor from which any Marxist dimension is evaded (no reference to the division of society into classes in particular, nor to the economic dimensions and the concept of productive forces)[13]

The third thesis is based on the works of Engels and deals with the relations between materialist dialectics and natural sciences. The tormented history of the relationship between science and dialectics requires some attention. Twenty years before this congress, Lenin had already intervened, relying on the dialectics of nature to counter idealistic positions among Russian

9 http://www.philosciences.org/notices/document.php?id_document=2133. "*On the necessity, for mathematics, to preserve and renew their contacts with reality. Marxism does not merely give an explanation of the historical evolution of mathematics according to the technical, economic and social conditions on which it depends, it also allows us to analyse the very mechanism of the path of scientific thought through crises and successive stages of syntheses, and to guide the direction of our research* "

10 http://poincare.univ-nancy2.fr/Presentation/?contentId=4421. "*The emergence of modern science in its purely theoretical dimension and in its relationship, essentially with the cultural, political and social history of Europe*"

11 *Lettres de Marx et Engels sur les sciences de la nature.* Éditions Sociales, 1973.

12 *ibid.* p22."*... the prerequisite for industry is a rather old science, mechanics, whereas the prerequisite for agriculture are entirely new sciences: chemistry, geology, and physiology*"

13 *To illustrate the opposition between internalism and externalism, one often takes as an example the history of quantum physics at the beginning of the 20th century in Germany. For the internalists, the rise of quantum physics was exclusively determined by internal factors. The improvement of observation techniques and the improvement of mathematics have led to the reformulation of postulates and theories that were better adapted to the understanding of quantum phenomena. For the radical externalists, none of this is true. The elaboration of indeterministic physics was in fact mainly due to the abandonment of the notion of causality and rationality, the causes of which must be sought in the defeat of the rationalist values of post-war Germany. It was the same in Art, where the rise of the Dada movement meant a critique of rationality. Physics thus becomes impregnated during this period of profound anti-rationalist ideological developments which affect Germany* "source Wikipedia.

revolutionaries. What was called the crisis of physics, which Lenin described as a growth crisis, corresponds to the multiple discoveries which, from the second half of the nineteenth century, profoundly transformed this discipline, and which, more recently, was characterized as a scientific revolution by T. Kuhn[14]

These transformations, which introduce new concepts conflicting with the preceding scientific paradigms, undermine the representation of matter as fixed, independent of its motion, or reduced to movements of translation. Lenin showed, as Engels had foreseen, that a materialistic conception had to become dialectic to allow these transformations to be thought of. The philosophical significance of the work Lenin wrote in 1909 far exceeds the polemic that has aroused it[15], as analysed in the recent work *Lenin epistemologis*t[16]. It shows the profoundly idealistic character of empirio-criticism, as well as of agnosticism: it is, therefore, first of all an ideological struggle against the spread of idealism[17] even among revolutionaries. On the basis of Engels' work, but in the scientific conditions of the beginning of the twentieth century, he reaffirms philosophical materialism (in which the category of matter signifies the existence of matter previous to the mind), and shows how the materialist dialectics makes it possible to envisage the external world as knowable, by successive approximations[18]. Hence he deduces that knowledge itself, instead of tending towards something fixed and definitive as many scientists and philosophers[19] see it, is by nature the place of constant transformations.

Communist scientists[20], contemporaries of Hessen, were, for their part, interested in the materialistic dialectics of Engels' writings. The great British biologist JBS Haldane has for 20 years

[14] Thomas Kuhn, *The structure of scientific revolutions*, (1962) . He marked the way of representing the development of the sciences. *Normal science* is essentially meant to deepen and consolidate a paradigm, but gradually accumulates anomalies until the paradigm has reached its limits and has to be replaced by another. This happens in a process that he calls a *scientific revolution*. Very useful, his theory is limited however to a battle of ideas, the confrontation of the paradigms in competition for the replacement, the one who wins being the one that ultimately carries the best conviction. By removing the relation of the sciences to the real, to the material world, Kuhn underestimates the persistence of the old in the new paradigm, the fact that the old paradigm often becomes a special case of the new, as the Newtonian theory becomes a case of the new physics. But above all he rejects the materialistic idea that scientific knowledge is continually (though non-linearly) related to an absolute truth, corresponding to the state of the existing world independently of the men who study it. The term "scientific revolution" is currently contested, and is generally put in quotation marks, which I shall omit in the remainder of this text.

[15] This polemic was mainly directed against the philosophical ideas of Alexander Bogdanov, who, ironically, is now considered as one of the precursors of the complexity sciences.

[16] Lilian Truchon. *Lénine épistémologue* , Delga, 2013.

[17] I always use this term in its philosophical sense (where it is opposed to materialism) and not in its current (moral) sense in which it opposes pragmatism, egoism, individualism.

[18] He thus exposes his theory of the reflection of the world in knowledge being a relative truth, gradually approaching (without perhaps ever reaching it) the absolute truth.

[19] The French mathematician René Thom, used to say that *« la science vise à constituer un savoir sur lequel le temps n'a plus de prise »* (*science aims at constituting a knowledge on which time has no more hold)* in *Halte au hasard, silence au bruit, le Débat* N°3, Gallimard, 1980.

[20] Although I generally claim the use of "scientist" to designate researchers from all disciplines, I will limit myself here to a brief overview of the use of Hessen's concepts only in the context of the so-called exact sciences. since the impact of Marxism on the social sciences was very important at least until the 1970s, it is not possible for me to make a review here.

linked his practice of biology (evolutionary genetics) and his political practice as a member of the English Communist Party to Marxist materialism. Simon Gouz has studied how JBS Haldane has found in the materialist dialectics (and described in several articles), a solution to his uneasiness in relation to the two opposing epistemological conceptions, reductionism and holism. Gouz also showed how Haldane was able to draw inspiration from this conception (in particular of the dialectics of chance and necessity, as well as the individual and the collective) to develop his work in population genetics[21]. For his part, the French biologist Marcel Prenant gives in his book *Marxisme et biologie* a beautiful illustration of what one might call the *dialecticity* [22] of biology, including the genetics he defended against Lysenko, (whom he tried however not to challenge what he believed at the time to be his experimental results).

And then it was the drama of the so-called Lysenko case. Much has been written on this subject, I will shortly recall this sad story. Lysenko was a Soviet agronomist, who developed a theory of the heredity of acquired traits in plants, from which he claimed, on the one hand, to improve Soviet agriculture (which subsequently proved to be a real catastrophe), and on the other hand to reject genetics and neo-Darwinism, in the name of what he called the "laws of dialectics." Genetics had shown that transformations undergone by organisms under the influence of environmental changes are not hereditarily transmitted. For Lysenko, who claimed that he had succeeded in transforming plant species by environmental changes, genetics, which he described as "Mendelo-morganism"[23] from the names of it's first two principal promoters, would thus have opposed these "laws". By not recognizing the fundamental influence of the external environment, genetics had to be false! And as Mendel was an Austrian religious and Morgan an American scientist, genetics was easily referred to as "bourgeois" science, which was opposed by the Lysenko's Soviet theory which, in conformity with these "laws of dialectics" was declared "proletarian science ". Lysenko's theory was the basis of gigantic Soviet agricultural plans, the disastrous results of which demonstrated it's inanity. But, supported by Stalin, who used him in his struggle against Soviet intellectuals (with the elimination of geneticists in particular), Lyssenko became president of the Academy of Sciences, and after 1948, the absolute master of Soviet

[21] Simon Gouz studied this aspect of the activities of Haldane during his thesis, a work which gave rise to two books: *J.B.S. Haldane Biologie, philosophie et marxisme Textes choisis d'un biologiste atypique Traduits et présentés par* Simon Gouz, Éditions Matériologiques, 2012 ; et *La science et le marxisme* Édition Matériologiques, 2012 .

[22] Lucien Sève et alii, *Sciences et dialectique de la nature, La Dispute,* 1998 , p164.

[23] Gregor Mendel (1822-1884), a Czech monk, discovered the laws of genetics by crossing varieties of peas. He proposed the concept of gene, then seen as an 'entity' of unknown nature. His works, initially ignored, were rediscovered at the beginning of the 20th century by several scientists who recognized it's purport, hence the terms of Mendel's laws and Mendelian genetics. Thomas Morgan (1866-1945), an American geneticist working on the Drosophila fly, showed that genes are localized on chromosomes, structures in the nucleus of cells, whose chemical nature was unknown at that time. It was not until 1955 that DNA was proved to be the support of heredity. Darwin obviously did not know all this, and he did not pronounce on the nature of the modifications which natural selection should retain or reject. He did not, therefore, reject the idea, defended by Lamarck, that these modifications might come from the action of the environment, a belief called the heredity of acquired characters, which was invalided (by Weissman) at the end of Nineteenth century. (extracted from wikipedia).

biology. Moreover, the Western communist parties also had to preach Lysenkoism, which resulted in the resignation of several scholars from those parties, including Haldane and Prenant (as well as Jacques Monod) around 1948. In France for instance *« les biologistes avaient à prendre parti pour les conceptions de Lyssenko, pour sa théorie de l'hérédité, faute de quoi ils se rangeaient ipso facto dans le camp des héritiers du nazisme...la mise en demeure ne s'adressait pas aux seuls biologistes, mais à l'ensemble des savants et intellectuels»* [24].

In the SSR, it was not only the death of Stalin, but also the departure of Krusev (in 1964) that allowed to remove Lysenko from his post at the Academy, although, since the mid-1950s, the failure of its methods has *de facto* led to a return to the traditional methods of agriculture.

The damage was considerable, both from the human point of view (geneticists driven from their laboratories, even imprisoned or murdered), as well as for the Soviet agriculture which suffered great catastrophes, not to mention the Soviet genetics which had to be reborn very late off its ashes. But another important victim of Lysenkoism was the materialistic dialectics itself, which was discredited for a long time by its falsifying instrumentation in this matter. This discredit quickly reached the whole materialist dialectics, be it nature's dialectics or historical materialism. « *Les décennies d'après guerre en France, avec les suites de l'affaire Lyssenko, puis le tout-structuralisme des années soixante, puis la vogue tardive du poperisme et de l'empirisme* logique, ont été sauf exception celles d'un profond recul de la naissante culture dialectique chez les scientifiques de la nature*[25] *"*. In France, some scientists (Pierre Jaeglé and Pierre Roubaud1[26], Efticios Bitsakis[27] and a few others[28]) were still trying to maintain this culture within the framework of the CERM4[29].

But shortly after 1968[30], dialectics began its crossing of the desert[31], including in the disciplines of human and social sciences where its influence had been intense. Then, after the collapse of the Soviet bloc, the neo-liberal wave and the "unique thought" swept away everything. It seemed that the dialectics of nature (like all Marxist thought) had lived, despite the tenacious but solitary

24 Dominique Lecourt, *Lyssenko. Histoire réelle d'une « science prolétarienne* , François Maspero, 1976.. P26. "*Biologists had to take sides for Lysenko's conceptions, for his theory of heredity, failing which they ipso facto stood in the camp of the heirs of Nazism... the demand was not addressed to Biologists only, but to all scholars and intellectual*s "

25 Lucien Sève *et alii. op.cit.* p108. *The post-war decades in France, with the aftermath of the Lysenko case, then the all-structuralism of the 1960s, followed by the late vogue of poperism and logical empiricism, were without exception, those of the retreat of the nascent dialectical culture among scientists of nature*

26 Pierre Jaeglé, *Dialectique de la nature : sur quelques concepts (qualité, quantité…)* in *Sur la dialectique,* Éditions Sociales, coll. CERM, 1977.

27 Efticios Bitsakis, *Physique contemporaine et matérialisme dialectique*, Éditions Sociales, 1973

28 *Epistémologie et marxisme*, Christian Bourgeois et Dominique de Roux editors, Le Seuil, 10/18, 1972.

29 Centre d'Étude et de Recherche Marxiste, research Institute of the communist Party (1960-1979).

30 *en 1972 la dialectique s'enfonce dans le silence public (in 1972 the dialectic sinks into public silence)* . Lucien Sève, *op.cit.* p14.

31 Isabelle Garo « *L'infâme dialectique » le rejet de la dialectique dans la philosophie française de la seconde moitié du 20e siècle.*https://www.academia.edu/29778210/_Linf%C3%A2me_dialectique_le_rejet_de_la_dialectique_dans_la_philosophie_fran%C3%A7aise_de_la_seconde_moiti%C3%A9_du_20%C3%A8me_si%C3%A8cle

resistance of some philosophers, among them Lucien Sève or Michel Vadée,[32] and in the USSR a Frolov (translated into french in1978) [33] who attempted to bring out biology and dialectics of the Lysenko's pit.

Over the past two decades, a renewal of interest in materialist dialectics has begun to emerge in the West[34], including philosophers of science (Gouz[35], Barot[36]) and scientists of nature. American biologists (Richard Levin and Richard Lewontin[37]) explicitly advocate dialectics, while the paleontologist Stephen Jay Gould[38] is inspired by it. In France, physicists Gilles Cohen Tannoudji, and Pierre Jaeglé[39], and a group of scientists from the University of Rouen[40], began again, around the philosopher Lucien Sève, to raise the glove of dialectics in the natural sciences, while others are engaged independently, such as the mathematician Evariste Sanchez-Palencia[41]. Can we conclude with Isabelle Garo « *En ce sens, je me risquerai à affirmer que la répudiation de la dialectique est la marque d'une séquence théorico-politique qui se referme. Et que le retour de la dialectique sera la preuve de cette affirmation et l'indice que s'ouvre une nouvelle séquence, réactivant un type d'analyse historico-politique qui intègre pleinement sa dimension politique constitutive*[42] » ?

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I propose here, as in Hessen's epigraphic quotation, to *apply the method of dialectical materialism and the conception of the historical process created by Marx, to an analysis of the genesis and development [*of the sciences of the complex] *in relation with the period in which they developed.* I will analyse the joint and interrelated roles of epistemology, economics, and ideology in the emergence and diffusion of complex sciences and concepts, as well as in the hindrance to their development. That is to explore in what way the use of materialism (dialectics and historical)

32 Michel Vadée, *Bachelard ou le nouvel idéalisme épistémologique,* Éditions Sociales, 1975.

33 L.T. Frolov, *dialecticss and ethics in biology*, Moscow, 1978. The author pictures a biology that is both dialectical and complex. Unfortunately, it is impossible to know whether he describes what science really was in the USSR at that time, or what the author advocated it to be!

34 *Dialectiques aujourd'hui* Bertell Ollman and Lucien Sève ed, Syllepse, coll. Espaces Marx, 2006.

35 Simon Gouz *op.cit.*

36 Emmanuel Barot D*ialectique de la nature : l'enjeu d'un chantier (-éléments pour un passage au concept)* http://michelpeyret.canalblog.com/archives/2016/02/25/33424430.html

37 Richard Levin et Richard Lewontin, *The dialectical biologist* 1987 by Harvard University Press

38 Stephen Jay Gould, The *structure of the evolution theory,* Harvard University press, 2002

39 Gilles Cohen Tannoudji, *La dialectique de l'horizon : le réel à l'horizon de la dialectique,* in Sève et *ali*i 1998 *op.cit.* p287 ; Pierre Jaeglé *Subjectivité et objectivité de la connaissance scientifique ibid.* p319 ; Pierre Jaeglé et Pierre Roubaud *La notion de réalité,* Éditions Sociales, 1990.

40 Lucien Sève *et alii, Émergence, complexité et dialectique* , Odile Jacob, 2005.

41 Eftichios Bitsakis *La nature dans la pensée dialectique,* L'Harmattan 2001, Jacques Bonitzer *Les chemins de la science,* Éditions Sociales, 1993 . Evariste Sanchez-Palencia, *Promenade dialectique dans les sciences,* Hermann, 2012.

42 *"In this sense, I would venture to affirm that the repudiation of dialectics is the mark of a closing theoretical-political sequence. And that the return of dialectics will be proof of this affirmation and an indication that a new sequence is opening, reactivating a type of historical-political analysis that fully integrates its constituent political dimension.* Isabelle Garo *op.cit.*

in its various dimensions enables us to enlighten this evolution[43]. But in doing so, I became aware that an important evolution of the mindset is at work in these disciplines, an evolution which I call the *complexity thinking*, which is close to materialistic dialectics and which calls a profound modification of rationality, coping with the transformations of the modern world. This emergence of a new way of thinking based on a scientific revolution, which itself is subject to major obstacles, is not self-evident, and here again, the Hessen method has proved invaluable in understanding the various contexts in which the relationships and differences between the revolution of the complex and the complexity thinking have developed

Since the last quarter of the last century, the complex has gradually spread in many scientific disciplines, in various forms, such as thermodynamics of dissipative structures, dynamics of non linear systems, the theory of chaos, Fractals, systemic, complex adaptive systems, complex thought ... Partial attempts at regrouping them have been made in the United States since 1986, with the *Santa Fe Institute of Adaptive Complex Systems*, and more recently in Europe and France, in national and regional *Institutes of complex systems*. The term sciences of complex systems tends to be generalized, in sciences and in the humanities, to designate approaches that involve the use and development of methods of modelling and simulation. For his part, Edgar Morin, in forging l*a pensée complexe (complex thought)*, has allowed the idea of complexity to penetrate the social sciences, independently of mathematics. I use the term *revolution of the complex*, to designate it as a scientific revolution according to Kuhn, capable of bringing about a paradigm shift in many disciplines[44], leading to a revolution / evolution of rational thought or mindset, which I call the *complexity thinking*. It was made possible by the advances in computer sciences and made necessary for the study of what was left behind by the previous paradigms. Having developed mainly since the last quarter of the twentieth century, it is thus concomitant with the rise of neo-liberalism in its globalized and financial form, the informational (computer) revolution, and the considerable increase in the complexity of the resulting interactions, from the company level to the world level. Contrary to the revolution of the turn of the nineteenth-twentieth century in physics, this revolution of the complex concerns phenomena on a human scale, and includes all disciplines, in the humanities and social sciences as in the sciences of nature. Yet it has led to very large rejections and refusals and is still marginal (and often confined to specialized institutes).

This revolution of the complex is a major epistemological and scientific revolution, capable of bringing about a profound modification of scientific strategies and forms of thinking, which also displays a striking proximity with a philosophic trend, materialist dialectics. Linked to the advances

[43] I will take up and develop here a number of ideas initiated in my book *émancipation et pensée du complexe* (*Emancipation and complexity thinking*), Le Croquant, 2015.

[44] With the exception of mathematics which do not need a paradigm shift to study complex systems, like other disciplines.

in information technology, it participates in the current evolution of the productive forces (the so-called *Informational revolution*). Yet it has been considerably slowed down in some of its developments which proved to be contradictory with the neo-liberal economy as well as with the dominant ideology. It is therefore at the heart of the contradictions of the present world, the economic contradictions between the productive forces and the mode of ownership, epistemological contradictions between reductionism and holism, as between linear and non-linear fields, ideological contradictions between liberal ideology and the ideologies of emancipation. Would it then contribute to outstripping these contradictions by allowing the emergence of a new rationality?

This work represents the development and deepening of a part of a first book, that addressed the possible applications of the complexity thinking in politics of social transformation, published as a small general public book "*émancipation et pensée du complexe*" le Croquant publisher 2015[45]

Chapter I displays an historical overview and a brief presentation of the sciences of complex systems. It is intended to make the understanding of their concepts as simple as possible without the mathematical and computer tools from which they originated.

In chapter II, I briefly describe the non-mathematical currents of the complex revolution. Then I present the new form of thinking which I call the *complexity thinking,* that is emerging from the revolution of the complex, of which it represents a major element, although very often underestimated.

Chapter III deals with the epistemological contexts in which this revolution develops, the contradictions (between reductionism and holism, as well as between linear and non-linear fields) that it allows to outstrip by including them. These contexts stand as impediments to the development of this revolution. I also discuss the importance of a materialistic dialectics for an epistemology of the sciences of the complex.

Chapter IV, devoted to the current economic and political contexts, shows how the complex is at the heart of the contradiction between the advance of the *productive forces* (influenced by the New Information Technologies) and the *production's relations* (neo-liberal capitalism) which oppose the progress. I discuss how the interests of financial companies interfere even in the evolution of some scientific paradigms.

In Chapter V, I address the ideological context, a term in which I embrace the philosophy - often implicit- of the scientists and the dominant mode of thinking. I show that in the complex revolution, as in Newton's *Principia*, we find the contradiction between the spontaneous materialistic philosophy of scientists and the dominant ideology that drives them towards idealism or agnosticism and above all banishes the dialectics. I also highlight the contradiction between

[45] Soon to be followed by "*émancipation, dialectique et complexité*" to be published by the same publisher

liberal and individualistic ideology and the behaviours favoured by the choice of the complex. Finally, I analyse the role of the Cartesian approach as an obstacle to the diffusion of the thinking of the complex and to the development of the sciences of complex systems.

This requires asking questions about how to change the general mindset, teach and disseminate this new way o thinking both at university and school level and, more broadly, to scientists, "decision-makers" and all citizens, which is the topics of Chapter VI.

To conclude, a new rationality is emerging, that may tentatively be called *dialectical complexity thinking,* which becomes necessary to cope with the increasing complexity of the world, and to fight against the irrationalism engendered by the fear of this complexity.

The major difficulty of this division into chapters is that these contextual elements are not separated but are deeply interrelated, and that to speak of one without mentioning the other may pertain to one-dimensional and impoverishing analyses. This will require frequent references between chapters. Thus the reader may chose any order to read these chapters.

But this is precisely the essence of complexity, of this revolution in the methods of thinking and working which it is necessary to understand in the multiplicity of its dimensions, as already invited by Boris Hessen, a materialist and a dialecticsian. As Simon Gouz writes "« *Or c'est précisément cela qui fournit une unité à ce qui se formule à présent comme une triple thèse [de Hessen]: premièrement, les sciences sont la réponse théorique à des besoins matériels, économiques, de la société, incarnés dans des intérêts de classe, en cela elles forment une part des forces productives humaines et l'histoire des sciences reflète celle du développement de ces forces ; deuxièmement, cette réponse théorique se formule au travers de superstructures idéologiques, c'est-à-dire d'une production d'idées déterminée par des intérêts politiques dans la lutte des classes et conditionnée par les circonstances spécifiques et les rapports de forces entre ces classes en lutte ; troisièmement, ce qui se développe à travers cette détermination, c'est une connaissance du monde objectif, c'est-à-dire que la rationalité qu'exprime l'histoire des sciences reflète, à travers des rapports sociaux qui en rythment le développement, la nature des phénomènes*[46].

[46] Simon Gouz *op.cit*. p 523. "*It is precisely this which provides a unity to what is now formulated as a threefold thesis: first, that the sciences are the theoretical answer to the material and economic needs of society embodied in clases's interests, in this they form a part of the human productive forces, and the history of science reflects that of the development of these forces. Secondly, this theoretical response is formulated through ideological superstructures, that is to say, a production of ideas determined by political interests in the class struggle and conditioned by the specific circumstances and the relations of forces between these struggling classes. Thirdly, what is developed through this determination is a knowledge of the objective world, that is to say that the rationality expressed in the history of the sciences reflects, through social relations which pace the development, the nature of phenomena.* "

Chapter I The revolution of the complex.

My thesis will be that a new scientific revolution is emerging, the revolution of the complex, which has become apparent since the 1970s. Whereas the previous large-scale scientific revolution, that of physics at the turn of the nineteenth-twentieth century, was concerned with scales of space and time either infinitely large or infinitely small, this new one is concerned with our scales of time and space, and spreads into almost all scientific domains from Physics to humanities.

The previous revolution required highly specialized mathematical equations. This one generates concepts that can be understood and even used without resorting to mathematics, even though it stems from relatively new mathematics, non-linear mathematics, and was made possible by the advances of computers and computer simulations. Even more so than its predecessor, its propagation in the diverse scientific circles encounters persistent resistance in the form of rejection or, worse still, deforming pseudo-assimilation. This diversity makes it difficult to unify[47] the concept, and endows all attempts to classify and regroup these approaches a subjective and reductive side, a reproach whose present work can not be exonerated either. Born independently in several disciplinary fields, complex[48] originally took on different aspects, the similarity of which, hence a certain unity, only appeared gradually and always partially. We have even been able to speak of " *ambivalences fondamentales inhérentes à la notion de complexité*[49]».

There is, therefore, no clear and unambiguous definition of this term, not a single denomination to designate this revolution of knowledge and modes of thought, but rather a network of terms which overlap but are not equivalent and which form a stream rather than a discipline: Chaos, fractals, artificial intelligence, complex thought, complex systems' science, network science, non linear dynamic systems, systemic theory, catastrophe theory, levels theory, thermodynamics of dissipative structures. .. It is all this that I group together under the term of the revolution of the complex. It means both that profound rearrangements of scientific paradigms[50] and even of our modes of thought have become possible and necessary, and that they still encounter fierce resistance, whose causes we shall seek. All these terms correspond to properties discovered recently, often independently, in different disciplines, and often under the impulse of technical problems first raised during the last war and then linked to the development of techniques and organization. These properties depend less on the objects concerned than on their interactions, their relationships, and even the way they are envisaged. A first consequence, since interactions are more important than objects, is the generic, trans-disciplinary aspect of a number of concepts and methods of the

47 Michel Alhadeff-Jones *three generations of* complexity *theories: Nuances and anbiguities*. *Educational Philosophy and Theory* (vol. 40, n°1), 2008 pp.66-82.

48 The term *Complexity* is also used. I choose the word *Complex,* may be a little less polysemic.

49 Michel Alhadeff-Jones *op.cit."Fundamental ambivalences inherent in the notion of complexity "*

50 I use this word in the sense of T. Kuhn to designate all the theories and ideas that characterize a disciplinary field (and here, almost all disciplinary fields) at a given moment.

complex. This necessitates a redefinition of scientific objects and a possible redrawing of the fields of investigation, depending on the various types of interactions involved. This also leads to many communication difficulties, linked to traditions and speciality of each discipline. Finally, since a complex system is determined by the interactions between its elements, the time and space scales in which they are studied, and the inter-disciplinarity that their study often requires, it may be asked whether concepts derived from the exact sciences can be transposed, which is not without raising polemics.

Moreover, most of the properties of complex systems are still unusual, disturbing, non-trivial. They do not conform to the usual logic, are not accessible by linear mathematics, are not intuitive[51]. In order to study these interactions, it is often necessary to use mathematical models or computer simulations in disciplines (biology and human sciences) where these methods are not usual. In addition, these tools are new, and require a great deal of research.

However, in spite of these difficulties, the idea is that natural or social systems are predominantly complex systems, and can be studied as such, not by simplifying them to the extreme, as it was necessary when convenient methods were lacking.

The sciences of complex systems therefore encompasses fields the led themselves to mathematical modelling or computer simulations. A short presentation is given in this chapter. Next chapter will deal with the transformations brought about by the revolution of the complex to the forms of thinking and the mindset.

But first it is essential to remove the confusion between complex and complicated. The opposite of complicated is simple. Complex, whether adjective or name, has no opposite (I will use simplification or linearity depending on the case[52]). A complex system may be simple, encompassing few elements or few interactions, or complicated if they are many or heterogeneous. It is true that most complicated natural systems are also complex, for they not only contain a large number of elements, but these may display a large number of interactions. We shall see that, for some authors, only complicated systems can be called complex. This position often stems from the nature of the technological problems that have necessitated the development of some of the methods associated with the complex. But, and I will show why, I do not share this conception.

As Gleick already wrote in 1987 “"*In the last twenty years physicists, mathematicians, biologists and astronomers have invented new ideas. Simple systems generate complex behaviour. Complex systems generate simple behaviour. And more important the laws of complexity are universal*.[53] "

[51] Intuition being constituted by the accumulation of prior experiments or conceptualizations, scientific revolutions are almost by definition non-intuitive.

[52] Some authors have proposed using the term simplex, but since it has a very different mathematical meaning (a 'triangle' with n dimensions), it does not seem very relevant to me here.

[53] Jame Gleick *Chaos: Making a New Science* Paperback edition *(1988) from Penguin Books (the citation is translated from the french edition)*

I-1 Brief Overview of the Revolution of the Complex

Without making a history of the discoveries that have shaped the landscape of the sciences of the complex, I will sketch in broad outlines a few of them to show the slow progress in time until the explosion of the 70s, the role played by the computer sciences and the wide diversity of approaches, disciplines, inter-disciplinarity and countries[54].

It is often said that this history begins in 1888, when the French mathematician Henri Poincaré, working on the stability of the solar system, or more precisely on the possible influence of the moon on the stability of the trajectory of the earth around the sun, discovered a family of behaviours extremely difficult to describe and represent, which will be called, much later, deterministic chaos. At the end of the nineteenth century, another French mathematician, Jacques Hadamard, discovered a property that will not be understood until much later, the sensitivity to the initial conditions. These very complicated mathematical discoveries will remain almost unknown, at least in the West, for nearly 60 years. Yet an important school of Soviet mathematicians worked in the field of non linear and stochastic dynamics between 1927 and 1967[55] (Kolmogorov, Liapunov, Sinai and many others), but they are still largely ignored in the Western world, where the idea of an "empty" interval of 60 years, launched by the American scientific journalist James Gleick is still running.

On the other hand, various authors in distant and mutually unfamiliar disciplines may, in retrospect, also be considered as precursors. In 1900, the French physicist Henri Bénard observed the formation of convection cells appearing in a liquid heated under certain conditions, but this observation was only understood much later to become, under the name of Bénard's cells, a typical example of auto -organization. In 1917 the scot D'Arcy Wentworth Thompson published *On growth and forms*, a whopping work in which he showed that the forms of the living obey geometric constraints similar to those observed for physical phenomena[56]. In 1925-1926 two mathematicians (one English and one French) proposed independently the now-called Lotka-Volterra1[57] equations, or predator-prey model, which are still used and improved today, to describe the complex dynamics (oscillating or even chaotic) of biological systems in which a predator and its prey interact.

Next was the work of Von Neuman (1945), which, based on research by the US Army on anti-aircraft artillery guidance processes, gave rise to cybernetics, with the importance of feedback for homoeostasis of systems. The filiation between cybernetics and the revolution of the complex is not direct. In the USA, cybernetics have had essentially mechanistic developments, while in Europe

54 History is often skewed by the fact that very important American popular books, presenting these questions in a very lively way, have been bestsellers, but are much too much prejudiced in favour of US researchers: Gleick op.cit., Roger Lewin *Complexity: the theory of life on the edge of chaos*, Macmillan Publishing Company, 1992

55 Simon Diner *Les voies du chaos déterministe dans l'école russe* in *Chaos et déterminisme*, Dahan Dalmedico *et alii* Le Seuil, 1992 pp 331-368.

56 D'Arcy Wentworth Thompson, *On growth and forms* first published in 1917 then revised in 1942

57 Couple of first-order non linear differential equations

it interested physicians in particular, and gave rise, with Bertalanffy (1950) to the theory of systems, which later became the systemic (cf Chapter II). This work is at the origin of the theory of automata, while McCulloch (biologist) and Pitts (logician) relying on the properties of the nervous system proposed the concept of neural network. These techniques were to play an important role in the simulation of complex systems and were combined with the mathematical theory of communication formulated in 1947 by Shannon, the father of the theories of information and communication. These theories are based on the idea that information (defined by digital units or "bits") can be measured statistically.

Then, in 1950, a soviet chemist, Belousov discovered oscillating behaviours and strange spatial organization during a chemical reaction, discovery that fell into oblivion and discredit for lack of satisfactory explanations. Rediscovered in 1961 by Zhabotinsky, it still did not attract the attention of the West, until 1968. Since then, it has been mathematically modelled and simulated by computer and has become the well known Belousov -Zhabotinsky's reaction, a dynamic non-linear model of self-organization under the conditions of an open system far from equilibrium, or dissipative structure.

In 1951, Alan Turing, the English inventor of the universal machine, the father of theoretical computing, proposed a model of self-organization in a closed system, which he would use to model morphogenesis, such as the spots on certain mammals coat[58].

In 1960 the German physicist Von Foester published S*elf-organized systems and their environment*, in which he described a now famous experiment: shaking small magnetic cubes in a box, he obtained organized forms and deduced the theory of "*the order resulting from noise*"[59]. This idea will be reworked in 1972 by Henri Atlan, who prefers the term "*complexity resulting from noise*"[60]

In the 1960s, Lorenz, an American mathematician interested in weather forecasting problems, discovered the extreme sensitivity to the initial conditions of the behaviour of a relatively simple system of differential equations designed to model the climate. This system will become the prototype of chaotic systems. But he published his model in 1963 in a meteorological journal, read only by specialists, (and he seems to have heard of neither Poincaré nor Hadamard's work). Yet it is he who will be known to the general public or rather his famous metaphor of *the butterfly effect* that illustrates the sensitivity to the initial conditions and the impossibility of long term previsions of chaotic systems.

58 A.Turing *The Chemical Basis of Morphogenesis* Philosophical Transactions of the Royal Society of London, series B, Biological Sciences, Vol.237, pp. 37-72.

59 Noise means here (and in the remaining of this work) random fluctuations.

60 Complexity is here derived from the theory of information. Henri Atlan, *Entre le cristal et la fumée,* Le Seuil (coll point), 1979 .

It was also in 1963 that the embryologist Brian Goodwin began his work on morphogenesis. He explained that . "« *les moyens de contrôle moléculaires, tels que la rétroaction, la répression, le contrôle de l'activité enzymatique - en d'autres termes la logique intrinsèque locale d'un système complexe – donnaient spontanément naissance à des comportements oscillatoires et des schémas structuraux globaux*. .. le fond de l'ouvrage – *apparition de l'ordre comme produit inévitable de la dynamique d'un système*»[61]

The physico-chemist Ilya Prigogine, after studying in Brussels in several disciplines, was working on thermodynamics far from equilibrium and begun to publish in 1968. He revealed many unexpected behaviours that appear far from the equilibrium, in structures that dissipate energy (dissipative structures): oscillations, multistationnarity, deterministic chaos and the appearance of organized forms. He emphasized the irreversibility of the "time's arrow" (contrary to doxa in physics) and the impossibility, in many cases, of predicting the behaviour of a physico-chemical system. It is for him *the end of certainties*, which he assimilates to the end of determinism, whereas other physicists working in the field of statistical physics on the dynamics of non-linear systems will describe such behaviours as *non-predictable determinism*.

Around the same period was launched the *théorie des catastrophes* by the french mathematician René Thom, although the latter vehemently refused to see the proximity of his works with those of Prigogine or other pioneers of complexity like the biologist -philosopher Henri Atlan.

Among the pioneers are also Humberto Maturana and Francisco Varella with their *autopoietic theory of life* (1972), where they consider, beyond self-organization, that self-reproduction is the essential characteristic of living systems.

All these precursors have in common both a good familiarity with mathematics, a great curiosity that has often led them to take an interest in several disciplinary fields and the will (or even the courage) to seek out of the beaten path.

Other currents, also around this time, may be associated with this nascent movement, but come from the human and social sciences and do not use mathematical or computer methods. Bachelard, already in 1934 introduced *Le nouvel esprit scietifique* by a chapter called "« *la complexité essentielle de la philosophie scientifique* »"[62] . While aware of developments in complexity in physics, the psychologists of the Palo Alto school[63] insisted on the specificity of

61 In Lewin *op.cit.* p 31. *Means of molecular control, such as feedback, repression, control of enzymatic activity - in other words, the intrinsic logic of a complex system - spontaneously gave rise to oscillatory behaviours and global structural schemes.* The basis of the work, *the appearance of order as the inevitable product of the dynamics of a system. (*translated from the French version*)*

62 *the essential complexity of scientific philosophy* Gaston Bachelard « *le nouvel esprit scientifique* » 1934,

63 The Palo-Alto school, launched 1950 by Gregory Bateson also features Donald D.Jackson, John Weakland, Jay Hamey, Richard Fisch, William Fry, Paul Watzlwick and the Rockefellers.

humans and, since the 1950s, forged a psychology based on interactions between members of a family and on the resulting feedback loops[64].

To all this must be added the parallel development of computer techniques. Launched during the war at the request of the American Army, the Engineering Sciences and Computational Sciences developed complex models from the 1950s onwards to solve technical questions such as the development of the network of telecommunications. Their impact was accentuated by a series of successive technological advances.

Since the 1970s, discoveries and studies multiplied in various fields and the role of increasingly powerful computers became decisive in these discoveries. Researchers were increasingly aware of the proximity of apparently very different systems that they were manipulating and were beginning to meet in colloquiums and collaborate, thus avoiding the reticence or malice of their colleagues. But these groupings do not lead, at least for the moment, to a single current. The image would be rather that of a river delta, with multiple channels that intersect, converge and diverge.

Pure mathematicians have quickly provided a framework, the topology of non linear systems (Stephen Smale, Michael Barsley), which popularized the terms of chaos theory (James Yorke), fractals (Benoit Mandebrot), iterations and doubling periods (Mitchel Feigenbaum), dynamics of non linear differential equations (Ian Ekeland, Jan Stewart, A. Douadi). The theory of graphs, whose origins can be traced back to an article by the Swiss mathematician Leonhard Euler in 1735, precedes and allows a science of networks[65] that is part of the revolution of the complex.

Computer science plays a dual role. On the one hand, mathematical advances could not have taken place without the progress of computers. Thus the curves which Poincaré had not been able to draw are now drawn at full speed by computers. And on the other hand, computer scientists, using cellular automata due to Von Neumann in 1945, were able to explore other aspects of these complex systems. These include J. H. Conway and his *game of life*[66] (1970), Stephen Wolfram, who described (1981) a new class of complex behaviours later named *the frontier of chaos* and Chris Langton, the upholder of artificial intelligence. It is also from the power of computers that the science of networks emerged.

On the physics side, there was the theoretical study of whirlpools, by Ruelle1[67] and Takens, who in the 1970s shaped the expression "*strange attractors*," or a group of "deviant" American students who formed *Collective dynamical systems* at the end of the 70s. One can also mention Hao Bai Lin author of a *form of order without periodicity*. The Danish Per Bak, starting from the

64 Gregory Bateson, *Steps to an Ecology of Mind* Chandler Publishing Company 1972
65 This term, which is not accepted by all researchers, is claimed byHughes Bersini' in *Des réseaux et des sciences, biologie, informatique, sociologie ; l'omniprésence des réseaux*. Vuibert, 2005.
66 See the video on https://en.wikipedia.org/wiki/John_Horton_Conway#Conway.27s_Game_of_Life
67 David Ruelle, *Hasard et chaos*, Odile Jacob,1991.

theoretical study of a pile of sand along which occur varied and unpredictable sliding, proposed in 1987 the theory of *self-organized criticality* which had important repercussions in many disciplines[68].

In biology, studies on prey/predator dynamics multiplied in ecology; the Belgian microbiologist René Thomas pointed out in 1981 the importance of positive feedback loops as necessary to obtaining multistationnarity; the Belgian biologist Deneubourg was studying, i*n vivo* and i*n silico* populations of ants, a wonderful model of self-organization ; in the USA, Stuart Kauffman was using interactions networks to show the constrained behaviour of systems that might be very complicated, provided they have a limited number of interactions: he deduced that life was in no way due to an exceptional event, but on the contrary, had been inevitably due to appear. A little later, computer multi-agent systems succeeded in simulating the self-organization of biological systems such as the social amoeba *Dyctiostemium discoideum,* or a shoal of fish and a flight of starlings. (These works were done by computer scientists and rarely interested biologists).

Humanities and social sciences were not absent from the movement. Some used models and simulations: economists studying changes in cotton market prices found strange attractors; geographers and lawyers found in complex models more adequate methods to describe their systems; sociologists discovered the S curves showing the non-linearity of the progression of ideas; psychologists, following the neurologists (here is Varella again) used these new concepts through modelling. But others worked only with the concepts of the complex (See Chapter II): we find Edgar Morin, who represents a transdisciplinary domain on his own, the group of Palo Alto, as well as the historian school of Annales which continue their progression, and systemic, which developed both quantitatively and qualitatively. But the two universes remained often separate.

These researches and discoveries were often ignored, or even rejected, by academic institutions, and had to take refuge in specialized institutes[69]. Interdisciplinary institutes of complexity first appeared in the United States. The very term of complexity, including the doctrine of deterministic chaos, but going far beyond, came into play with the creation in 1984 (by the Nobel Prize for physics Murray Gell Man[70] of the very famous Santa Fe Institute. Created by renowned scientists, the aim of this institute was first of all inter-disciplinary interplay and scientific independence. But it attracted very quickly researchers who could not get accepted by the institutions, because they worked precisely on what will be later called complex systems. Thus in 1986, Santa Fe, by becoming *the institute of adaptive complex systems*, was going to give a great impulse to this new domain and its transversal character. There, mathematicians (such as Langton,

68 Per Bak, *How Nature Works: The Science of Self-Organized Criticality*. New York: Copernicus, 1996.

69 Thanks to many of the popular books mentioned above, these ideas were more easily accepted by a part of public opinion than by the scientific institutions. Among these books, Ilya Prigogine and Isabelle Stengers *la nouvelle alliance* NRF Gallimard, 1979, (*Order out of Chaos: Man's new dialogue with nature*) played a very important role.

70 Murray Gell Mann *the quark and the jaguar* 1994

the upholder of artificial life), computer scientists, physicists, biologists (such as S. Kauffman), economists, sociologists and anthropologists did meet to confront and discuss. In 1993, the scientific journalist Roger Lewin wrote "*Since its founding in 1984, the [Santa Fe Institute] has attracted a core of physicists, mathematicians and computer genius. The computer is the microscope through which they observe the real as well as the abstract worlds. Nothing that makes up our universe escapes them: chemistry, biology, psychology, economics, linguistics, and sociology occupy the same intellectual orbit. Artificial worlds are part of the lot, worlds whose existence is manifested only on a computer. The link between these disparate worlds ... is called complexity. For some, the study of complexity is nothing less than a major scientific revolution* "[71]. The program of a course on complexity, organized in 2013 by this institute, shows that this objective remained relevant[72].

In Europe, and particularly in France, complexity studies were slow to be implemented: institutes of non-linear physics appeared first, followed since the 2000s by regional Institutes of Complexity Sciences, linked in a National Network of Complexity Sciences (RNCS) itself linked to a European network of complex systems. Mathematics (applied) and computer science play an important role. But these conceptions and methods are not (yet) widely shared, although the number of scientists who strive to use them does increase.

It is also to try understanding these drawbacks, that I will devote this work. But first of all, let's quickly see what are these complex systems sciences, of what conceptual revolution they are engrossed?

I-2 Non linear Dynamic Systems (NLDS)

As already mentioned, there is no single, coherent definition of complex systems. In order to highlight the main properties, I will therefore start from a subset of relatively simple complex systems, non linear dynamic systems (NLDS) well characterized and studied, both by mathematicians and physicists. They have revealed a number of characteristic properties which are found in most complex systems.

I-2-1 Three important terms.

System means that we are interested in a collection of interacting objects, taken as a whole, in its global characteristics and in the nature of the interactions between its components. As such, the system will also depend on the point of view that brings together certain components. The solar system includes the sun and the planets, but the earth itself is a system, or a set of systems. We can

71 Roger Lewin, *op cit* .(translated from the French translation)

72 The program offers an intensive introduction to complex behaviours in mathematical, physical, living and social systems for PhD and post-docs in science and the social sciences seeking to conduct interdisciplinary research on complex systems. The program includes non-linear dynamics and pattern formation, scale theories, information theory, adaptation and evolution, ecology and sustainable development, adaptive calculus techniques, Modelling tools and applications of these nodal subjects to various disciplines.

talk about systems and subsystems. In some cases, these subsystems are relatively determined as levels. The approach consists first of all in making a survey of the objects of the system and their interactions, in the form of a map, such as the road map linking the cities of a region, or the gene regulation graph[73]. The terms structure or graph have sometimes been used in this sense.

The purpose of the study of **dynamic systems**, is to describe changes in time and space (transformations) in the state of systems as a function of the causes of these changes, insofar as these causes are precisely the interactions between the objects of the system (internal causes).This is where mathematics comes into play when the evolution of dynamic systems as a function of time can be modelled by ordinary differential equations (ODE). The behaviour of each variable in the system is defined by its tendency at any time (increase, decrease, remain stable), depending on the influence of other system variables. Mathematically, we solve a dynamic system if we can trace the evolution of each variable as a function of time (which is called integrating the differential equations). Very often, the system evolves over time towards its solution, where the values of the variables do not change any more. This can mean that the system has reached an equilibrium and no longer moves (like the pendulum at the end of the race), but this most often means that the transformations compensate each other like the bath that fills at the same speed as it is emptied so that the volume of water remains constant. This is called a stationary state. It can be stable, as in the case of the bathtub, or unstable as the pencil that is placed on its point. We distinguish the linear dynamics, known and studied for a long time, and the non linear dynamics which belong to the complex systems.

Non-linear means that the interactions between the objects that make up the system (and which are therefore the causes of the transformations) are such that there is neither proportionality of the effects to the underlying causes nor the additivity of causes on these effects. Simple cases of non linearity are manifested in everyday life in the jar of jam which opens only after a lot of unsuccessful efforts but which then opens at once (threshold effect), In the mayonnaise which takes, suddenly and not gradually, in the whirlpools, in the hurricanes, in the traffic jams... But until relatively recently, non-linear dynamics (in which at least one of the interactions is non-linear) were seldom studied, because mathematics can not solve (integrate) most differential equations that model them. More precisely, the mathematical difficulty in calculating the majority of non-linear systems is such that it has only been solved with computers. It is not that the linear systems are more numerous than the non-linear systems in nature or in society, on the contrary. But until now, even if it were known that proportionality and additivity were rather rare properties, they were the only ones that were known to be mathematically treated and they had become universal: they were the bases of all our rationale and, more fundamentally of our logic. Science often behaves like the

[73] This approach, the completeness of which is generally impossible, is not straight forward and we shall return to it in the next chapter

drunkard of the joke, who seeks his lost keys under the street-lamp because it is the only place where there is light. This is why, for a very long time, we have had to resort to simplifications to study these equations under linear conditions (and let us not forget that the integrable equations which allowed to send men into space made proof of their effectiveness). The proportionality between causes and effects is what one always learns from kindergarten, and this is far beyond mathematics, since we are always convinced that the greater our effort, the better the effect will be, although we repeatedly have the opposite effect (as well know parents whose children do the opposite of their repeated injunctions). So it is only rather recently – no more than half a century- that mathematicians become able to master non-linear dynamic. systems (NLDS). Much later on, as we shall see in Chapter III, what has become trivial for mathematicians, many physicists and some engineers, spread into other fields where linearity, have shaped reasoning for centuries. But this delay also has other less obvious causes, economic causes (see Chapter IV) and ideological causes, linked to dominant liberal way of thinking (see Chapter V).

I-2-2 Systems of non-linear differential equations.

Since the majority of non linear differential equations are non-integrable, computers offer two solutions. Either one calculates the trajectories (that is to say the evolution of each variable over time) step by step on a computer. Or, one is interested in the solutions toward which the system converges after a certain time. Thus, the properties of many systems of non linear differential equations are well known at the present time, and we can take stock of these behaviours which are bizarre, disturbing, counter-intuitive, which researchers often call non-trivial, and which nevertheless allow to reliably represent the transformations of many real dynamic systems.

The first type of solutions is common to all dynamic systems (linear or non-linear), it is a single steady state, where the system is not motionless (it would be equilibrium), but the modifications compensate. However, while linear systems have only one stationary state, non linear systems may have several ones, the system arriving in one of them according to the initial conditions (value of the variables at the beginning of the movement). This is multistationarity. Each solution is called an attractor, and we call the set of initial values of the variables that inevitably lead to the attractor, the basin of attraction (as a watershed draws all the run-off water to its river). For a given dynamic system, the solution to which it will tend, depends on the values of the variables at the beginning of the movement. If they are on the boundary between two attraction basins one can not know where the system will go. In this case, a very small fluctuation can send the system to one basin or to the other. This is a case of unpredictability that can be imagined as a marble at the top of a narrow wall that will necessarily fall to one side or the other, but one cannot tell which one (unless a well-adjusted flick, or a gust of wind, eliminates chance). This property of NLDSs means that *the same system may behave differently,* d*epending on its history*, that is, the initial conditions, or even randomly in some circumstances. The system is then called **deterministic**, because the solutions are known, but **not predictable**, when the choice of one of the solutions is random. This is a first example of non-predictive determinism.

It has also been shown that for a system to display multistationarity, there must exist a positive feedback between some of its elements. This means that some of the interactions loop on themselves (feedback). For example, A positively influences B, which positively affects C, which positively affects A. Thus, *in fine*, each element has a positive influence on itself (positive feedback). Such a system has two stable stationary states, either A, B and C are present (or favoured), or these elements are all absent (or disadvantaged). Another configuration, clearly less intuitive, corresponds to a positive feedback loop where A has a negative influence on B (disadvantages B), which negatively influences (disadvantages) A . In this case also, *in fine*, A favours itself. The system has also two solutions: either A is present (or favoured) and B is absent (or disadvantaged), or it is the opposite. A positive feedback loop can involve a large number of interacting elements but includes an even number of negative interactions. It is a form of **causality**, called **circular**, since each element is both cause and effect. This is for instance, the vicious circle. I stress this property because cybernetics and then systemic have most often known only the negative feedback loops, which act to allow *in fine* the action of each element negatively on itself and which are therefore responsible for the effects of homoeostasis. The best known example is the thermostat: if the temperature rises, the thermostat shuts of the radiator, which causes a decrease in temperature, which shuts on the radiator. In contrast, the determining importance of positive feedback loops in the behaviour of dynamic systems was demonstrated only recently[74].

But here does not stop the strangeness of the behaviour of the NLDS. In some cases the dynamics never stops, we say that it has a periodic solution, because the variables always pass by the same values. A metronome gives a good idea of such a stable behaviour, just as, as a first approximation, the heart beat[75].

Finally, the most famous of these atypical behaviours, of these non-stationary solutions, is deterministic chaos. This is the solution discovered by Henri Poincaré while studying the effect of the moon on the rotation of the earth around the sun. It has been extensively studied, as it has a very large number of properties, of which I will only mention the most important. It occurs in some non linear dynamic systems, with at least 3 interacting variables. The system oscillates irregularly and never repeats the same oscillation twice. An encephalogram plot gives a good idea of this type of behaviour. If we simulate on a computer a system of differential equations displaying a chaotic solution, we can repeat the simulation as many times as desired. If we start from exactly the same

[74] It was conjectured by the biologist René Thomas in the early 80s and then mathematically demonstrated in the early 2000s.

[75] Strange behaviours as compared to the usual linear equations, but very common in reality.

initial values of the variables (which may be possible on a computer), we will find each time the same trajectory. But if we start with different initial values be they very close (even to the tenth decimal place, for example!), the trajectory will be different, the differences increasing with time. If this system of differential equations models a real system, it is more than likely that the values of the variables can not be measured with absolute precision, so it will not be possible to predict the behaviour of the variables in the long run. (This explains, for example, why it is impossible to predict the weather to more than a few days). Thus, a small difference can have considerable consequences. This is what the mathematician meteorologist Lorenz has popularized with the (deliberately simplistic) image of the butterfly, of which a wing beat is supposed to be able to trigger a hurricane on the other side of the globe. A deterministic chaos is characterized by the time necessary for the value of a deviation of the initial values of a variable to be multiplied by 10. We again have to do with a deterministic behaviour (it is reproducible if we can redo it in exactly the same way). But it is in reality unrepeatable, hence not predictable.

However, the word chaos, even characterized as deterministic, is confusing. Indeed, these chaotic trajectories, if they never take the same value, are constrained. Think back to the encephalogram, the oscillations are irregular, certainly, but not so much. Their amplitude does not take all possible values! Deterministic chaos is not pure chance, quite the contrary[76]. Besides, if a chaotic system is very sensitive to initial conditions, any system with this type of sensitivity is not necessarily chaotic and it is not always easy to determine whether an irregular natural system is chaotic or not.

Up to now, we have only seen the reciprocal influence of the variables on the transformations of a system as a function of time. But a system in embedded in an environment that can influence its dynamics and will be represented as constant parameters (external causes) in the equations. These parameters may also change. For example, temperature is often an important parameter of chemical or biochemical reactions. If a parameter begins to evolve, common sense will tell us that the system will evolve in proportion (the chemical reactions will be faster if the temperature increases). In many cases this is true. But with these devils of non-linear systems, one must learn to beware. And we are right! It has been shown that NLDS can change the type of solution, as soon as a specific parameter (*control parameter*) exceeds a so-called *critical threshold*. A system with a given stationary state can change from steady state to oscillating, chaotic or multistationary (and vice versa). This phenomenon has been called **bifurcation**. A concrete example is, once again, mayonnaise, the parameter that switches the mixture from the liquid (stationary)

[76] If we plot a curve in 3-dimensional space, representing the evolution of the values of the variables of a chaotic system with 3 variables (phase space), the curve obtained never overlaps, but it capriciously loops inside a very particular volume that is called the strange attractor. Each system has its attractor, and their forms are quite diverse. The most famous, discovered by Lorenz has a shape reminiscent of a butterfly. Other studies bring these strange attractors closer to the fractals discovered and popularized by the mathematician Mandelbrot.

state to the (stationary but different) gel state, is the amount of oil in the emulsion[77]. In physics, this process is called a phase shift (of second order). A physical or chemical system thus acquires a historical dimension, since, at each bifurcation, a choice is made which determines what will follow. When it occurs, a succession of random choices illustrates the uncertainty of a historical path, even when, at each step, the possible states between which the system "chooses" are perfectly determined and knowable through the equations by which it could have been modeled[78].

Finally, when a physical system is subjected to the variation of one of its control parameters, it often becomes very unstable near the bifurcation point and begins to fluctuate before adopting its new regime. The top which oscillates in all directions before falling when its speed decreases, is a good illustration. This boundary zone is particularly sensitive to external actions: during a fork bifurcation[79], the choice of the final state (attractor) is random, with the same probability of arriving in one or the other of the new stationary states, but a very small perturbation can drive the system toward one of the new attractors.

It should also be recalled that natural systems in a stationary state, are generally not in equilibrium. For example, the concentrations of the different chemical species confined in a volume may perfectly remain constant while a multitude of chemical reactions consume or produce these species which, moreover, can leave or, on the contrary, gain the volume through the surface which delimits it. In the stationary state of non-equilibrium all processes compensate; at the equilibrium they are all separately arrested. Thus as an adult, when our weight and form do not change, we are in a stationary state, the equilibrium is reached only at death. The characteristic behaviours of the NLDS are thus those studied by the dynamics of far from the equilibrium systems (dissipative structures) which Prigogine has discovered and popularized and which has allowed him to import the fundamental notion of the arrow of time (historicity) in the very heart of physics[80].

So far, I have not considered the spatial dimension, as if the systems were uniform in space, the variables having the same value at any point of the system's volume. The uniformity of an unbalanced system is reasonable, however, only if the system is small or if it is forced to be

[77] The system, in the liquid state, contains oil and water (in egg yolk). Upon mixing, an oil-water emulsion is formed where the relative amount of the two varies slowly as the oil is added. Mayonnaise “takes” when the liquid turns into gel (bifurcation called phase change in physics), and this occurs for a critical water / oil ratio.

[78] It might also be questioned whether a revolution that suddenly broke out like the Tunisian revolution, the fall of the Bastille, or even the riots in the suburbs, were not similar to this type of process, although they could not be modelled.

[79] A bifurcation that moves a system from a behaviour that tends toward a single stationary state (one attractor) to a behaviour where two stationary states are equally possible (two attractors) .

[80] Physics worked mostly on systems (linear) which are reversible with respect to time, there was no historicity. By working on systems far from equilibrium, and therefore non-linear, Prigogine has introduced irreversibility (or arrow of time) into physics, which some physicists have not accepted.

homogeneous (if a liquid is stirred for example). In other cases, space and diffusion phenomena must be addressed[81].

Again, bifurcations can occur in non-linear systems. Let us take the example of a container where a chemical reaction takes place (Belousov - Zhabotinsky 's now famous reaction). If the system is kept out of balance, by progressively adding one of the reagents, one observes under some conditions, after a bifurcation point, a certain degree of global coherence in time and space at the level of the various elements of the system: certain reactive molecules are concentrated to form progressive spiral waves or another form depending on the shape of the container containing the system[82]. This is called **self-organization**: some global properties (here the spirals) appear in a system, although neither the intrinsic properties of the constituent parts (the reagents and products of the reaction), nor the nature of their interactions (Chemical reactions) have changed. Only the distributions have been changed in the space of interactions between these parts. This reaction could be modelled by partial differential equations whose graphic solutions obtained by computer resemble the configurations observed experimentally. A trafic jam, with its knots (where the vehicles are all stopped) and its bellies (where the circulation resumes for a short time), is also an example of self-organization.

These global properties, the appearance of which depends on the conditions (in this case the concentration of the various molecules or cars) and whose configuration also depends on the environment (shape of the container in the case of the chemical reaction, width of the road in that of traffic jam), represent a typical example of **emergence**, which is sometimes considered the very feature of **complexity**. Emergence manifests itself at a global level, but results from relations between the parts at the local level without it being possible to deduce the higher level from properties of the elements of the lower level. A global order emerges from the local disorder. This allows to define the notion of level where the whole (global level) is not equal to the sum of its parts. But these notions are the subject of a considerable ideological debate, which we shall analyse in Chapter V.

I-3 Complex Systems Science

1-3-1 Complexity of the NLDS

I stated previously that NLDS, these dynamic systems modelled by non linear differential equations, are a subset of complex systems. Some non linear differential equations have been the subject of mathematical studies to discover their properties especially in the case of deterministic chaos. For example, Otto Rössler sought the simplest system of differential equations capable of

[81] Mathematically, the model used is a system of partial differential equations (PDE).
[82] Changes in colour have made it possible to visualize this phenomenon.

generating deterministic chaos[83]. But many of these equations have been established to model existing dynamic systems, physical (vortices, climate, dissipative structures, phase transitions), chemical (Belouzof-Zabotinsly reaction), ecological (logistic equation- the prey / predator reaction-, the transmission of epidemics), biological (circadian rhythms, oscillations, differentiation), economic (stock market prices), societal (traffic jams, rumours, rushes). The properties of these systems have thus been highlighted and understood by mathematical methods, and computers have been used to find the solutions.

Based on these studies, what can we say? Some dynamic systems can be very simple (three or even two variables), presenting 3 types of solutions (of long-term behaviour): stationary with one or more attractors, oscillating or chaotic. They are often, but not always, sensitive to initial conditions, which makes them deterministic but not predictable. The same system, depending on the variations of the conditions of its environment (parameters), may display bifurcations characterized by the fact that a very small variation of a critical parameter at a so-called critical threshold can completely change the behaviour of the system[84], make it bifurcate from one type of solution to another, resulting in a historicity of the system. Feedback loops, in other words circular causality (especially positive feedback loops), are necessary for the emergence of non-trivial behaviours. Finally, when the dynamic system is deployed in space, bifurcations may give rise to self-organization that can emerge at a global level in the form of spatio-temporal structures that depend on the conditions and nature of the surroundings. These bifurcations correspond to the appearance of global changes in the behaviour of the systems without change in the nature of its constitutive elements (emergence).

All these properties characterize these new, non-trivial behaviours, different from those of the linear systems to which we are accustomed, one might say, because of our mathematical abilities in the absence of computers. They characterize *the complexity of NLDS.* However, few systems possess all of these properties, and even those that possess many of them, never present them all at once, as they depend on initial or environmental conditions.

A non linear dynamical system which, under normal conditions, exhibits oscillating behaviour, can bifurcate towards chaotic behaviour or a stationary state: this is the case of the heart when it undergoes fibrillation (a state of deterministic chaos, rapidly followed by the stationary equilibrium state of the stop, or death). In other words, if all these properties characterise the NLDS as complex systems, none of the latter can be defined by all of these properties, but by the presence of some of them. Ultimately, is a non linear dynamic system of which we know only one stationary

83 The result is known as the Rössler attractor.
84 We shall return to this later on (Chapter II), but here is an example of the proximity with the dialectical category of Hegel's qualitative leap.

state a complex system? Its usual behaviour is not complex, but it is susceptible if the conditions change, to fork towards a complex behaviour[85].

I-3-2 Other complex systems: a multitude of definitions

NLDS are systems in which objects (elements, variables) maintain non-linear interactions with each other. A non-linear dynamic arises for instance if an element is being transformed under the combined effect of two other elements of the system. In other words, there must be a lot of them! However, it is rarely possible to model them by differential equations, either because the nature of the interactions is not known precisely, which prevents quantification, or because the number and the heterogeneity of the elements are too large. But from the beginning of the studies of these systems, while they were still disparate and almost independent, computer scientists developed other methods of study. The first one were the cellular automata (invented in 1945 by Von Neumann, the most famous of which is the game of life by Conway). The simplest consists of a two-dimensional grid where each box represents an element whose modifications (sometimes only a black or white, on or off binary change) are governed by rules that depend on the state (black or white , on or off) of the neighbouring cells thus simulating the interactions between the neighbouring elements. Another computational method, multi-agent systems is even more powerful for simulating self-organizations such as a shoal of fish, an ant colony, or a flight of starlings, generated from very simple rules. Each element of the system is represented by an agent and its rules of interactions with the other agents are defined and programmed. From an initial position of the agents, the simulation is started, each agent, at each time step, calculates its movement according to the rules of interactions and the positions of the other agents. To simulate an ant colony, for example, two very simple rules are sufficient. Each virtual ant puts a virtual pheromone[86] on its path, which evaporates with time, and each ant goes to the highest concentration of neighbouring pheromone. Self-organized behaviour is obtained (the ants go together to the nearest food source, without the need for any leader) if the right conditions have been implemented (concentration and speed of pheromone evaporation, for example). As was shown in NLDS, this behaviour emerges only in some conditions. The evolution of the system depends both on the rules and the initial positions of the agents. If there are many possible solutions, (patterns) they will eventually be found by re-launching the simulation from various initial positions.

The study of interactions networks is an other example of the use of computers to understand a complex system. This method consists in considering the interacting elements as the nodes of a graph and the interactions as the arcs connecting these nodes. The goal is to understand the evolution of the system as a function of time. « *Leur nature simultanément collective et non-*

[85] Thus, the mathematical modelling of a biochemical reaction (glycolysis) in yeasts showed that it was likely to present oscillations, which had then indeed been evidenced experimentally later on.

[86] The actual ants deposit a chemical substance (the pheromone), which is simulated in virtual ants by a computer rule.

linéaire » fait que *« les mathématiques restent sans voix pour comprendre comment émergent les propriétés nouvelles car on ne peut comprendre cette influence réciproque qu'en mettant ces parties en présence par le biais d'une simulation informatique»*[87].

These methods allow predicting the possible behaviours toward which a system converges but, unlike the mathematical model, they do not allow to understand what is happening. The possible solutions are displayed on the computer screen, and as it is very fast, the simulation can cover a very large range of initial positions or help see what happens when modifications of the parameters are implemented. (*in silico* experimentation). But most challenging here is that the three types of behaviour described for NLDS are displayed: the system can reach a stationary state, where it freezes, and the configuration of this stationary state may depend of the initial state (multistationarity); In this stationary configuration, elements may organise into a structure reminiscent of the self-organization of the NLDS; the system can oscillate regularly; or it may become chaotic, never stopping and never passing through the same state. In a fourth type of behaviour (at the edge of chaos) discovered through these methods, the system presents a series of partial organizations, some fixed, some other variables, (as is shown under certain conditions in the game of life).

Even though they may have numerous elements, the systems I have mentioned so far are composed of homogeneous elements that can be discerned at a local level and at a global level. These systems exist, of course, in nature but they are also important for understanding complexity and for studying it in larger, more complicated, even heterogeneous systems with several levels of organization.

For those involved with these more complicated complex systems, the emphasis on one or another aspect of complexity is not always the same, but we still find some of the concepts highlighted by the behaviours of NLDS. Here are two different descriptions. One is included in the introduction to the book devoted to the symposium held at Cérisy in 2008 on *déterminisme et complexité*[88] : « *Structurés sur plusieurs niveaux d'organisation, composés d'entités hétérogènes elles-mêmes complexes, les systèmes complexes recouvrent aussi bien les systèmes naturels que les systèmes artificiels sophistiqués ... Les systèmes complexes, depuis les objets nanoscopiques de la physique jusqu'à l'écosphère, résultent de processus d'émergence et d'évolution : les interactions*

[87] Hughes Bersini, 2006 op cit."*Their simultaneously collective and non-linear nature"* means that *"mathematics remains speechless to understand how new properties emerge because one can only understand this reciprocal influence by bringing these parts together by means of a computer simulation"*

[88] D*éterminismes et complexité, du physique à l 'éthique : autour d'Atlan*, in *colloque de Cérisy sous la direction de Paul Bourgine, David Chavalarias, Claude Cohen-Boulakia*, La Découverte, 2008. "*Structured on several levels of organization, composed of complex heterogeneous entities, complex systems cover both natural systems and sophisticated artificial systems. Complex systems, from nanoscopic objects in physics to the ecosphere, are the result of processes of emergence and evolution: individual interactions generate collective behaviours that can manifest organized structures. These emerging structures in turn influence individual behaviours. The causes are multiple and causality works both ascending and descending between levels of organization.* "

individuelles engendrent des comportements collectifs qui peuvent manifester des structures organisées. Ces structures émergentes influencent en retour les comportements individuels. Les causes sont multiples et la causalité fonctionne à la fois de façon ascendante et descendante entre les niveaux d'organisation. »

The other comes from a research program at the CNRS in 2004[89] *« Un système complexe peut être défini comme un système composé de nombreux éléments différenciés interagissant entre eux de manière non triviale (interactions non-linéaires, boucles de rétroaction, etc.). Un système complexe se caractérise par l'émergence au niveau global de propriétés nouvelles, non observables au niveau des éléments constitutifs, et par une dynamique de fonctionnement global difficilement prédictible à partir de l'observation et de l'analyse des interactions élémentaires*».

Can we also talk about complex systems when the system involves human beings, who are by nature all different and who, because they think, can modify the system during operation? This is a non-trivial issue, which has given rise to many controversies to which we will return. Advocates of the systemic approach sometimes speak for this reason of hyper-complex systems. For their part, members of the Santa Fe Institute launched the *Prediction Company*, *a company whose goal was to use dynamic systems theories to predict trends in financial and monetary markets as well as stock and bond prices*[90]. In France, the mathematician Gérard Weisbuch and the physicist Jean Pierre Nadal, carried out research on the modelling of collective social behaviours. They were able to show " *comment des comportements différenciés et pour certains aléatoires, donc libres, aboutissent à un comportement collectif modélisable, donc prédictible.*[91] » This is the case for the operation of a wholesale fish market in Marseille, studied by G.Weisbuch, or the dynamics of urban segregation studied by J.P. Nadal[92]. There are, therefore, cases where human groups behave as (or can be assimilated to) complex systems, and where studies of human behaviour using modelling or simulation of complex dynamic systems have been effective to understand what is happening, or even to act, (In the study of a throng issuing from a door, simulations showed how to put a pillar in front of a door in order to diminish the dangers).

Complex systems are defined, depending on the case and according to the authors, by their structure, by the existence of non-linear interactions, by the emergence of different levels of organization, or by their non-trivial collective behaviours (multistationarity, chaos, bifurcations,

89 *Action concertée systèmes complexes en SHS* (Sciences de l'Homme et de la Société), 2004."*A complex system can be defined as a system composed of many differentiated elements interacting with each other in a non-trivial way (non-linear interactions, feedback loops, etc.). A complex system is characterized by the emergence at global level of new properties, not observable at the level of the constituent elements, and by an overall dynamic of operation that is difficult to predict from the observation and analysis of the elementary interactions*. "

90 Roger Lewin *op.cit.* translated from the French translation

91 Colloque Cérisy *op.cit*. p 395. *"How differentiated behaviours some of which may be random, therefore free, lead to collective behaviour modelisable, therefore predictable."*

92 Laetitia Gauvin, Jean-Pierre Nadal and Jean Vannimenus, "*Schelling segregation in an open city: a kinetically constrained Blume-Emery-Griffiths spin-1 system*", arXiv:1002.3758, *Phys. Rev. E* 81, 066120 (2010)

self-organization, emergence, feedback loops). Some authors, relying on the large number of entities, insist on the structure, the heterogeneity and the presence of levels of organization, with emerging properties. Others insist on non-linearity and dynamics. This multiplicity of definitions has objective causes linked to the heterogeneity of objects grouped under the term complex systems, ranging from natural systems (from molecules to human societies), to artefacts such as the web. This necessarily corresponds to a multiplicity of points of view, all of which overlap, of course, but where the emphasis is not on the same properties. We shall see (Chapter V) that these differences stem also from ideological or philosophical criteria, which are particularly important in these fields.

What matters here is that, despite their great heterogeneity and the vast number of areas in which they can be found, these systems share some of their properties so that methods of study are common. These methods constitute the core of what has been called the *science of complex systems.* On the one hand, it is necessary to apply existing methods to new systems and, on the other hand, to develop new methods which the very heterogeneity and variety of these systems require. The National Complex Systems Network (NCSN), which aims to bring together scientists from all fields wanting to use the concepts and to share the methods of complex systems science systems writes « *Parce que les systèmes complexes nécessitent d'être analysés selon de nombreuses échelles spatiales et temporelles, les scientifiques affrontent des enjeux radicalement nouveaux, lorsqu'ils tentent d'observer des systèmes complexes, qu'ils apprennent à les décrire efficacement et à développer des théories originales de leur comportement et de leurs régulations»*[93]

This is why the complex systems' sciences are still in their early stages and would justify a great effort of theoretical and experimental research, most often interdisciplinary if only between mathematicians and / or computer scientists, and specialists in all other areas where complex systems are under study. As we shall see, this is still far from being easy.

Computer simulation methods (which are actively developed, either to simulate real systems or to study complex properties) have made it possible to find all the properties highlighted by the NLDS. But they have also made it possible to work on complex systems much more complicated than those that can be modelled, both by the number of variables and by their heterogeneity, and thus they have prompted a confusion between complex and complicated, which we will often refer to, and which considerably obscures the question of complexity.

1-3-3 Complex is not complicated.

Many complex systems possess a large number of elements, with a large number of interactions with each other. The brain, with its millions of neurons and billions of interactions, is

[93] RNSC http://rnsc.fr/tiki-index.php. *"Because complex systems need to be analysed at many spatial and temporal scales, scientists face radically new challenges when they try to observe complex systems, learn to describe them effectively, and develop original theories of their behaviour and regulation "*

the paradigmatic paradigm of complicated complexity. Indeed, it is not only complicated, it is very complex according to our definition since it presents, for example, a deterministic chaos behaviour that can be detected on the encephalograms, and that it is capable of bifurcations (epilepsy corresponds to a bifurcation towards a regular oscillating regime of the encephalogram). It is a wonderful model of self-organization, since, as was demonstrated recently, there is no organizing centre that regulates its functioning. As a matter of fact, many complicated systems have multiple interactions on each element, they are non-linear hence complex systems, and display the same properties as those of very simple complex systems such as those of the Rössler equation (3 variables, 3 parameters). Conversely, a puzzle can be very complicated, but it has only one stationary state and the whole is equal to the sum of the parts, since the image, being pre-contained in the pieces, is not an emergent property. (It could simply be called a *resultant* property).

What determines complexity with regard to complication may be the existence of multiple, non-linear interactions, and feedback loops that give these systems at least some of the properties discovered by NDSL. It may also be the heterogeneity of the elements, which can interact with very different time scales, resulting in the emergence of different levels of organizations. Or « *complexité doit être compris ici comme richesse de l'information et des interconnexions, variété des états et des évolutions possibles, toutes choses bien différentes de la complication au sens de imbrication de liaisons linéaires, stables, souvent fixées de manière rigide de l'extérieur de l'organe* [94]». A complicated complex system has several of the global dynamic properties of a simple complex system, but it is much more difficult to study, resulting in two leeways. On the one hand, and often according to the methods they use or the systems they study, some scientists do not accept as complex some simple systems (such as NLDS), which may prevent them from grasping the nature of complexity, the crucial role of non-linearity, even the deep difference between complex and complicated. On the other hand, the dynamics of complicated complex systems are still difficult to master, both by mathematical methods and by computer simulations. This can lead to a resort in purely static studies, favoured by the use of databases that can be immense, to store and manage all the information about a system, without worrying about the dynamics of the system.

The question of networks, very fashionable a few years ago, illustrates these possible drifts. A network can be static[95] (a map of interactions), or dynamic, if one is interested in the functioning of these interactions. But the dynamics depends on the structure, and the studies of the structures of the networks have been essential prerequisites for often more difficult dynamic studies. If the

94 Jacques Mélèse, *approches systémiques des organisations : vers l'entreprise à complexité humaine,* les éditions organisations, Paris , 1979, p 8."*Complexity must be understood here as the richness of information and interconnections, the variety of states and possible evolutions, all quite different from complication in the sense of imbrication of linear, stable bonds, often rigidly fixed from the outside of organ* ".

95 Hughes Bersini *op.cit*. favours the term graphs in these cases and reserves the term network to those where time intervenes, but this distinction is little passed in the current use.

network contains a very large number of elements, its dynamics is not, or poorly, amenable to studies. Many studies of networks thus stop at the structures, but are nevertheless considered to belong to the sciences of complex systems[96]. By increasing the complication, we have gone from systems characterized by the existence of some of the properties of non-linear dynamics to systems simply characterized by their multiple interactions, that may be seen as static [97].

I- 3-4 Complexity and Chance: Uncertainty and Determinism

Among the new and destabilizing properties introduced by the revolution of the complex, the role of chance (some prefer to call it of disorder) is important. With sensitivity to initial conditions and non-predictable determinism, NLDS have brought chance into the heart of the macroscopic sciences[98], but it is also present in other complex systems. I mentioned how, by putting small magnetic cubes in a box and shaking the box, the physicist Von Foerster could show their organization and drew a theory of *"the order resulting from noise"*. The emergent order from disorder is at the heart of the theory of dissipative structures. It was also theorized by S. Kauffman with the idea that this characterizes a particular behaviour, characteristic notably of living beings, which he calls the *edge of chaos*.

It is possible to introduce noise, that is to say small random fluctuations, either in differential equations or during simulations. It was then observed that the results obtained were often closer to the real phenomena thus modelled or simulated than if one omitted these noises. We speak of stochastic models opposed to deterministic models (even those that are not predictable). Again, we must be very careful, because this noise, these small fluctuations, this chance intervenes to render more blur an otherwise determined process, to give it more degrees of freedom and not to do anything. An image will perhaps illustrate the role of this noise. A complex process has often, as we have seen, several solutions. Let us represent it as a landscape formed by two valleys separated by a pass. Lets throw a ball into one of the valleys. It remains there and eventually reaches the bottom . Adding noise means giving the ball rebounds, at random. One of them can make it pass the pass again and make it land in the other valley: the noise will have only allowed the ball to explore all the pre-existing possibilities, but not to completely escape the landscape. This is the principle of operation of the pinball machine! There are other cases, where the noise can cause a bifurcation, so change the landscape, but then again not higgledy-piggledy .

In addition, the importance of so-called stochastic processes has become recognized quite recently: it seems to be the rule, for example, in the distribution of molecules within a living cell

[96] One of the most studied networks is the web, which despite its billions of interactions has some simple structural properties: for example, you can connect any two sites in less than 19 clicks. (This is what is known as a "s*mall world*" network)

[97] We shall see later how confusion between complex and complicated fuels ideological debates, or allows drifts, and even political and economic pressures.

[98] Whereas quantum uncertainty only concerns the infinitely small.

that leads to variability unsuspected until the 2000s. It may even happen that by adding noise to linear models allow to approach behaviours that would be more rigorously described by non linear models more complicated to be solved.

Various terms have been called to evoke these properties grouped together, notably by Prigogine, under the term uncertainty[99], which raises the important question of the significance of scientific determinism, of which we shall discuss in Chapters III. But here again a confusion must be avoided. What strikes, amazes and surprises us in the computer simulations of these systems is that, on the basis of often very simple rules, fantasy figures, kaleidoscope-like have nothing to do with chance, since they can be reproduced at will, provided that the simulation starts from exactly the same rules and the same initial positions of the elements. But researchers who implemented these rules did not always expect these results that were thus unpredictable for them. This confusion between unpredictability due to novelty and the role of chance in a complex process is the source of many debates about the importance and status of randomness (is this a fundamental property of Nature or a consequence of our ignorance, or both?) As we shall see in Chapter V.

I-3-5 Complexity and inter-disciplinarity.

Disciplines have a history. In France, they were first codified by Napoleon, and they are based on a differentiation of fields of knowledge, and thereby they are shifting, some are born others disappear, all change, but the existence of strong disciplinary barriers remains "*Les disciplines présentent ainsi une unité à la fois épistémologique (lois et principes, ontologies…), cognitive (méthodologies, pratiques, critères d'évaluation…) et sociologique (dynamique du système de publications, groupes au sein desquels les chercheurs se connaissent, se reconnaissent, se cooptent,* [100] They are also institutionalized places where power operations take place, and they delimit the frameworks of university teaching.

Obviously, their borders are sometimes trespased. this justifies our starting with a point of vocabulary: pluridisciplinarity, interdisciplinarity, transdisciplinarity, are not synonyms. Marcel Jollivet, summarizing a seminar held in 2001 on the theme "*Linking Knowledge, Transversality, Interdisciplinarit*y" writes[101] "*L'interdisciplinarité est définie par l'un des intervenants comme «*

99 Ilya Prigogine *la fin des certitudes*, Odile Jacob, 1996.

100 (Kleinpeter, 2013). cité dans 36 Dossier de veille de l'IFÉ • n° 120 • Novembre 2017 *L'avenir de l'université est-il interdisciplinaire ? (The disciplines thus present a unity that is both epistemological (laws and principles, ontologies ...), cognitive (methodologies, practices, evaluation criteria ...) and sociological (dynamics of the system of publications, groups in which researchers know each other, recognize, co-opt,)*

101 Published in *Nature, Sciences et Sociétés*,,Vol 10, N° 1, 2002,p.78-95 *"Interdisciplinarity is defined by one of the speakers as "an approach of dialogical assembly of the disciplinary contributions necessary for the analysis of a complex object ". The term "dialogic" is used to signify a fundamental difference with the pluridisciplinarity, in which the contributions of the disciplines are simply juxtaposed. Five levels of integration are to be distinguished in an interdisciplinary approach... from a point of view that overlooks all disciplinary points of view. This entails a particular requirement of rigour. On the other hand, it must be stressed that the reference to the whole refers neither to a global coherence nor to an exhaustive knowledge of the whole. It is necessary to accept both the encyclopaedic aspect of knowledge and its unfinished character, and interpretations that refer to contradictory dynamics ". ...*

une démarche d'assemblage dialogique des apports disciplinaires nécessaires à l'analyse d'un objet complexe ».Le qualificatif « dialogique » est employé pour signifier une différence fondamentale avec la pluridisciplinarité, dans laquelle les apports des disciplines sont simplement juxtaposés. Cinq niveaux d'intégration sont à distinguer dans une démarche interdisciplinaire ...d'un point de vue qui surplombe tous les points de vue disciplinaires. Ceci entraîne une exigence particulière de rigueur. Par ailleurs, il faut prendre garde au fait que la référence à la totalité ne renvoie ni à une cohérence globale, ni à une connaissance exhaustive du tout. Il faut accepter à la fois l'aspect encyclopédique de la connaissance mobilisée et son caractère inachevé, et les interprétations qui renvoient à des dynamiques contradictoires ».

Multidisciplinarity juxtaposes disciplines, interdisciplinarity integrates them, transdisciplinarity makes them overlooked by a unifying point of view, for example the complex.

One of the strong tendencies of the present sciences is parcelling, ultra-specialization, due to the considerable increase in knowledge, but also to scientific strategies analytical and reductionist. This specialization is most often opposed from the point of view of the complex, both because a dynamic system does not necessarily correspond to the disciplinary fields previously designed by and for the static and analytical study of phenomena and because the tools and the methods of the sciences of complex systems being generic, transcend the disciplinary barriers. In addition, the generalised use of models or simulations requires training in mathematics and computer science that is not taught (in France) at a sufficient level for other scientists (except physicists).

The reasons cited by the NNCS for claiming interdisciplinarity are mainly based on the identity of the methods to study the complex, whatever the support. The network intends to help each one in their discipline to import these common methods and to stimulate research to discover new ones. But this often also leads to launch new research subjects, that stand between the boundaries between disciplines, because each discipline, even sub-discipline, determines scientific issues from within its borders[102].

Is the reciprocal true, does interdisciplinarity lead to complexity? Cooperation between disciplines is often required by finalized or applied research (see Chapter IV). This may involve placing studied objects in a wider context, which will, *de facto*, be complex. In this case, even if the claim of interdisciplinarity is not the result of an explicit search of complexity, it may promote its emergence[103]. I also mentioned how the Santa Fe Institute, initially dedicated to interdisciplinarity, quickly developed into the Institute for adaptive complexity .

[102] See Isabelle Stengers, U*ne autre science est possible*, La Découverte, 2013.
[103] But it can also involve juxtaposing techniques within a very fashionable technical platform

Chapter II The complex as a mindset.

In the context of the complex systems sciences, methods of mathematical modelling and computer simulation have been devised that continue to be developed both for the exact sciences and, in a number of cases, for the social sciences. But, as we have seen, new scientific concepts did emerge from the properties revealed through these methods.

These new concepts require, and lead to, a renewal of the mindset which, unlike those associated with the revolution of physics at the beginning of the last century, concerns all the scientific disciplines in which these methods can be used. They can be understood, as I have tried to show, independently of the computers or equations that led to their discovery. This makes it possible to suppose that these concepts derived from the exact sciences can be used, and even discovered, without the methods which have been initially necessary. Parallel to the sciences of systems, complexity approaches have been developed, which do not require the use of mathematics and have nearly no part in the complex systems sciences, but which are part of the complex revolution of the complex. I have mentioned above the school of Palo-Alto and the history's school The Annals, but more and more disciplines or researchers are using concepts of complexity[104]. Most often, however they do not formalize their use as a method.

These new concepts correspond to a renewal of the way of thinking, which opposes, while encompassing, the classical form (linear, Cartesian, reductionist), which at present dominates scientific as well as lay thinking to which I will refer here as the dominant way of thinking (see V-3). This new form of thinking concerns all the scientific disciplines in which these methods are used, but the actors themselves are not always aware of it because they very often perceive only the technical novelty,

In 1982 Edgar Morin wrote[105] ;« *De toutes les parts surgit le besoin d'un principe d'explication plus riche que le principe de simplification (disjonction/réduction) et que l'on peut appeler le principe de complexité. Celui-ci, certes, se fonde sur la nécessite de distinguer et d'analyser, comme le précédent. Mais il cherche de plus à établir la communication entre ce qui est distingué : l'objet de l'environnement, la chose observée et son observateur.Il s'efforce non pas de sacrifier le tout à la partie, la partie au tout, mais de concevoir la difficile problématique de*

[104] it even may concern lawyers

[105] *"From all parts arises the need for a richer explanation principle than the principle of simplification (disjunction / reduction) and which can be called the principle of complexity. This principle, of course, is based on the need to distinguish and analyse, as the previous one. But it also seeks to establish communication between what is distinguished: the object of the environment, the thing observed and its observer. It endeavours not to sacrifice the whole to the part, the part to the whole, but to conceive the difficult problematic of organization, in which, as Pascal said, "it is impossible to know the parts without knowing the whole, not more than to know the whole without knowing particularly the parts ".Edgar Morin, Science avec Conscience, Fayard, 1982 p43*

l'organisation, où, comme disait Pascal, « il est impossible de connaître les parties sans connaître le tout, non plus que de connaître le tout sans connaître particulièrement les parties». It is to these requirements that his *Complex Thought* answers.

By the years 70-80, some scientists had already perceived that these new concepts were creating a new way of thinking, leading to a new conception of the world. Their books, which aroused great interest at the time, are sometimes forgotten now, while they remain relevant in many ways. These concepts of the complex, without the mathematics that allowed them to be born, can thus allow, besides their direct use in the sciences where modelling is not an option (as is often the case for the human and social sciences), a more general renewal of the forms of thinking and vision of the world. It is this aspect that I will develop now, by first presenting the principal authors or currents of thought who have approached it.

For the problem is still there, the new form of thinking has still not been imposed, despite the fact that the complexification of the world makes it more and more necessary, and that advances in the sciences of the complex makes it more and more accessible. Indeed, in spite of the diversity of these sciences of the complex, their coherence is increasing, and this coherence arises precisely from this new form of thinking. It emanates from all these practices, without being formalized, and I will try to present it under the name of *the complexity thinking*.

II-1 The precursors

II-1-1 Ilya Prigogine

Prigogine's work on the thermodynamics of non-equilibrium and the formation of dissipative structures has been mentioned in Chapter I as one of the branches of this "metamorphosis of the science" that are the sciences of the complex. However, with the publication of the book "*la nouvelle allianc*e[106]", in collaboration with the philosopher Isabelle Stengers, this physicist highlighted the way in which a new scientific way of thinking, destined to become a general form of thinking, emerges from this new way to do science. This is what the philosopher Arnaud Spire will call later "l*a pensée Prigogine*[107]".

At the beginning of the introduction of their book, *la nouvelle alliance,* the authors write: « *Nous pensons que ces questions ne sont pas seulement des questions scientifiques et que les enjeux de la métamorphose de la science ne sot pas tous d'ordre scientifique....La science fait partie du complexe culturel à partir duquel à chaque génération, des hommes tentent de trouver une forme de cohérence intellectuelle....au delà* de *son contenu théorique, la métamorphose que nous allons décrire renouvelle notre conception des relations des hommes avec la nature et la science*

[106] Ilya Prigogine, Isabelle Stengers. *Order out of Chaos: Man's new dialogue with nature.* english translation 1984 Flamingo. *ISBN 0-00-654115-1*.

[107] Arnaud Spire *La pensée-Prigogine*. Desclée de Brouwer 1999

comme pratique culturelle [108]». This was summed up by the sociologist Reda Ben Kirane "*« en partant dune réflexion théorique sur la chimie et la thermodynamique, réflexion qui a finalement consacré l'école de Bruxelles de l'auto-organsiation, Ilya Prigogine en est venu progressivement à une philosophie de la science qui s'intéresse à des « lois du chaos », formulées en termes probabilistes, à un monde fluctuant, bruyant, né de l'existence de particules instables, d'un univers évolutif en expansion et de structures dissipatives ….*[109] »

Prigogine's vigorous polemics against the reversible time of physics, has promoted the arrow of time while the introduction of the concept of uncertainty into rationality, was mostly retained probably because of the book "*la fin des certitudes"*[110]? But *la Nouvelle Alliance* also invites us to reconsider the way in which we think of nature and our place in nature and resonates in a premonitory way for our century confronted with the depletion of resources and climatic upheavals. «*L'histoire que nous allons conter est aussi celle de la nature, à la fois celle de nos conceptions de la nature et celle de nos rapports avec elle, des effets que nous y produisons et des processus que nous y cultivons systématiquement, en la peuplant notamment de machines. ... Le temps aujourd'hui retrouvé, c'est aussi le temps qui ne parle plus de solitude, mais de l'alliance de l'homme avec la nature qu'il décrit.* [111]»

II-1-2 Joel de Rosnay and *Le Macroscope*.

As early as 1975, Joel de Rosnay's " *Le Macroscope*"[112] summarizes the knowledge of the time on complexity and depicts the change in the world view that should follow. The *macroscope* is thus named by analogy with the microscope and the telescope, to evoke an instrument (here an instrument of thought) allowing to see the infinitely complex, that the "classical" methods do not allow to apprehend. *« il nous faut donc un nouvel outil. Aussi précieux que furent le microscope et le télescope dans la connaissance scientifique de l'univers, mais qui serait cette fois, destiné à tous deux qui tentent de comprendre et de structurer leur action. Aux grands responsables de la politique, de la science, de l'industrie, comme à chacun d'entre nous. Cet outil, je l'appelle le macroscope (macro, grand ; et skopien observer).*

[108] *Op cit* p 9-10 *We believe that these questions are not only scientific questions and that the stakes of the metamorphosis of science are not only scientific... Science is part of the cultural complex from which, at each generation, men attempt to find a form of intellectual coherence... beyond its theoretical content, the metamorphosis that we are going to describe renews our conception of man's relationship with nature and science as a cultural practice.*

[109] Réda Ben Kirane *La Complexité vertiges et promesses* ed le pommier 2002 p 37. "*Starting from a theoretical reflection on chemistry and thermodynamics, a reflection which finally consecrated the Brussels school of self-organiation, Ilya Prigogine gradually came to a philosophy of science which is interested in" laws from chaos ", formulated in probabilistic terms, to a fluctuating, noisy world born from the existence of unstable particles, an evolving universe of expansion and dissipative structures ....*"

[110] Published in English as *The End of Certainty: Time, Chaos, and the New Laws of Nature* Free Press,1997

[111] *Op. cit* .p 18-19 *The story we are about to tell is also about nature, both that of our conceptions of nature and that of our relations with it, the effects that we produce there and the processes that we systematically cultivate there, by populating it notably with machines. ... The time now recovered is also the time that no longer speaks of loneliness, but of the alliance of man with the nature he describes.*

[112] Joël de Rosnay, *Le Macroscope, vers une vision globale*, le Seuil, 2014

Le macroscope n'est pas un outil comme les autres. C'est un instrument symbolique, fait d'un ensemble de méthodes et techniques empruntées à des disciplines très différentes...le macroscope est considéré comme le symbole d'une nouvelle manière de voir, de comprendre, et d'agir.[113] »

The focus is therefore on the way of thinking, and its translation in terms of action, particularly in terms of organization (of a company, a state or an ecosystem). He defines his systemic approach as opposed to classical thinking and emphasizes the critical importance of negative feedback loops to ensure the stability of a complex system, and of positive feedback loops (that were only known at the time as a growth enhancer – the snowball). He also proposes an education to, and through, the systemic approach, based on the themes to be treated and their interdisciplinary approach but also on self-learning. (see chapter V-5). This considerable work had a certain resonance at the time, but is now nearly forgotten, although its contributions remain largely relevant.

Among these forgotten precursors is Henri Laborrit[114], and also in a certain way the *groupe des dix*[115] formed from 1966 to 1979, by scientists wishing to enlighten politics thanks to the recent contributions of sciences, and who have very quickly put cybernetics then complexity on their agenda .

II- 2. Systemic

Coming from the least mechanistic branch of cybernetics, systemic, which appeared in the 1950s and was popularized by the biologist Ludwig von Bertalanffy as *systems theory*, implies a certain vision of the world, of nature, of the living and especially of humanity, But this term actually includes a fairly wide variety of positions, in which I will distinguish two major currents. One can be described as holistic, for it is interested in the wholeness of often static systems regardless of their elementary composition. For the other, the totality of a system comprehends its dynamics and is thus very close to what I have presented as a complex systems. In 1979 Jacques Mélèse wrote *« la prise en compte des relations entre tout et parties, entre l'individuel et le collectif, de l'improviste attachée à la dynamique des processus de fonctionnement, d'évolution et d'apprentissage...le qualificatif de systémique est, je crois le seul à l'heure actuelle qui comporte de telles connotations..* [116]». This systemic approach of complex systems is then a methodology of

[113] *ibid* p 2 "*So we need a new tool. As valuable as were the microscope and the telescope in the scientific knowledge of the universe, but this time, intended for all of them who are trying to understand and structure their action. To the great leaders of politics, science, industry, as to each of us. This tool, I call it the macroscope (macro, big, and skopien observe). The macroscope is not a tool like any other. It is a symbolic instrument, made of a set of methods and techniques borrowed from very different disciplines ... the macroscope is considered as the symbol of a new way of seeing, of understanding, and of acting.* "

[114] Henr Labori,t *La nouvelle grille,* Robert Lafont, 1974

[115] cf Brigitte Chamak, *Le groupe des Dix,* Éditions du rocher, 1997. I discuss this gorup's impact in *émancipation et pensée du complexe Op Cit*

[116] *Jacques Mélèze op cit* p10 *"The taking into account of the relations between whole and parts, between the individual and the collective, of the unexpected attached to the dynamics of the processes of functioning, evolution and learning ... the term of systemic is, I believe the only one at present that has such connotations.*

understanding and controlled action on the real, of which Jean Louis Lemoigne1[117], engineer and philosopher, is the the prominent figure . As such, systemic is a branch of the complex revolution, supported by mathematical modelling, directed to action, and aware of its epistemological dimension that lay claims to the work of Edgar Morin (see below).

Systemic also feeds a trend of *decision support* that I will illustrate from the book by Arlette Yatchinovsky. Here are some principles from this book intended to help business management using the systemic approach that is thus defined[118]:

« A l'opposée d'une vision mécaniste, déterministe (telle cause créée tel effet), elle traite conjointement effets et causes dans leurs interactions

Elle associe, rassemble, considère les éléments dans leur ensemble, les uns vis à vis des autres et dans leurs rapports à l'ensemble, ... à l'inverse de la logique cartésienne qui dissocie, partage, décompose pour simplifier la problématique.

Elle prend en compte l'ensemble du système auquel appartient l'élément, l'individu ou le problème considéré, afin de l'appréhender par ses interactions avec les autres éléments du même système, ... à l'inverse de l'approche analytique qui prend en compte l'élément, l'individu ou le problème considéré pour, à partir de lui, tenter d'appréhender l'ensemble ».

This describes a way of thinking totally opposite to the current form described here as mechanistic, deterministic, analytical, and most often Cartesian. It is a global approach, where the interactions (relationships) between the elements are less important than the overall behaviour itself.

Systemic also highlights the porosity of interacting systems and the primacy of the organizing principles of the encompassing system, on its subsystems. The stability, the equilibrium of the system being the result of its dynamics, the change of this equilibrium must overcome the principle of homoeostasis: it is subjected to a sufficiently significant action and for a sufficiently long time (in order to be appropriated by the entire system) to be integrated by the system as an operating criterion. In affiliation with cybernetics, systemic therefore emphasizes negative feedback loops and homoeostasis, stability and finality. It also includes, in a preponderant way, uncertainty.

Finally, it defines a hyper-complexity whose *« réalité est par et dans son mouvement, mettant en jeu d'innombrables paramètres interactifs, structurés et fonctionnant selon une logique de système. Le cerveau humain, l'humain, les groupes humains sont des exemples de systèmes*

[117] For a general presentation Jean Louis Lemoigne in « *Systémique et complexité* » special issue of R*evue internationale de systémique*, 1990

[118] Arlette Yatchinovsky, *L'approche systémique pour gérer l'incertitude et la complexité*, ESF publisher, Coll. Formation permanente,1999. « *At the opposite of a mechanistic, deterministic vision (such cause creates such an effect), it deals jointly with effects and causes in their interactions. It associates, brings together, considers the elements as a whole, with respect to each other and in their relation to the whole... unlike the Cartesian logic which dissociates, shares, and decomposes to simplify the problematic. It takes into account the whole system to which belongs the element, the individual or the problem considered, in order to apprehend it by its interactions with the other elements of the same system... contrary to the analytical approach that takes into account the element, the individual or the problem considered, trying to apprehend the whole from them*.

hypercomplexes. Tout système est un élément « vivant » dont la stabilité réside dans la raison d'être, dans le traitement d'une problématique, dans la poursuite d'un but, d'une finalité qui le définit : cette stabilité n'est pas immobilisme mais « équilibration de sa dynamique fonctionnelle », c'est à dire que l'écartement de la ligne projetée doit générer un dispositif contraire de retour à ce vecteur de progression (comme un dispositif de pilotage automatique) [119]».

We can see obvious convergences with the concepts arising from the sciences of complex systems, with an emphasis on regulation and dynamic stability. But notions such as non-linearity, self-organization, emergence, bifurcations, or processes far from equilibrium, as well as the importance of positive feedback loops, are non-existent (or operate implicitly).

Whether static or dynamic, systemic often puts emphasis on stability, which, as we will see in Chapter IV, may explain that it has been often accepted within the framework of the " liberal economy" since it remains compatible with the hierarchical organization of enterprises.

II-3 Edgar Morin and the "complex thought" .

Philosopher / sociologist / anthropologist, Edgar Morin, has constructed what he calls the *complex thought*, through a considerable work[120] which can not be analysed here. He presented a first version of it, in 1982 in a book which made date *Science with conscience*[121]. And more recently he has given a very brief summary[122] on which I will rely for an even more compact presentation, in order to confront this thought with the other aspects of the revolution of the complex .

Morin presents his *Complex Thought* as built along 3 levels. First, three theories: the *theory of information*, which enables him to *enter a universe where there is at once order, disorder, and extract from it a new one.* Then, *cybernetics,* to which he borrows ideas of feedback, negative for homoeostasis and positive seen only as amplification. Finally the *theory of systems*, based on the fact that "*the whole is more than the sum of the parts*", which hierarchises the levels of organization through the notion of emergence. This first level provides him with the notion of organization.

To this first layer he adds the contribution of various currents of the sciences of complex systems, von Neumann, von Foerster, Atlan and Prigogine. He mainly retains the notion of uncertainty and the order resulting from the disorder which he summarizes by the formula: *order / disorder / organization.* This second level gives him the notion of self-organization

[119] Ibid "*Reality is by and in its movement, involving innumerable parameters that are interactive, structured and functioning according to a system logic. The human brain, the human, the human groups are examples of hypercomplex systems. Every system is a "living" element whose stability lies in the raison d'etre, in the treatment of a problem, in the pursuit of a goal, of a finality that defines it: this stability is not immobility but "equilibrium of its functional dynamics",* i.*e. that the spacing of the projected line must generate an opposite return device to this progression vector (such as an autopilot device).*

[120] Edgar Morin *La méthode,* 6 volumes and 2000 pages

[121] *Op cit*

[122] Edgar Morin et Jean Louis Lemoigne, Chapitre IV, *La pensée complexe, une pensée qui se pense, in l'intelligence de la complexité* , L'Harmattan 1999.

To this he adds three other principles which are its own: the *dialogic principle* which unites two antagonistic principles *which are inseparable and indispensable for understanding the same reality*[123]; the principle of *recursion,* or the generating loop in which the products and effects are themselves producers of what produces them, like the human being which produces society and is produced by it; the *hologrammatic* principle for which the whole contains the parts and the parts contain the whole[124], like the differentiated cells containing the genome of the whole organism, itself composed of cells.

On the basis of these tools, Morin constructed a thought, which is opposed to what he calls simplifying thought (which systemic described as Cartesian thought). But, unlike systemic the complex thought does not want to substitute for simplifying thought and replace its principles by opposing principles. On the contrary, the aim is to encompass, surpass, this thought, to bring about the union of simplicity and complexity.

« Ce n'est pas une pensée qui chasse la certitude pour l'incertitude ... la démarche consiste au contraire à faire un incessant aller et retour entre certitudes et incertitudes, entre l'élémentaire et le global, entre le séparable et l'inséparable ». It consists in « *relier tout en distinguan*t ». or « *Et la complexité ce n'est pas seulement penser l'un et le multiple ensemble, c'est aussi penser ensemble l'incertitude et le certain, le logique et le contradictoire, et c'est l'inclusion de l'observateur dans l'observation »*[125]

In this text, Morin enumerates seven principles of complex thought.

The systemic or organizational principle, which implies the non dissociability of the whole and the parts and the emergence of levels of organization*: the hologrammatic principle; the principle of the retroactive loop; the principle of the recursive loop; the principle of self-eco-organization* or *autonomy-dependence:* living beings reproduce themselves by spending energy that comes from the environment: their autonomy is therefore dependent on the environment. *The dialogic principle*; *the principle of reintroduction of the knowing in all knowledge*: He writes for example:*« La nécessité de penser ensemble, dans leur complémentarité, dans leur concurrence et dans leur antagonisme, les notions d'ordre et de désordre nous pose très exactement le problème de penser la complexité de la réalité physique, biologique et humaine. Mais pour cela […] il nous faut […] nous inclure dans notre vision du monde »*[126]

[123] More precisely, in *La méthode : la nature de la nature le Seuil, Paris, 1977,* he shows that the whole may be more or less than the sum of the parts, in other words the exact formula must be "*the whole is different from the sum of the parties* ".

[124] This notion seems to me very close to that of non-antagonistic contradiction described by Lucien Sève, and I shall return to this in Chapter III. The example that they both give is that of the wave / particle duality of light

[125] *ibid*. p 92.*connecting and distinguishing*. Or *And complexity is not only to think of the one and the multiple together, it is also to think together the uncertainty and the certain, the logic and the contradictory, and it is the inclusion of the observer in observation.*

[126] *ibid.* p 89.*The need to think together, in their complementarity, in their competition and in their antagonism, the notions of order and disorder, very exactly raises the problem of thinking the complexity of physical, biological and human reality. But for this [...] we must [...] include ourselves in our vision of the world.*

As early as 1982, Morin summarized the tasks of complex thought ;*«La pensée complexe doit remplir de très nombreuses conditions pour être complexe : elle doit relier l'objet au sujet et à son environnement ; elle doit considérer l'objet non comme un objet mais comme un système/organisation posant les problèmes complexes de l'organisation. Elle doit respecter la multidimensionnalité des êtres et des choses. Elle doit travailler/dialoguer avec l'incertitude, avec l'irrationalisable. Elle doit non plus désintégrer le monde des phénomènes, mais tenter d'en rendre compte en le mutilant le moins possible »*[127]

We can see then that the *complex thought* is built above all on the basis of its own concepts and borrows only a few of the concepts of the sciences of complexity and NLDS. The dialogic, recursive and hologrammatic principles (discussed in the next chapter with regard to their relationship with dialectic) and the principle of reintroduction of the knowing in all knowledge, on which Morin insists, are his very own contribution. He incorporates systemic concepts of emergence. Non-linearity is present, but reduced to feedback, since the absence of proportionality between cause and effect is not highlighted. The non-trivial behaviours of non-linear systems are reduced to self-organization (and sometimes to chaos). Although he relies on data and advances in the natural sciences, and refuses the separation of scientific domains, he has concentrated on the anthropological and sociological domains. Beyond that he is recognized as a source of inspiration by many advocates of systemic, as well as by trainers and researchers in the sciences of education[128].

The work of Edgar Morin thus contains both a method, (he denies having built a system) and its use, mainly in the human and social sciences. He very often insists on the profound rupture of the modes of thought to which his method leads, and on the fact that the evolution of sciences and situations makes it indispensable. It is therefore a particular branch of the complex revolution, alongside the sciences of complex systems and the dynamics of non-linear systems.

II-4 The complexity thinking

What I call the *complexity thinking*, is a renewed mindset, resulting from the revolution of the complex and which forms part of it. It emanates from the practices of the sciences of the complex and somewhat represents what is common to all these disciplines not in the form of a "smaller common denominator", but rather as what encompasses them and gives them coherence. It is therefore shared, in a more or less implicit way, by many of the actors involved in this revolution

[127] *ibid.* p 305-6. *Complex thought must fulfil many conditions in order to be complex: it must relate the object to the subject and to its environment; it must consider the object not as an object but as a system / organization posing the complex problems of the organization. It must respect the multidimensionality of beings and things. It must work / dialogue with uncertainty, with the irrationalisable. Nor must it disintegrate the world of phenomena, but attempt to account for it by mutilating it as little as possible* "

[128] Clenet Jean et Daniel Poisson, *Complexité de la formation et formation à la complexité,* L'harmattan, 2006.

of the complex, which makes it moving, unfinished, and moreover, as we will see very often, ignored by many of those who implement it.

This complexity thinking is not formalized, and this book hopes also to be a step in the process of its explicitation. It is both an epistemological approach to understanding the common concepts and approaches resulting from, and at work in, the various sciences of the complex, and a reflection on whether and how these concepts may be transposed beyond the sciences and techniques (mathematics and computer science) that gave birth to them. It is a question of looking into how these approaches and these concepts draw a form of thought, at the same time scientific and "profane" way of thinking in deep rupture with the traditional way of thinking. It is also a question of going beyond, because it does not abolish it but draws its narrow limits. It joins in many ways the dialectical philosophical tradition. (Chapter III). This new way of thinking can be in return useful for the development of the sciences of the complex from which it emerges (chapter III), and can also be the base of the indispensable renewal of rationalism. (chapter V).

We have seen that the sciences of the complex cause an upheaval / deepening of the meaning of the most fundamental scientific concepts: determinism can become non-predictive, causality can escape the categories of Aristotle and become circular, a global order can arise from local disorder, chance becomes necessary... Science wobbles on its former foundations, to the point that the great scientist I. Prigogine considered that determinism was dead. I see it rather as a transformed science, not only in its methods, but, more fundamentally, in its concepts, what I wanted to emphasize when speaking of a scientific revolution. *«A maints égards paraît donc amorcée une fluctuation géante de la rationalité scientifique où sont remises en chantier jusqu'à des catégories fondamentales de l'être et de la pensée»*[129]

Exceeding (and encompassing) the classic (still dominant) form of thought, complex thinking uses the concepts of NLS and complex systems sciences to be able to think about objects and processes, precisely in their complexity[130]. And because these concepts concern multiple systems on a human scale, they are likely to fertilize thinking far beyond the simulation or modelling of complex systems. I will therefore have to face the thorny question of the legitimacy of the transposition of scientific concepts.

II-4-1 What are the "ingredients" of the complexity thinking?

From all that precedes, it appears that there can not be a rigid definition of the complexity thinking, but it is possible to present "ingredients" more or less shared by the various disciplinary fields, and the way in which they can fit together to help thinking about the complexity of today's world.

[129] Lucien Sève 1998 *op.cit.* p 110 . *In many respects, therefore, a giant fluctuation of scientific rationality seems to have begun, in which fundamental categories of being and thinking are put again to work*

[130] It is also what Jean Clénet (*op cit)* calls *a renewed form of understanding: the intelligence of complexity*

There is a first stage common to all the sciences of the complex, which represents a first and decisive break with the dominant form of thinking, it is the choice, (the decision) to take into consideration a phenomenon, a process, or even an object, not isolated and in itself, but as part of a complex system, or as a system. In other words, it is a question of considering and understanding the global organization of the interactions between the elements which constitute it, or those with which it interacts and, if possible, the transformations and the levels of organization (and not to simply analyse the components, as does Cartesian / reductionist thinking, or to see it only in its entirety as does holism and partly, systemic). This choice is not always easy to make, because it often opposes our most ingrained habits of thought (as I will analyse in chapter V). And because it often requires an other choice.

How, indeed, determine the set of elements to connect? Sometimes the division seems obvious, if one deals with manifest organizational levels. At each level there is a set of elements of the lower level and each level is one of the elements of the higher level. This is particularly evident in biology, where the cell, the tissue, the organ, the organism, the ecosystem are all recognized levels, which correspond to divisions in sub-disciplines. Note also that this division in turn, makes it difficult to reasoning in terms of system, since it imposes non porous barriers between the levels.

But in many cases there is more than one system to which the phenomenon under consideration can be attached. This implies a second choice, that of the criteria to be used depending on the point of view to be privileged. (we can think of multiple ways of considering a landscape as a system). In these cases, any choice arises from a point of view that is necessarily partial and one-sided, but which reveals an aspect of reality. In other words, it is essential to accept the incompleteness of the approach, incompleteness which often also calls for a plurality of points of view. And these complementary points of view, do not simply add like the pieces of a puzzle, but are likely to present contradictions. Knowing them is necessary to understand a complex situation but does not necessarily facilitate decision-making[131].

To pose the necessity of this choice as the primary act of the *complexity thinking*, does not imply at this stage any transposition of scientific concepts and meets also complex thought and systemic approaches. Like these, complexity thinking is different from classical ways of thinking, whether scholarly or not. Like them, this way of thinking, concerned by the *dynamics* of a process as a whole, seeks the *multiplicity of causes*, *ie* the multiplicity of interactions between objects that can be heterogeneous, but also *interactions between these interactions*, *ie* the regulations, the relationships between the actors of the process, and the emergence of properties at higher levels. Edgar Morin has perfectly characterized the implications, the difficulties and the imperative necessity of such a choice, as well as the necessity, not to replace the simplifying way of thinking

[131] One can think of the conflict around the airport of Notre Dame des Landes, where many of the opposing conceptions were based on a dynamic and systemic analysis, but not taking into account the same data or the same social project.

but to integrate it by going beyond. This stage, where systemic thinking often ends, is already a strong break with classical, dominant thinking in both science and social and political life. It is necessary to give up the so convenient binarism (either, or else) because a system of interactions very rarely has only two components. It is necessary to give up the comfort of the analysis, from which one can be satisfied to having found one component, which is then claimed as fundamental. Above all, we must give up the comfort of thinking that the truth lies in simplicity, and that we can dispense with reflecting on the multiple contexts in which we find ourselves, which also eliminates history and chance. The examples are innumerable. let's take agrofuels, which is supposed to be a civilisational advance because they help reduce oil consumption. Certainly, but in agro-fuel, there is also agro, and it is important to also look at the system from this point of view, including by integrating the financial speculation on cereals that is accelerated, and the resulting famines, or the palm oil trees that require deforestation.

But complexity thinking, in order to concretise this approach, to succeed in understanding the dynamic of the interactions must be enriched by the concepts emanating from the sciences of complex systems (and it is in this sense that it is in essence unfinished). This second stage is more delicate because it involves a transposition of concepts from one discipline to another, or even to lay thought. It is a thought that monitors out-of-equilibrium behaviours, searches for multistationnarity, oscillations, deterministic chaos, bifurcations and self-organized processes, emergence; it knows the importance of feedback loops, negative, but also positive as necessary conditions of multistationarity, therefore of the plurality of possibilities; it is prepared for the uncertainty, the importance of noise.

It is therefore essential to evaluate the usefulness and even the relevance of these concepts in the absence of mathematical and computer tools that gave birth to them. This approach meets, as we have seen, many reluctance, not only among those who challenge anyway complexity, but also among those who fear a dogmatic use and a totalitarian veneer of scientific concepts transposed and therefore unsuited especially towards social or societal issues involving human beings.

II-4-2 areas of application and choice

And first of all, we must apprehend their areas of application. All is not uncertainty or noise, everything does not lead to bifurcations, everything does not self-organize automatically, disorder does not always generate order, chaotic systems are not so common and unpredictability (or uncertainty) is not an absolute (as space travellers have very happily experienced), but the property of some (complex) systems.

It is therefore not a matter of automatically replacing conventional concepts with new ones, but of having these new concepts at the ready when they are relevant for analysing the world in its complexity. We always think through concepts. Why should one deprive oneself of those of the complex, if they prove useful, under the pretext that they come from recent scientific disciplines that have forged them through mathematical or computer models? Why should we favour those who derive from older mathematical models, fully integrated into our imagination that forgets the source, such as proportionality, that no one doubts the legitimacy of employment outside the Thales' theorem.

The choice to consider a process as a complex dynamic system implies to focus primarily on interactions. But these can be linear or non-linear. Why would linearity be more acceptable than non linearity? Taking into account non linearity allows us for example to know that there is not always proportionality between the effort and its results. This is essential provided that we do not use this knowledge to any process, but to increase the spectrum of assumptions and observations that will have to be made to understand it or to try to predict the behaviour of a system, (even the result of our actions). If the interactions are non-linear, then non-intuitive behaviours can be expected to occur, which helps to first detect them and then better manage them.

In the case of a complex system, the bifurcations obey a certain number of different behaviours and present certain regularities which it is obviously useful to know. For example, the historian Immanuel Wallerstein, the current leader of the Annales School, studying the current crisis of capitalism, considers that it is different from those of the past and its erratic turbulence reminds him of what is happening in a non-linear system shortly before a bifurcation. He therefore posits the hypothesis that such a bifurcation is in progress (in the coming half century)[132] and draws some proposals for action. In what way is it less responsible and justified than to assume that the world system has reached a stable and definitive steady state?

This does not lead us to reject the results obtained by the non-complex paradigms, but to integrate them into a much larger mind set, which implies a global revolution of thought, which meets and integrates the complex thought of Edgar Morin. These concepts function neither as laws, nor as general metaphors that it would suffice to press on this or that reality. They can provide analogies to make assumptions in the framework of the initial choice; or they can help searching for some kinds of interactions, such as feedback loops, to see if they are responsible for particular behaviours or whether they can help resolve some problems. As analogy lets think of a thermostat. If it is too cold in a room, should you put the boiler up or adjust the thermostat, *ie* influence the feedback loop that regulates the temperature? These hypotheses will often be more plausible than those based on linear reasoning, but they still have to be demonstrated if it is possible, and if not, it must be remembered that they are hypotheses, just like those that emanate from linear thinking that we find too often obvious only because of our education. (see also Chapter V)

[132] Immanuel Wallerstein. *World-systems analysis : an introduction* Durham: Duke University Press 2004.

Finally, this point of view very often requires a plurality of approaches. Just as it is sometimes necessary to go around a sculpture to have a complete idea, so it is frequent that only one method is not sufficient to perceive the complexity of a system. Analytical approaches remain useful in the panoply of methods, but cease to be the only ones possible. Since all modelling is inherently a simplification, it is useful to resort, whenever possible, to several models to cover a larger spectrum of system properties, or to several sub-systems to better understand the properties of a process1[133]. This plurality prevents a dogmatic and sterilizing use of the complexity thinking, but it also leads to admit, what is not reassuring, the fundamental incompleteness of a complex process.

In short, the concepts from the sciences of the complex, seem to have a proper base that allows them to be effective outside the domains and conditions that gave birth to them, and in particular to be usable without the mathematical computer arsenal that characterizes these sciences. Therefore the complexity thinking uses a certain transposition of scientific concepts from one field to another and as such, it requires caution and discernment and in no way dogmatic veneer. But as such it is in no way a fixed system, but a living and continuous creation, even if for the moment, it remains implicit, or even ignored by many of those who help to make it live.

II-5 Sciences of the complex and complexity thinking: a dialectical relation

Though it emanates from the practices of complex systems sciences, the complexity thinking is not it’s immediate translation.

For many of us the form of thinking is "natural". Only the content changes, be it scientific concepts or ideology. Recently, the difference in the form of thought in different civilizations, such as Chinese thought[134], has been highlighted, but what about "Western" thought? Epistemology is interested in scientific forms of thought, but this discipline belongs to philosophy, of which, in France at least, scientists in "exact" and natural disciplines are deprived. What E. Morin calls "*knowledge of knowledge*" belongs to the field of human sciences. Thus, since Greek antiquity, there has been a minority but persistent current of thought, dialectics, which in the West is opposed to the Aristotelian form, but which is unknown to scientists[135]. Those who, with strong arguments in

133 A recent book, *Le monde qui émerge : les alternatives qui peuvent tout changer (The Emerging World: Alternatives That Can Change Everything).* Christophe.Aguiton and Geneviève Azam ed, les liens qui libèrent pubisher, 2017 confronts various systemic and alternative conceptions of the changes needed to overcome global dysfunctions and insists on the importance of the diversity of design as well as the need for their complementarity to overcome capitalism.

134 François Jullien l*es transformations silencieuses* Poche 2010, Richard Nisbett t*he geography of thought* the frre press, 2004.

135 Since the 1970s, for ideological and political reasons, it has been largely ignored.

support, propose other forms of thought come up not against a refusal, which could be the basis of an argument, but against deafness (or blindness).

The complexity thinking therefore has, to be known, to impose itself both among scientists and in the population in general, many obstacles to overcome that I will examine in the following chapters.

One concerns knowledge of the sciences from which it emanates. Familiarity with at least some aspects of the complex sciences, for example non-linearity, or certain systemic approaches, could facilitate the acquisition of complexity thinking, by preparing to understand emergence or self-organization as well as the notion of system and dynamics. The mathematician Ian Stewart[136] said that linearity represents a very small domain of reality, compared to non-linearity and gave the image of biologists who would have known only dinosaurs and who would speak of "non-dinosaurity" by discovering the rest of the living world. Similarly, the world is essentially complex and its complexity, methods and concepts have been known for over half a century. These concepts should therefore be part of every scientist's arsenal, but also of every citizen's thought. For this they should be taught in all schools, whereas they only appear (at least in France) well after the baccalaureate and in a few fields, so that only mathematicians, and some engineers, physicists and chemists are aware of them at the end of their studies. (see chapter V)

But this is not enough, because even among the scientists who practice the sciences of the complex a large number are not aware of the fact that they think otherwise. They simply believe they are manipulating new methods, and do not realize (or even refuse) that they lead to a new way of seeing the world. Thus, practicing a complex science is not enough to appropriate a complexity thinking, so long as the dominant form of thought is felt as "natural". This deficiency represents a handicap for the very development of the sciences of the complex, insofar as this form of thought being what gives their coherence to these sciences, its ignorance hinders the implementation of the necessary transdisciplinarity, and the confrontation of concepts.

II-6 Traps of uncontrolled complexity.

Thinking the complex is therefore not widespread. But today's society, with the countless interactions that have developed on a global scale, whether economic and financial, communications, transport, trade, is increasingly felt as "complex". And, either for lack of knowledge of what it is, or to try to avoid the epistemological rupture that this requires, we notice that the terms of complexity are more and more often used, but in a wrong meaning, whether in the media, or even in certain scientific circles.

I have already mentioned the confusion between complex and complicated. It is omnipresent, and

[136] Ian Stewart, *Does God Play Dice: The New Mathematics of Chaos* initially published by Blackwell Publishing 1989.

often used, notably by the media, to suggest a degree of dissuasive complication for the 'simple' citizens who must let the experts take care of it for them (it is complex!!! followed by a deep sigh). From a scientific point of view, this reduction justifies the use of analytical methods alone to study systems recognized as complex. One can think of biodiversity, reduced to the list of living species present *hic* and *nunc* in a given space, independently of history, or dynamic interactions between species.

But there are other ways to reduce complexity, for instance by retaining only one of its characteristics. A very widespread reduction consists in keeping only the notion of uncertainty, which can go so far as to consider that complex means uncertain. Not seeing the limits of linear determinism, and therefore not taking into account the degrees of uncertainty, is harmful both in science and in politics, but retaining only complexity as uncertainty is fraught with dangers. From a scientific point of view, this justifies relativism for which all opinions are equal, since everything is uncertain! And this justifies a pragmatism (the buzzword!), based on a short-sighted approach and rid of context and historicity, relegated to the rank of "theory".

In fact, each time complexity is reduced to one of its ingredients, it is "de-complexified", and one falls into arguments that have a strong chance of being erroneous. One can quote self-organization[137] seen as an automatic result of a gathering, bifurcation taken as a change of path, and not as a change of state, the chaos brought back to a great nonsense... If the current debates on the emergence between scientists (cf Chapter V) show that it is not enough to have a training in sciences of the complex to have a unanimous vision of its concepts, such a training is nevertheless necessary not to fall into the traps of an uncontrolled complexity.

Now, as we will see in the following chapters, the complexity's sciences are currently hampered in their development. The national and regional Institutes of complex systems have been set up in France to give life to the interdisciplinarity of the models and methods that constitute them. They are still marginal and these methods are neither widespread nor, most often, even taught. There are still many obstacles that limit the development of the sciences of the complex and prevent the acquisition and diffusion of the complexity thinking and I will try, by studying in the following chapters the epistemological, politico-economic and ideological contexts of this revolution, to better understand its nature and that of the obstacles it encounters.

[137] *Emancipation et pensée du complexe* op cit

Chapter III epistemological contexts.

Quand on cherche les conditions psychologiques des progrès de la science, on arrive bientôt à cette conviction que c'est en termes d'obstacles qu'il faut poser le problème de la connaissance scientifique. **….** *C'est dans l'acte même de connaître, intimement, qu'apparaissent, par une sorte de nécessité fonctionnelle, des lenteurs et des troubles. En fait, on connaît contre une connaissance antérieure, en détruisant des connaissances mal faites, en surmontant ce qui, dans l'esprit même, fait obstacle à la spiritualisation.* G.Bachelard[138]**.**

Objet des sciences de la nature : la matière en mouvement, les corps. Les corps sont inséparables du mouvement... ; leurs formes et leurs espèces ne se reconnaissent qu'en lui ; il n'y a rien à dire des corps en dehors du mouvement, en dehors de toute relation avec d'autres corps.. La science de la nature connaît donc les corps en les considérant dans leurs rapports réciproques, dans le mouvement. F.Engels[139]

III-1 The very unequal fate of two discoveries.

In 1961, the biologists Jaques Monod and François Jacob published two papers in the same scientific journal[140]. The first, that led them to win the Nobel Prize, opened the way to the use of bacterial genetics for the study of genetic regulation. The aim was to understand how genes enable and regulate the synthesis of proteins and thereby vital functions. By contrast he second article, still unrecognised to date, focused on the dynamic aspects of these regulations, that is to say, beyond the functions, on the functioning, and had already foreseen many non-linear behaviours[141]. In short, these authors opened two avenues for the study of biological regulation: the path of molecular (reductionist) analysis and that of the (non-linear) dynamics of their functioning. They have pursued only the first one, which has developed exceptionally rapidly and led to the outcome around 1975 of what has been called genetic engineering and biotechnology. The second, however, remained forgotten (or dormant) with rare exceptions[142]. This second direction of research pointed to what will later be the application to biology of the dynamics of non-linear systems, a branch, as we have seen of the sciences of complex systems.

Of course, the experimental techniques required by the first method already existed in 1961, whereas computers, which would make possible the development of the sciences of the complex, were still in their infancy. Later on the impressive results obtained attracted all the attention and

138 Gaston Bachelard, *La formation de l'esprit scientifique*,Vrin,1967 p 13. *When we look for the psychological conditions of scientific progress, we soon come to the conviction that it is in terms of obstacles that we must pose the problem of scientific knowledge... It is in the very act of knowing, intimately, that, by a kind of functional necessity, slowness and troubles appear. In fact, we know against a previous knowledge, by destroying badly done knowledge, by overcoming what, in the very spirit, hinders spiritualisation.*

139 letter toMarx 1873 in Karl Marx et Friedrich Engels, *lettres sur les sciences, Éditions* Sociales, 1973 p 77.. *Subjects of the natural sciences: matter in motion, objects. Objects are inseparable from movement... their forms and species can only be recognized in it; there is nothing to say about objects outside movement, outside any relationship with other bodies... The science of nature therefore knows the objects by considering them in their reciprocal relationships, in the movement.*

140 *Cold Spring Harbor Symp. Quant. Biol.* 1961, n° 26 .

141 Monod, J. and Jacob, F., « *General conclusions: teleonomic mechanisms in cellular metabolism, growth and differentiation » ibid.* pp 389-401.

142 Reviewed in Michel Laurent, G. Charvin , J. Guespin-Michel, *Bistability and hysteresis in epigenetic regulation of the lactose operon*. Cell Mol Biol, 2005, pp 583-94.

shaped the ways of studying regulations, stressing the pre-eminence of the analytical and static approaches. So the few scientists who explored the second path remained isolated, even when computers became commonplace and knowledge about non-linear dynamic systems accumulated from physics. The 'all-molecular' paradigm had become too strong to allow for a dynamic and complex approach.

It is tempting to be satisfied with this explanation: molecular biology has taken precedence over the study of dynamics because of lack of computers, and the resulting paradigm has prevented the emergence of a new one. In short, there has been a bifurcation, in which biology had followed the attractor of molecular biology, and therefore of the reductionist approach. But this may not encompass the whole story, since, even in physics, the arrival of the possibilities of study of the complex did not allow it's rapid development, which only young brilliant enthusiasts could undertake as stated by the best seller written by a scientific journalist of the New York Times [143]. Everything would be merely a matter of a struggle (of power) between curious and enterprising minds and academic routine. But is it again so simple?

As one answers only to the questions one asks, I wanted to follow the lesson from Boris Hessen and question the respective roles of epistemology and society, both from the point of view of productive forces and ideas (while remaining aware that these aspects are not really separable). In this chapter I shall study the epistemological contexts which have both made possible the emergence and hinder the full development of the sciences of the complex and the complexity thinking.

III-2 Epistemological obstacles.

III-2-1 Linearity.

Fundamentally, the sciences of complex systems concern systems, simple or complicated, in which at least some of the interactions between elements are non-linear. We have also seen that this non-linearity was first ignored, because mathematics lacked the means to approach it. The world appeared to be entirely linear, that is, proportionality and additivity seemed the rule and logic was rooted in linearity. Classical mechanics as well as quantum mechanics deal precisely with these linear interactions[144] and, by using linear simplifications, physics and engineering have succeeded for a very long time to explain the world and to transform it by increasingly efficient techniques. It is therefore not surprising that all mindsets, be they from scientists or profanes, have been shaped by this linearity. It is the normal, logical thought, that of Cartesian rationality, of Newtonian physics, which was most widely diffused in and by the sciences until the last century, and which is still taught at all levels of education. As we shall see in chapter V, it is also the support of the

143 James Gleick *op.cit.*
144 This corresponds to the reversibility of time, which was also a major obstacle namely to the introduction of the *arrow of time* in physics by Prigogine.

dominant ideology. It pertains both to scientific thinking and to rational common sense. One can look at it as a *basin of attraction* not easily left to reach that of the non-linearity and the complex.

What does a way of thinking shaped by linearity mean? Proportionality and additivity are the hallmarks of linear causality. This generates a simple determinism: to one effect corresponds one cause, to understand the effect you only have to understand the cause and the stronger the cause, the stronger the effect (proportionately). Linear thinking means also the linear succession of causes and effects: A implies B which gives C... It is a hierarchy based thinking. There is only one primary cause in this linear causal chain. That a causality may be circular, that a solution can be multiple, that there may be no proportionality or additivity between causes and effects, that each cause may have multiple effects and each effect arise from multiple causes and that certain deterministic behaviours are unpredictable, are so many propositions that not only common sense but scientific thinking rejects, which may even seem irrational since they are partly irreconcilable with formal logic[145].

Bachelard wrote, as early as1934 « *Alors que la science d'inspiration cartésienne faisait très logiquement du complexe avec du simple, la pensée scientifique contemporaine essaie de lire le complexe réel sous l'apparence simple fournie par des phénomènes compensés ; elle s'efforce de trouver le pluralisme sous l'identité... »* [146] And yet, eighty years later, this contemporary scientific thinking is still far from being general.

Thus, faced with the failure of the use of linear tools to study the dynamics of complex systems, the study of dynamics have often been abandoned in favour of a static conception which is also articulated, as we shall see in Chapter V, with ideological fatalism and philosophical essentialist conceptions (essence being dissociated from the conditions of existence).

Facing the complex requires a somewhat dramatic renewal of the way of thinking, therefore it is not surprising that we have witnessed a hateful rejection akin to that encountered by the other great scientific revolutions. Mention is made, for example, of the (indisputable) role of religion in the rejection of Copernicus and Galileo's theories, but can we imagine the reaction of common sense when people (be they scholars) were asked to believe that the earth is spherical and the inhabitants of the antipodes walk "with their heads downwards"? More recently, Paul Langevin wrote, about relativity « *il est difficile à notre cerveau de s'habituer à ces formes nouvelles de la pensée* [147]». The revolution of the complex represents in my opinion, a conceptual revolution as important as the Copernican revolution, insofar as it also challenges and transforms our vision of

145 Despite very old notions such as *the vicious circle or the hen and the egg* that show that circular causality was known, but not appropriated as causality.

146 Gaston Bachelard *Le nouvel esprit scientifique, op.cit* chapter *l'épistémologie non cartésienne,* p 139. "*While Cartesian-inspired science made logically complexity with simple, contemporary scientific thinking tries to read the real complex under the simple appearance provided by compensated phenomena; it strives to find pluralism under identity.*

147 In Bitsakis, 2001 *op.cit*., p 302. "*It is difficult for our brain to get used to these new forms of thinking* "

the world. In that respect it receives the support of the dialectical logic, which was precisely built up in the faults of formal logic to understand the transformations, and therefore the dynamics, and which in many cases anticipated the results of the sciences of the complex[148]. The fact that the revolution of the complex developed at a time when political and ideological conditions had almost totally eliminated the dialectics particularly the materialist dialectics from the conceptual landscape, is likely to have contributed to its difficulties in the face of linear thinking, not only in philosophy but also in the sciences.

Among the fundamental questions related to linear reasoning is that of determinism. This term has various meanings but the most common remains that of Laplacian determinism: knowing all that concerns the present and the past, Laplace's demon must necessarily be able to predict the future. It is precisely the proportionality between the causes and the effects that is at stake in this reasoning, and the non-predictable determinism of the NLDS violates it frontally. Here again is a major epistemological obstacle, insofar as predictable determinism has long been, and still is, considered as the foundation of scientificity, and science as synonymous with rationality. Everything that ultimately rests on the proportionality and additivity of causes and effects seems to shatter in a non-linear world[149].

Thus, some scientists reject the new paradigm, for the sake of determinism as warrant of rationalism and / or logic. This was the case, for example, of the mathematician René Thom, whose works, however, the theory of catastrophes, can rightly be included in the complex's science gallery. Yet he attacked Atlan, Prigogine and Morin virulently, accusing them of a "« *fascination pour l'aléatoire* » which « *témoigne d'une attitude anti-scientifique par excellence* »[150]

More recently, and with nuances, this is also the question raised in an issue *Autour du chaos*[151] of the review of the rationalist union. They do not object to non-linearity in physics but to its use outside the field of physics by the sciences of complex systems at large (and therefore the complexity thinking). The following quotation from Claude Allègre in July 1994 in an interview with the newspaper Le Point enlightens the problem in its ambiguity and possibilities of drift. « L*e monde entier semble évoluer vers le chaos. Les certitudes idéologiques d'hier s'effondrent, les tempêtes boursières se multiplient, les guerres renaissent, les économies semblent échapper à tout contrôle [...] ; en physique, en biologie, l'instabilité est créatrice ; elle est aussi transportable dans les sciences sociales […]. Pour ceux que le monde actuel désespère, c'est l'occasion d'un grand bol*

148 This does not prove the truth of the complex sciences, but the perspicacity of dialectics.

149 For Prigogine, it is the irreversibility of mechanics that is totally challenged by complexity, but non-linearity is the condition of irreversibility.

150 René Thom, « *halte au hasard, silence au bruit* », le Débat, Gallimard,1980 N°3. *fascination for the random"* which *"bears witness to an ultimate anti-scientific attitude.*

151 *Autour du chaos*. Raison présente n°115, 1995.

d'espoir »[152] There is, in this quotation (removed from its context), a major confusion: can everything that is disorder, everything that is thought under the usual term of chaos, be rethought in terms of the new paradigm of deterministic chaos? Obviously, this is not true. This confusion, to which the term deterministic chaos can lend support is not, in my opinion, inherent in inter-disciplinarity, but marks the confusion of a non rigorous enough mind. It is, however, one of the arguments against the complex. To fight (rightly) fanciful or purely irrational interpretations that seek to rely on the complex does not oblige to condemn in advance any transposition of the concept outside the field of physics[153]. To deduce from these errors that chaos with its non-predictable determinism would be valid only in physics and that the new type of determinism which it makes us foresee should not become a transposable paradigm also represents an error of reasoning stating that complexity thinking, insofar as it can serve as a pretext for misuse, should be rejected as irrational These polemics are an example of linear reasoning ' *if some people use this mode of thinking wrongly, it is the way of thinking that is at stake*'. It is important to note that these criticized usages often originate from the unilateral use of complexity concepts being applied without discernment.

Prigogine,for his part, asks : *La question est alors de savoir dans quelle mesure l'identification de cette intelligibilité au déterminisme définit une science historiquement datable, ou, comme le mathématicien René Thom le soutient, caractérise l'essence même de la science*[154]. In other words, to those who consider (Laplacian) determinism as the immutable essence of science, he opposes a historicity of science, the present phase of which would accept indeterminism. This conception was quickly distorted by the idea that science had become impossible, opening the way to elativism an irrationalisms.

At the Cerisy symposium (*determinisms and complexities*) in 2004, all participants did not share the same position on the question, which the organizers presented thus : « *Pour les systèmes complexes, le non-déterminisme n'est pas synonyme d'imprévision radicale. Certes, la prédiction parfaite de ce qui va arriver au sens de Laplace, ne peut être faite en certitude et dans le détail. Mais l'idéal serait de prévoir en probabilité ce qui peut arriver, comme le fait l'équation de Schrödinger* [155]*. Chaque fois que cet idéal n'est pas accessible, il faudra - à nouveau idéalement- être capable de préciser quelle est la nature des incertitudes qui demeurent. Et ces incertitudes*

152 *Ibid.* p 11 Th*e whole world seems to be moving towards chaos. Yesterday's ideological certainties are collapsing, stock market storms are multiplying, wars are re-emerging, economies seem to be out of control [...]; in physics, in biology, instability is creative; it is also transportable in the social sciences [...]. For those whom the present world despairs, it is the occasion of a great bowl of hope.*

153 As an example of a coherent use of the concepts derived from the NLDS to characterize the upheavals of the current situation, I refer to the analysis of Emmanuel Wallerstein mentioned above.

154 Ilya Prigogine et Isabelle Stengers, Hasard et nécessité, *encyclopaedia universalis* (Edition 1997).*The question is then to what extent the identification of this intelligibility with determinism defines a historically datable science, or, as the mathematician René Thom maintains, characterizes the very essence of science*

155 In other words, instead of predicting what is to be, one predicts what can be

pourront aller jusqu'à l'imprévision radicale [156]».The notion of non-predictable determinism seems to me more adequate to summarize the achievements of the complex' sciences on this subject[157]. Uncertainty becomes an element with which science must cope, without rejecting determinism, which, however, must in turn be transformed by incorporating unpredictability.

But the complex, especially through the use of deterministic chaos as a method of study or as a metaphor, has quickly slipped from the natural sciences to the social sciences and through the media, to the general public. Again, this epistemological position, which admits that a determinism may be unpredictable, was soon by-passed by all sorts of idealist assertions denying the materiality and the knowability of the world (see also chapter V). Thus, through an obvious feedback loop, all these misuses have contributed to slowing down the development of the sciences of the complex, within the scientific communities themselves.

The materialistic[158] foundation of science is, for the majority of scholars, based in particular on the repeatability of experiments. Is this denied by a non-linear formalism? Does the conception of multistationnarity states and chaotic behaviours, the notions of emergence or self-organization, threaten science? Is irrational the position summarized by the term "non-predictable determinism", which modifies the nature of determinism? Laplace's demon loses a power he had never had before, and science can explore the immense territories of non-linearity and complexity that had remained untouched until then, without abandoning those, more restricted, of linearity. I find here the position expressed by Paul Langevin in the debate on determinism in physics" «*Aujourd'hui on parle de « crise du déterminisme » alors qu'au vrai, la détermination objective des faits est mieux connue qu'elle l'était hier. Certes, à mesure que notre connaissance du réel progresse, nous sommes amenés à modifier la conception que nous nous faisons du déterminisme* [159]».

All these novelties have raised numerous polemics even among the participants of the adventure of the complex. These polemics are often ideological as well as epistemological and, as we shall see in Chapter V with the example of emergence, they can also arise from the diversity of scientific practices involved in the sciences of the complex. But, if the argument of misuse can be rejected, the epistemological question raised in the current issue of Raison présente remains, that of the transposition of the concepts of the complex into disciplines other than physics, which is similar to that of trans-disciplinarity.

[156] Colloque de Cérisy *op.cit.* p13.*"For complex systems, non-determinism is not synonymous with" radical imprecision". Of course, the perfect prediction of what will happen in Laplace's sense can not be done in certainty and in detail. But the ideal would be to predict what may happen in probability, as Schrödinger's equation does. Whenever this ideal is not accessible, it will be necessary again ideally to be able to specify what is the nature of the uncertainties that remain. And these uncertainties can go as far as radical unpredictability.*

[157] But this does not exhaust the question, for it remains the role of randomness, of noise.

[158] I will not consider here the distinction between materialism and realism.

[159] Paul Langevin 1939 cité par Bitsakis *op.cit.* p 331. *Today we speak of "crisis of determinism "whereas in reality objective determination of the facts is better known than it was yesterday. Certainly, as our knowledge of the real progresses, we are led to modify our conception of determinism.*

III-2-2 The difficulties of inter- and trans-disciplinarity.

Necessary, as we have seen, to the sciences of complex systems, as a basis of complexity thinking, interdisciplinarity can also constitute an important obstacle to their diffusion.

On the one hand, it is difficult to practice and it takes a long time for actors to be able to do better than to rub shoulders by juxtaposing their qualifications, a long time that is most often refused by current science policies, which nevertheless advocate pluridisciplinarity[160]. (see Chapter IV)

On the other hand, the institutions (notably the French University recruitment commissions) are organized on a disciplinary basis and, despite various solicitations, keep their domain fiercely. It sometimes follows that mathematicians, computer scientists or physicists may be led to tackle by themselves questions pertaining to the humanities or economics, even biology. These studies, although relevant and interesting, do not disseminate to researchers in these disciplines, who remain unconnected with the contributions and approaches of the complexity sciences. This obviously does not contribute to removing the epistemological obstacles encountered to transfer concepts between disciplines.

In France, le *Réseau National des Systèmes complexes* (RNSC), was built on the idea that there exist generic laws of the complex, independent of the nature of the elements, but dependent on the nature of their interactions. « *La mission du RNSC est de rassembler tous les acteurs qui souhaitent contribuer au développement de la science des systèmes complexes au-delà des barrières institutionnelles, disciplinaires et géographiques.* **...** *Le RNSC offre ainsi la possibilité aux chercheurs venant de différents horizons de travailler ensemble sur la problématique des systèmes complexes*[161]».

What seems certain is that for transposition, therefore transdisciplinarity, to exist, it can not be in any way, nor about everything. For example, a review of the themes of the networks affiliated to the RNCS, or of the themes presented at the international congresses of complex systems organized by the European Network of Complex Systems, shows that this transversality is limited mostly to computer science or applied mathematics to a complex issue within a classical disciplinary field. What is transposed is less the problematic (which is, however, transformed by the choice of seeking a system), than the methods to approach it.

Antoine Danchin wrote, in *1980: « Le principe sous-jacent à toutes ces attitudes, qu'on peut qualifier d'attitudes holistes* [For the author-in this ancient article at least- all that belongs to the

[160] The "slow science" movement, which demands time for reflection, is from this point of view indispensable. See Isabelel Stengers, *Une autre science est possible,* La découverte 2013.

[161] RNSC, http://rnsc.fr/tiki-index.php. *The mission of the RNSC is to bring together all the actors who wish to contribute to the development of complex systems science beyond institutional, disciplinary and geographic barriers... The RNSC thus offers the possibility to researchers from different backgrounds to work together on the problematic of complex systems.*

sciences of the complex was amalgamated to holism], *est l'introduction d'un principe d'émergence de l'être, qualité essentielle du monde dont on postule l'existence en dehors de la matière.... A cet égard la thermodynamique est un outil de choix, puisqu'il est possible de faire sans cesse un va-et-vient confus entre le macroscopique et le microscopique, entre le déterministe et l'indéterministe, afin d'imposer n'importe quel point de vue* »[162]. Without, of course, following A. Danchin in this condemnation, it is necessary to be guarded against the reproach (even the temptation) to use interdisciplinarity to "impose any point of view ". It is therefore a question of remaining vigilant, of never pasting the complexity thinking, or of the methods of studying complex systems, but of taking into account "« *la logique propre de l'objet en propre* » [163]. It is in this perspective that complexity thinking may play an important role, to guide questions and the choice of transdisciplinary subject matter, even in cases where no modelling is possible.

The difficulty of transdisciplinarity may be the origin of the paradoxical fact that the necessity of a complexity thinking, is not (or little) recognized in these institutes of complex systems who believe in remaining 'strictly scientific', notwithstanding the fact that they do transform the rationality. Most often they do not recognize it nor admit all the consequences. Complexity thinking, because resulting from the sciences of the complex, is the glue that will allow them to reach a trans-disciplinary coherence that may facilitate their implantation and their generalization.

Edgar Morin, a transdisciplinary researcher who calls himself a nomad, saw this necessity, but did not influence the scientists of complex systems, nor did he take, in my opinion, the entire measure of their conceptual contributions. He remains in a separate continent and embodies in a way the difficulties of recognizing, sharing and even fully understanding the relationship between complexity and inter (or trans-) disciplinarity. Thus, one of the 6 research themes of the Edgar Morin Institute (Interdisciplinary Institute of Contemporary Anthropology (EHESS-CNRS) remains, still nowadays, *Transdisciplinarity and Complexity*. This transdisciplinarity however remains mostly confined to the social sciences and underestimates the question of whether we can go any further and to what extent the laws, or rather the behaviours of complex systems, discovered from physical or biological systems can be applied to societies and to individuals? Those who oppose it do so either in the name of free will that would make vain any attempt to find laws to

[162] Antoine Danchin *L'invasion du biologisme*. Le Débat n°2, Gallimard, 1980 p 75-76 *"The underlying principle of all these attitudes, which can be described as holistic attitudes is the introduction of a principle of the emergence of being, the essential quality of a world whose existence is postulated outside matter.... In this respect, thermodynamics is a tool of choice, since it is possible to constantly make a confused back and forth between the macroscopic and the microscopic, between the determined and the indetermined, in order to impose any point of view.*

[163] Karl Marx *Critique du droit politique hégélien*, (1843), Paris Éditions sociales 1975 p 149 translation from german suggested by Lucien Sève. *the proper logic of the object in itself*

social behaviour or because human beings are likely, because they think their practice, to change the rules of the ongoing system.

Therefore we can (still today and despite many advances) conclude with Edgar Morin *« que les efforts conjugués de la surspécialisation, de la réduction et de la simplification, qui ont amené des progrès scientifiques incontestables, amènent aujourd'hui à la dislocation de la connaissance scientifique en empires isolés les uns des autres (physique, Biologie, Anthropologie), lesquels ne peuvent être reliés que de façon mutilante par la réduction du plus complexe au plus simple et conduisent à l'incommunicabilité de disciplines à disciplines que n'arrivent absolument pas à surmonter les pauvres efforts interdisciplinaires. Aujourd'hui il y a occultation de tout ce qui se trouve entre les disciplines qui n'est autre que le réel...* »[164].

However, at present, the situation is paradoxical. Project funding related to research policies in the context of the knowledge economy (see Chapter IV), ask for inter-disciplinary research, without removing the majority of institutional obstacles to the practice of such research. The CNRS, by implementing thematic interdisciplinary commissions (CID), tries to create more favourable conditions, but *« Les forces centripètes des revues disciplinaires phares, l'insuffisance de lieux dédiés susceptibles d'assurer une pérennité des projets au-delà des financements (contractuels) de court terme et l'absence d'un vivier de jeunes chercheurs formés à l'interdisciplinarité contribuent grandement à insécuriser les pratiques interdisciplinaires[165]».* In the humanities and social sciences, however, studies that have been grouped under the term "cultural studies", such as gender studies, require interdisciplinarity and may help to make the disciplinary boundaries more permeable.

But disciplines, research and teaching form a complex system in which one element can not be modified without creating unforeseen and possibly undesirable effects. Reforms in secondary education, for example, where studies by theme (and therefore interdisciplinary) have been imposed, without reflection and overall preparation, are sometimes catastrophic on the level of knowledge of science students in particular. This is why, due to this lack of a global reflection based on a complex way of thinking "'*les disciplines, pierre angulaire de l'architecture des connaissances et de l'organisation du travail académique, ont donc encore de beaux jours devant elles, d'autant plus beaux qu'elles savent faire preuve d'une certaine résilience*[166]."

[164] Edgar Morin, 1982, *op.cit.* p 66. t*hat the combined efforts of subspecialisation, reduction and simplification, which have brought about unquestionable scientific progress, lead today to the dislocation of scientific knowledge into empires isolated from each other (physics, biology, anthropology) which can only be mutilated by the reduction from the most complex to the simplest and lead to the non-communicability of disciplinary disciplines that can not be overcome by poor interdisciplinary efforts. Today there is a concealment of all that lies between the disciplines that is none other than the real ...*

[165] Endrizzi Laure op cit "T*he centripetal forces of leading disciplinary journals, the insufficiency of dedicated places likely to ensure the sustainability of projects beyond short-term (contractual) funding and the lack of a pool of young researchers trained in interdisciplinarity contribute greatly to the insecurity of interdisciplinary practices"*

[166] Endrizzi Laure op cit *the disciplines, the cornerstone of the architecture of knowledge and the organization of academic work, still have a bright future ahead of them, all the more beautiful because they know how to show a certain resilience*

III-3 Reductionism and Holism.

These are the two conceptions which, under various names, have crossed and divided the field of science since their origin, and in regard to which the sciences of the complex have to position themselves.

III-3-1 Biology as an example [167]

Since I have opened this chapter with the example of regulatory networks in biology, let us continue on this path, especially as in biology the opposition between reductionism and holism is very old and marked. I will illustrate it by this rather long quotation of the work of François Jacob (underlines are from me).

"*... la biologie n'est pas une science unifiée. L'hétérogénéité des objets, la divergence des intérêts, la variété des techniques, tout cela concourt à multiplier les disciplines. Aux extrémités de l'éventail, on distingue deux grandes tendances, deux attitudes qui finissent par s'opposer radicalement. La première de ces attitudes peut être qualifiée d'intégriste ou d'évolutionniste. Pour elle, non seulement l'organisme n'est pas dissociable en ses constituants, mais il y a souvent intérêt à le regarder comme l'élément d'un système d'ordre supérieur, groupe, espèce, population, famille écologique.*

Cette biologie s'intéresse aux collectivités, aux comportements, aux relations que les organismes entretiennent entre eux ou avec le milieu [...]. Le biologiste intégriste refuse de considérer que toutes les propriétés d'un être vivant, son comportement, ses performances peuvent s'expliquer par ses seules structures moléculaires. Pour lui, la biologie ne peut se réduire à la physique et à la chimie (...) parce que, à tous les niveaux, l'intégration donne aux systèmes des propriétés que n'ont pas les éléments. Le tout n'est pas seulement la somme des parties.

"A l'autre pôle, de la biologie se manifeste l'attitude opposée qu'on peut appeler tomiste ou réductionniste. Pour elle, l'organisme est bien un tout mais qu'il faut expliquer par les seules propriétés des parties. Elle s'intéresse à l'organe, aux tissus, à la cellule, aux molécules. La biologie tomiste cherche à rendre compte des fonctions par les seules structures. […] On voit combien diffèrent ces deux attitudes. Entre les deux, il n'y a pas seulement une différence de méthode et d'objectifs, mais aussi de langage, de schémas conceptuels et par là-même d'explications causales dont est justiciable le monde vivant »[168].

[167] The following text is inspired by the Paper from Janine Guespin-Michel, *réductionnisme et globalisme* La Pensée, 1998.

[168] François Jacob, *La logique du vivant*, Flammarion, 1970 p 14-15. "*... biology is not a unified science. The heterogeneity of objects, the divergence of interests, the variety of techniques, all this contributes to the multiplication of disciplines. At the extremities of the spectrum, there are two main trends, two attitudes that end up radically opposed. The first of one can be described as holist or evolutionist. For it, not only the organism can not be dissociated in its constituents, but it is often advisable to consider it as the element of a higher order system, group, species, population, ecological family.*
This biology focuses on the communities, the behaviours, the relationships that the organizations maintain with each other or with the community [...]. The holistic biologist refuses to consider that all the properties of a living being, its behaviour, its performances can be explained by its sole molecular structures. For him, biology can not be reduced to physics and chemistry (...) because, at all levels, integration gives to a system properties that the elements do not have. The whole is not just the sum of the parts.

From an epistemological point of view, biology is therefore placed between two poles, reductionism and holism, which Jacob tells us to be both two opposing attitudes and two types of methodologies to study different objects. This ambiguity will redistribute the concepts of Reductionism and Holism themselves between two poles, the methodological pole (analytic or globalist) and the philosophical pole (reductionist or holist).

From a strictly methodological point of view, analysis and globalism seem complementary, since they seek to identify different aspects of the living world, using different techniques and methods. But immediately this complementarity is modulated. Holists *«refuse to consider that all the properties of a living being, its behaviour, its performances can be explained by its sole molecular structures ».* There is therefore refusal on the part of the holistic pole of what is at the base of the work of the reductionist pole. For the reductionists, not only the physical laws are the only ones at work in the living (physicalism), but above all, the analytical methods are not only the most effective, but the only ones likely to allow the explanation of the living. Thus the study of the constituents of a level is necessary and sufficient to understand the higher level. Holists can accept physicalism, (those who refuse it, can be assimilated to the vitalist movement, born at the beginning of the nineteenth century that all the scientific efforts of this century led to invalidate). On the other hand, they consider that *the whole is more than the sum of the parts*, and deduce that the study of the constituents of an organizational level is useless for the comprehension of this level. They only admit interactions going from the higher level to the lower level (so-called downward causality) that the reductionists absolutely refuse[169]. Between the two poles, the whole history of biology and all the ambiguity of this opposition, which has created struggles and tensions of a harshness all the more intense because it is also linked, especially in the economic contingency and current science policy, to the allocation of funding and research positions. They also correspond to ideological and even economic battles, as we will see in next chapters.

But this dichotomy is far from characterizing only biology. We find it, with a specific but relatively synchronous evolution, in the social and human sciences (with structuralism for example on the reductionist side, and existentialism and a part of phenomenology which is similar to to the holist pole). And even if this distinction may seem at first foreign to physics, where the complementarity of levels of study seems more obvious, it has not remained absent from these

"At the other pole, biology manifests the opposite attitude that can be called tomist or reductionist. Here the body is a whole but must be explained by the properties of the parts. I is interested to the organ, the tissues, the cell, the molecules. Tomist biology seeks to account for functions by structures alone [...] We see how different these two attitudes are. It is not only a difference in method and objectives, but also in language, in conceptual schemes and hence in causal explanations for the living world ".

169 Nowadays, philosophers of science modulate these criteria by speaking of strong and weak reductionism, which they do not all define in the same way. I will not introduce these discussions here.

debates. Indeed, what appears to be a seemingly simple dichotomy intersects and brings together a series of oppositions, which correspond to pivotal concepts of all western knowledge.

III-3-2 Crystallized oppositions

Since ancient times, knowledge has progressed by borrowing concepts or points of view (complementary or contradictory) from pairs of opposite that have often been used alternately in the course of the history of science. The emblematic example is that of light, studied alternately from the point of view of the continuous (wave) or the discontinuous (corpuscle), points of view which are both aggregated (and exceeded) in the elaboration of the quantum concept of the photon. The reductionist and holistic poles very often adopt these opposing concepts, which thus crystallize and become fixed. We are going to examine it through the history of biology, the very term which appeared in opposition to the conception of life as a machine (assembly of parts) of the seventeenth and eighteenth centuries. The physics (mechanics) of the time being unable to account for many properties of the living, was rejected as an explanatory principle and replaced by a vital impulse (hence the term vitalism), of divine nature. Since it was not possible to explain the living with the laws of mechanics, it was thought to be totally different from the inorganic world, not coming under the laws governing the physico-chemical world. The whole history of biology during the first three quarters of the nineteenth century is that of the overthrow of this vitalist vision and the rehabilitation and then the victory of physicalism, made possible by a physics already very different from that of previous centuries. However, this reversal, which did not take place without sometimes bitter struggles, has never been complete, and has gradually given substance to the opposition between the two poles, designated much later as reductionist and holist, thereby helping to strengthen and expand this opposition.

We know that it was the chemical synthesis of urea[170] that brought the first serious blow to vitalism and put physicalism back in the saddle. Cell theory, by affirming that every living organism is entirely made up of cells and that every cell comes from a pre-existing cell[171], has added the analytical dimension to the physicalist approach, consecrating, after an epistemological and ideological struggle of some 30 years, the victory of the analytical paradigm [172].

From the middle of the nineteenth century, especially with the work of Claude Bernard, vitalism became minority, in France at least, and physicalism stood out: « *Les progrès les plus spectaculaires de la biologie ont pris naissance au moment où l'on a pu reconnaître qu'il était possible d'analyser les êtres vivants en n'invoquant pas d'autres principes que ceux de la physique*

[170] In 1828, the German chemist Friedrich Wöhler chemically obtained urea, proving that an "organic" molecule was not fundamentally different from other molecules.

[171] The first principle was stated separately by Schleiden and Schwann in 1838-1839. The second one was stated by Virchow in 1858

[172] Georges Canguilhem, *La connaissance de la vie,* Vrin, 1969 studied in great detail the mechanisms by which an experiment (observation of cells under the microscope) gave rise to a theory.

et de la chimie. »[173] explains Antoine Danchin. In the process, the analytical method, which had led to the discovery of cells, becomes the rule, first as a method, then gradually as an attitude. At the same time that vitalism vanished, (at least temporarily, because, with the intelligent design it resurfaces in the US, in a way that rightly worries the scientists of this country),it gives way to holism which is fighting mainly against the reduction of the living to its parts. Thus, the opposition Reductionism / Holism covers, almost entirely, the opposition *whole/ parts*. For the former, the whole is the simple sum of its parts, for the later it is irreducible to its parts. *The whole is more than the sum of the parts* became a slogan, rallying cry of the anti-reductionists[174].

During the debates that accompanied the birth of cell theory, the discontinuity of the new unity that is the cell, is opposed to the continuity of tissue, which Bichat defended. The *discontinuous-continuous* opposition (in space), which corresponds to the techniques used (microscope versus scalpel), is thus associated with that of part /whole. But the cell is also the individual that opposes the collective of the body, which thus adds the *individual / collective* opposition, strongly influenced at the time by the debates between republicans and monarchists[175].

This progressive agglomeration of key concepts around opposite poles has continued to this day, under the influence of technological progress in particular. This is the case of two new oppositions more relevant in current thinking: *content / form* and *local / global*. Reductionism evokes and convokes as follows: *part, discontinuous, content, local, individual,* whereas holism brings together *whole, continuous, form, global, collective*.

And that's not all: every time the reductionist can, he eliminates movement, thus time. When he can not, he seeks "reversible" time and works at thermodynamic equilibrium. Here again, the globalist attitude is the opposite. The process takes precedence over the thing (black box), the irreversible is the absolute law of development, of evolution. The list goes on, on the side of the conception of time, with the couples *thing / process*, *instant / duration*, *static / dynamic*. Then chance breaks into the arena, with new pairs of opposites: *order / disorder*, *necessity / chance,* and therefore *determined / indeterminate*.

At the same time, insofar as reductionism has always been the most resolute opposition to vitalism, a new and more general opposition is being introduced, encompassing the former, that of *materialism / idealism*. (Note that reductionism is materialist, but is not at all dialectical[176], 1 will come back to this below).

173 T*he most spectacular progress in biology began at the moment when it has been recognized that it was possible to analyse living beings by invoking no principles other than those of physics and chemistry. Antoine Danchin, op.cit. pp 68-81*

174 Long before the term reductionism was used.

175 Georges Canguilhem *op.cit.* studies how the words themselves, in their anthropomorphism, carry these ideas of continuous and discontinuous respectively. He also shows how Republicans praised the "republic of cells"

176 See Lucien Sève et alii 2005 *op cit*.

Thus each discovery is broken down into two opposites which aggregate rapidly and most often implicitly to the two main poles[177]. Each of these poles thus cover a network of notions, continually enriched by the accretion of new conceptions, either by the addition of new terms, or by the more or less implicit extension of meanings. This leads not only to widening the gap, but over all to dogmatic attitudes. Here is a particularly striking example: In the 1970s, the British scientist Mitchell, proposed the theory that explains the generation of cellular energy not by a protein, which was sought vainly then, but by a flow (of protons). Although perfectly reductionist, this theory had to face an opposition so violent that he was obliged to publish at his own expenses (before receiving the Nobel price 10 years later) simply because the explanation by a flow (dynamic) opposed the habits of explanation by molecules (static). But the adoption of this theory did not reverse the usual trend of looking for proteins as the only causes of cellular processes.

These oppositions, which are further reinforced in the context of a shortage of funding and strong technological pressure, are not restricted to biology and give rise to real inter-school battles, of which we will see that the ideology is not excluded. But precisely because each side holds to one aspect of things, these opposing attitudes both belong to that with E. Morin, we can call the "*classical science*". Uncomfortable with these oppositions, which they feel are unilateral, false, some researchers have tried to relativise certain tensions, which leads to a so-called weak reductionism, where, for example, the properties of the whole are certainly explained by those of the parts but imply their interactions. But others have considered these oppositions to be sterilizing and have tried to overcome them.

III-3-3 Oppositions or dialectical contradictions?

The question of overcoming the opposition between reductionism and holism was at the heart of the questions that concerned the famous biologist J.S.F. Haldane, in the 1920s. Well acquainted with the holistic positions defended by his father (J.S. Haldane), he was a reductionist by his scientific practice as a biochemist and a geneticist. But neither of the two attitudes suited him, and it was finally Marxism, and more precisely the materialist dialectics, which enabled him to find a way out of his discomfort, as S.Gouz has very finely analyzed it[178]. "*Dans les années 1920 et jusqu'au début des années 1930, Haldane éprouve de grandes difficultés à se faire une opinion*

[177] These are obviously general assertions that can always suffer from exceptions. Jacques Monod, the leader of the reductionists, has nevertheless been accused by René Thom of being a supporter of chance.

[178] J.B.S. *Haldane Biologie, philosophie et marxisme. Textes choisis d'un biologiste atypique. Translated and proposed by* Simon Gouz, Éditions matériologiques, 2012. I*n the 1920s and early 1930s, Haldane had great difficulty in forming a stable opinion about reductionism. On the one hand, he sometimes assimilates the reductionist method to the scientific method (assimilation undoubtedly reinforced by his activity in biochemistry); that is why he judges holistic theories (even materialistic) unsatisfactory. On the other hand, he faces the scientific limits of reductionism. These difficulties and the recourse he finds against them in Marxism are set out in the 1940 article, "Why I am a materialist" published in the materialist journal 'Rationalist Annual'. The Marxist theoretical answer that he formulates is developed in "Quantum mechanics as a basis for philosophy" and in "Biology and Marxism". He thinks that, in the context of dialectical materialism, mechanism and holism can be understood as two moments equally necessary but also insufficient to understand reality. This is not an anti-reductionist materialism, but a materialistic framework capable of encompassing the opposition between reductionism and holism. We can also see in the model that he proposes to classify the interactions between heredity and environment in the article of 1946, "The interaction of nature and environment" an implementation of this overcoming of the opposition between reductionism (in this case in its hereditary expression) and holism.*

stable concernant le réductionnisme. D'un côté il lui arrive d'assimiler la méthode réductionniste à la méthode scientifique (assimilation sans doute renforcée par son activité en biochimie) ; c'est pour cela qu'il juge les théories holistes (même matérialistes) insatisfaisantes. D'un autre côté, il se heurte aux limites scientifiques du réductionnisme. Ces difficultés et le recours qu'il trouve face à elles dans le marxisme sont exposés dans l'article de 1940, « Pourquoi je suis un matérialiste » publié dans la revue matérialiste Rationalist Annual. La réponse théorique marxiste qu'il formule est développée dans « La mécanique quantique comme base pour la philosophie » et dans « Biologie et marxisme ». Il s'agit pour lui de penser que, dans le cadre du matérialisme dialectique, mécanisme et holisme peuvent être compris comme deux moments également nécessaires mais également insuffisants dans la compréhension du réel.

Il ne s'agit donc pas d'un matérialisme antiréductionniste, mais d'un cadre matérialiste capable d'englober l'opposition entre réductionnisme et holisme. On peut voir également dans le modèle qu'il propose pour classifier les interactions entre hérédité et milieu dans l'article de 1946, « L'interaction de la nature et du milieu » une mise en œuvre de ce dépassement de l'opposition entre réductionnisme (en l'occurrence dans son expression héréditariste) et holisme". (underlined by me)"

Thus for Haldane, whom this conception has helped in his research[179], the individual chance of mutations and the equally individual necessity of selection are overcome by the (collective) evolution of species.

For his part, and at about the same time, the Frenchman Marcel Prenant, in his book "Biologie et Marxisme[180]also deals with this question. He writes in the concluding chapter of his work: *Dans tous les problèmes examinés ... nous avons reconnu deux conceptions extrêmes, qui ont toujours les mêmes caractères. L'une ramène tout phénomène de la vie à des propriétés intrinsèques et ... invoque un principe vital, une entéléchie, une finalité ... L'autre fait intervenir au contraire, le milieu extérieur, avec ses forces mécaniques, physiques et chimiques ; mais trop souvent elle veut, sans précautions, ramener toute la vie, y compris la pensée à des phénomènes du même ordre... la biologie empirique approche cependant, cahin-caha, d'une conception dialectique de plus en plus cohérente. Tous ses progrès décisifs consistent à renoncer, sous la pression des faits expérimentaux, à des conceptions rigides, à des oppositions diamétrales. Ils consistent si l'on veut ... à trouver, entre thèse et antithèse la synthèse convenable.*[181]

179 JBS Haldane is with Fischer and Wright, one of the fathers of population genetics.

180 Marcel Prenant, *Marxisme et biologie*, Éditions hier et aujourd'hui, 1948.In this book, the author shows that genetics, contrary to the claims of official lyssenkism, is not at all incompatible with dialectical materialism.

181 *In all the problems examined... we have recognized two extreme conceptions, which always have the same characteristics. One brings any phenomenon of life back to intrinsic properties and... invokes a vital principle, an entelechy, a purpose... The other, on the contrary, involves the external environment, with its mechanical, physical and chemical forces; but too often it wants, without any precautions, to bring all life, including thought, back to phenomena of the same order... empirical biology, however, is approaching, cahin-cahaha, an increasingly coherent dialectical conception. All its decisive progress consists in renouncing, under the pressure of experimental facts,*

Thus these two biologists converge[182] in finding in the materialist dialectics the conceptual tool which makes it possible to transform these oppositions into dialectical contradictions[183].

Lucien Sève writes "« *La dialectique est donc cette pensée logique qui ne se satisfait pas de proscrire les contradictions, ce qui n'a jamais empêché que s'en manifestent d'effectives, mais s'emploie à traiter ces dernières aux fins de les résoudre. Et comment résout-on – dialectiquement – une contradiction effective ? En osant d'abord, passant outre à l'interdit de la logique formelle, penser l'unité des contraires»*[184]. *« Les prenant au sérieux [*les contradictions*] comme telles, la pensée dialectique s'efforce quant à elle de faire droit à leur vérité en découvrant ou inventant l'unité plus profonde ou plus élevée au sein de laquelle les contraires qui s'y manifestent peuvent coexister coopérativement ou conflictuellement jusqu'à certains seuils »*[185]

Before going further, it becomes necessary to resolve an ambiguity about dialectical contradictions. Since Marx concentrated on working the antagonistic contradiction between the bourgeoisie and the proletariat, many authors share and propagate the reductive conception according to which a dialectical contradiction corresponds only to the case where opposites are incompatible in the long term. In this case the contradiction is asymmetrical, one of the opposites dominates the other, and the resolution of the contradiction is made by suppressing the two opposites as such, in a process that gives birth to higher term. Lucien Sève has clearly shown that this type of antagonistic contradiction is not the only one possible[186] *« Est non antagonique, la contradiction dans laquelle chaque contraire nie seulement son identité avec l'autre contraire. C'est pourquoi son développement suppose seulement la séparation transitoire et relative des contraires au sein de leur unité.*[187] *».* He even divides the non-antagonistic (symmetrical) contradictions into two classes: those which correspond to Hegel's favourite example of the oak and the acorn, where

rigid conceptions and diametric oppositions. They consist, if we want to... to find, between thesis and antithesis, the appropriate synthesis.

182 It is also this approach, although it does not refer to the dialectics, that is found in a text dating from 1904. In one of the first manuals where the cell theory was presented, the Treaty of histology of A. Prenant, P. Bouin and L. Maillard (quoted by Canguilhem op.cit.)

183 In contrast, more recently American biologists, Richard Levin and Richard Lewontin (op.cit.) also dealt with this problem from their conception of the dialectics, but they mainly engaged in a critique of the reductionism that was already dominant in all sciences in 1985, and did not replace this reductionism in its dialectical relation to holism.

184 Lucien Sève *et alii*, 2005 *op.cit.* p88. *The dialectics is therefore that logical thought which is not satisfied with proscribing contradictions, which has never prevented the manifestation of actual ones, but endeavours to treat them for the purpose of solving them. And how do we resolve- dialectically- an effective contradiction? By daring first, bypassing the prohibition of formal logic, to think about the unity of opposites.*

185 *ibid.* p 92. *Taking them [*the contradictions*]seriously as such, dialectical thought endeavours to underline their truth by discovering or inventing the deeper or higher unity within which the opposites that manifest themselves in it can coexist cooperatively or conflictually up to certain thresholds.*

186 *ibid.* p 92-125. *Is non antagonistic, the contradiction in which each opposite denies only its identity with the other opposite. This is why its development presupposes only the transitory and relative separation of opposites within their unit.*

187 Lucien Sève *une introduction à la philosophie marxiste,* Éditions Sociales, 1980, p468. More recently, he writes again "*a very widespread and very mutilating idea of the dialectics is that it disregards, as a matter of principle, the recurrent complementarity of two opposites, to the benefit of their only future incompatibility and their overtaking in a third term called " superior ".* 2005,*op.cit.* p 90.

the opposites follow one another in time and generate each other; this is the contradiction that Sève calls embryogenic deployment, while another, where the opposites coexist in their unity in a recurrent complementarity, is a cyclic functioning[188]. The paradigmatic example of this type of contradiction is the wave / particle duality, both opposing and inseparable properties of light.

And finally, we must always avoid a naive or dogmatic interpretation *« Bien entendu, ce n'est pas notre logique dialectique qui est dans les choses (on aurait là une niaise variante subjective d'idéalisme); ce qui est dans les choses, c'est ce que nous pouvons appeler une dialecticité que re-produit de façon approximative et incomplète la pensée dialectique, dialecticité dont l'existence objective est attestée par la périodique entrée en crise des représentations d'entendement»*[189]

III-4 Complexity and dialectics.

A dialectical thinking is therefore sufficient to avoid both anathema and total adherence to one of the poles I have described, and leads to the search for a "proper synthesis". But if it says what is logical, thus suggesting in which directions to search, it does not say, it can not say, *how*. As Marcel Prenant announced, the very progress of science will make it possible to provide the scientific methods necessary to prove this synthesis. And Edgar Morin to add « *« Ce sont les développements scientifiques les plus avancés qui nous poussent à sortir des alternatives lamentables comme ordre/désordre, (et réductionnisme/holisme, analyse /synthèse etc.), dans lesquelles s'enferment et nous enferment les simplifications autoritaires. Il s'agit, plutôt que d'opter pour deux ontologies ou deux logiques, d'ouvrir la pensée complexe du réel.»*[190]

III-4-1 The complex overcomes the contradictions between reductionism and holism.

The thesis I am defending here, following Edgar Morin as well as Lucien Sève, is that the complex represents the scientific breakthrough that offers the methods required to go beyond the dialectical opposition reductionism / holism. This constitutes a real epistemological break. In 2006, expecting a necessary paradigm shift in biology I wrote " *A l'heure actuelle, plusieurs types de recherches en biologie s'apparentent à cette tentative de dépassement et constituent ensemble une nouvelle discipline des sciences du vivant, dont le nom n'est pas encore fixé, mais que nous désignerons ici par « biologie des systèmes complexes ». Ces démarches s'appuient souvent sur des*

188 *ibid.* p120.

189 *ibid.* p 115.. *Of course, it is not our dialectical logic that is in things (we would have here a stupid subjective variant of idealism); what is in things is what we can call a dialecticity that is re-produces in an approximate and incomplete way by the dialectical thought, dialecticity whose objective existence is attested by the periodic entry into crisis of the representations of understanding*

190 Edgar Morin, *Réponse à René Thom* in le Débat 1980 N°6, Galimard, p 116. *It is the most advanced scientific developments that are pushing us to get out of lamentable alternatives such as order / disorder, (and reductionism / holism, analysis / synthesis, etc.), in which authoritarian simplifications lock us up. We must, rather than opting for two ontologies or two logics, open the complex thought of reality.* "

théories physiques, comme la dynamique des systèmes non-linéaires, ou des méthodes informatiques comme les automates cellulaires ou les systèmes multi-agents»[191].

Conversely, the crystallization of the opposition between reductionism and holism, (hence the refusal to consider the possible overcoming of this contradiction, thus considered as an eternal opposition, together with the ideological rejection of dialectics) represents in my opinion, one of the major obstacles (although not the only one, of course) to the progress of the sciences of the complex. Indeed, this double refusal, still very important nowadays, leads most often to recruit the complex under the banner of holism, resulting in another reduction.

To the extent that the sciences of the complex deal with systems and interactions, some people, have been led to consider it as the last avatar of holism. Thus holistic supporters have been prone to grab some aspects of the complex (but some only). It is, as I mentioned in Chapter II, what happens with systemic approaches, like that developed in Arlette Yatchinovsky's work. By systematically taking the opposite of the reductionist position, defined as a Cartesian method, without overtaking it, the author simply ends up in a holistic position, modernized by some of the concepts of the sciences of the complex. What is absent from these truncated conceptions is non-linearity.

Even worse the sciences of the complex have been completely rejected by some in the name of the defence of a reductionism considered as the only scientific posture. A. Danchin caricatured, in 1980, the positions he characterized as "anti-reductionist" and that he aggregated as holistic and even animist: « *Les propriétés intrinsèques du vivant sont considérées comme irréductibles à l'analyse, seule la considération du Tout peut être explicative[...] Il existe de nombreuses variétés de cette façon de voir, toujours à la mode, et il serait facile de proposer une collection de textes allant de Lamarck à Thom, de Lyssenko à Koestler, ou de Prigogine à la Nouvelle Droite, où est affirmée la toute-puissance du global et où l'attitude analytique est ridiculisée de diverses manières (la plus fréquente utilisant le terme de réductionnisme) , associé à diverses connotations plus ou moins injurieuses ».* [192]

In what way do the sciences of the complex allow the dialectical overcoming of the contradiction reductionism / holism? Precisely because they give the scientific means of overcoming most of the contradictions constituting the two attitudes, by viewing them as dialectical

191 *Le vivant entre science et marché : une démocratie à inventer, op.cit.* p 154. *Nowadays, several types of research in biology are similar to this attempt to go beyond and together constitute a new discipline of life sciences, whose name has not yet been fixed, but which we will refer to here by "biology of complex systems". These approaches are often based on physical theories, such as the dynamics of non-linear systems, or computer methods such as cellular automata or multi-agent systems.*

192 Antoine Danchin, *L'invasion du biologisme,* Le Débat n°2 *op.cit.* p 73. *"The intrinsic properties of the living are considered irreducible to analysis, only the consideration of the Whole can be explanatory [...] There are many varieties of this way of seeing, always fashionable, and it would be easy to propose a collection of texts ranging from Lamarck to Thom, from Lyssenko to Koestler, or from Prigogine to the New Right, where the omnipotence of the global is affirmed and where the analytic attitude is ridiculed in various ways (the most frequent using the term of reductionism), associated with various connotations more or less injurious.*

contradictions, which makes it possible to overcome them if they are antagonistic, or to consider them in their unity if they are non-antagonistic.

So let us take again the series of opposite attitudes of the cognitive thought that each of the poles crystallizes, such as analysed above: all / part, continuous / discontinuous, individual / collective, content / form, local / global, finite / indefinite, discontinuous / continuous, moment / duration, static / dynamic, order / disorder, determinism / indeterminism, chance / necessity, Mechanism / Vitalism, materialism / idealism.

All / part. What does dialectical logic tell us? « *La démarche d'entendement qui croit pouvoir penser le tout avant la partie et la partie avant le tout s'enferme ce faisant dans le non-sens. Prises indépendamment du tout, les parties ne sont en rien des parties; indépendamment des parties, le tout n'est en rien un tout. [...] Tout et partie ne sont donc pas en vérité les concepts de deux sortes différentes de choses. Comme Hegel le dit d'autres couples catégoriels, tel celui de la cause et de l'effet, tout et partie ne forment qu'un seul et même concept: celui du rapport tout/partie »* [193].

So we have a clearly non-antagonistic contradiction, as are the following four.

What do NLDS teach us? They show how the quantitative modification of the interactions between parts (chemical molecules of the Beluzov-Zhabotinsky reaction in the example from chapter I) lead to the emergence of a self-organized whole, which is neither independent of the parts, nor the result of their sole properties: it depends on the relations between these molecules at the microscopic level and the whole they form at the macroscopic level. In general, the sciences of complex systems emphasize, as we have seen in Chapter I, the existence of successive levels, each of which is a whole emerging from the interactions of the lower level and dependent on those of the higher level, hence the relationships between levels.

Individual / collective and *local / global*, are two non-antagonistic dialectical contradictions (the individual is built only from the collective, which results in turn from the individual, just as local and global can not exist separately and there is symmetry between these opposites). They are obviously contained in the concept of self-organization, as we have illustrated with the reaction of Belousof-Zhabotinsky, but could equally well be illustrated by a traffic jam, whose overall shape (blocked nodes and bellies more fluid) and the collective behaviour are due to the individual behaviour of each motorist, in his will to advance locally as quickly as possible.

[193] Lucien Sève *et alii*. 2005 *op.cit.* p 129. *The process of understanding that thinks it can think the whole before the part and the part before the whole is locked into nonsense. Taken independently of the whole, the parts are in no way parts; independently of the parts, the whole is in no way a whole. So whole and parts are not really the concepts of two different kinds of things. As Hegel says of other categorical couples, such as that of cause and effect, whole and part form only one and the same concept: that of the relationship whole/parts.*

Discontinuous / continuous. If dialectical logic, with the category of qualitative leap, says that a continuous change can be transformed into a discontinuous qualitative leap, the sciences of the complex show how: this can happen, either during a bifurcation, either simply at the border between two basins of attraction, or between two levels of organization.

Order / disorder: I will let the floor to Lucien Sève : « *Simon Diner, après avoir brossé un impressionnant tableau détaillant les apports majeurs des scientifiques russes de l'époque soviétique à la découverte et à la formalisation mathématique du chaos déterministe – des travaux de K. I. Mandelštam et A. A. Andronov à ceux de V. I. Arnold et Ia. G. Sinaï en passant par l'œuvre capitale d'A. N. Kolmogorov –, en caractérise la portée culturelle d'ensemble comme «l'instauration d'une véritable conception dialectique des rapports de l'ordre et du désordre qui n'a pas fini de nous étonner*[194]» And to Edgar Morin : « *La nécessité de penser ensemble, dans leur complémentarité, dans leur concurrence et dans leur antagonisme, les notions d'ordre et de désordre nous pose très exactement le problème de penser la complexité de la réalité physique, biologique et humaine* [195].

Determinism / indeterminism and *necessity / chance*: These two pairs are not identical, but the answer given by the sciences of complex systems is the same: with the notion of unpredictable determinism, or that of order resulting from noise, they show the impossibility of bringing each of these notions to the absolute and thus of opposing them (what Morin called metaphysics of chance or necessity)

Mechanism / vitalism: this opposition was born with biology as such, due to the incapacity of the purely mechanical sciences of the end of XVIIIth century, to explain the living. It intersected the opposition *materialism (mechanistic) / idealism.* This contradiction, clearly antagonistic, still dominates the field of philosophical polemics concerning the sciences (see chapter V). It has nevertheless been surpassed by dialectical materialism which makes it possible to think of all the transformations (known and to be known) of the properties of the matter1[196] without recourse to a spirit or to the disappearance of matter when the newly discovered properties contravene the assumptions of mechanistic materialism (or of any paradigm preceding the discovery). With dissipative structures, self-organization, the notion of boarder of the chaos, the sciences of the complex bring new knowledge concerning the possible mechanisms of these transformations. However, we will see in Chapter V that idealistic ideology is very resilient and that, through a

194 Lucien Sève *et alii*, 2005 *op.cit.* p 71. *"Simon Diner, after having painted an impressive picture detailing the major contributions of Russian scientists during the Soviet era, to the discovery and mathematical formalization of deterministic chaos – from the work of K. I. Mandelštam and A. A. Andronov to those of V. I. Arnold and Ia. G. Sinai through the capital work of A. N. Kolmogorov- characterizes the overall cultural scope as "the establishment of a true dialectical conception of the relations of order and disorder which has not ceased to surprise us*".

195 Edgar Morin, 1982 *op.cit.* P89. *The need to think together, in their complementarity, in their competition and their antagonism, the notions of order and disorder poses us very exactly the problem of thinking the complexity of physical, biological and human reality*.

196 V.I.Lénine, *Matérialisme et empiriocriticisme op.cit*. see the Introductory chapter

mysticism of emergence, some scientists working with complex systems claim to be idealist or agnosticiss, or even vitalist of a sort.

In all these areas, however, while holistic positions are just as unsatisfactory and one-sided as reductionist attitudes, analytical methods as well as global methods remain important for giving substance to the systems whose complex dynamics are to be studied. *Static / dynamic*, could thus be more of a methodological difference than a contradiction. The complex really exists only in dynamics, even if it is sometimes out of reach of our current means of study, but it most often requires a preliminary static description. The sciences of complex systems share with holism the need to be interested in the dynamics and globality of systems, with reductionism the usefulness of analysing the composition of these systems and with dialectic, the need to work on the relations (interactions) in order to understand the transformations. That is why, the same causes that push some to enthusiastically welcome the sciences of the complex, will push others to refuse them, to fight them, or to skew them, by sticking to one or the other of the contradictory positions.

We have seen that the reductionists, at first, tried, helped in this by many holists, to amalgamate holism and sciences of the complex and therefore refuse the complex. Then, when the scientific thrust became too strong, they tried to weaken it, to skew it. I will take the example of systems biology, whose very name indicates a desire for a systemic, global approach. After a very short time, when the dynamics of biological systems were also considered, system biology has often been restricted, under the pressure of the US fashion and some computer lobbies, to a huge accumulation of data[197], their classification in databases, even the constitution of interaction maps, but without studying the dynamic of these interactions. Here we find the replacement of the complex by the complicated, which excludes non-linearity. Holists, on the other hand, also help to narrow the scope of the complex: by refuting the idea that the complex can be simple and understandable, they reject the NLDSs out of the realm of complexity. Systemic is ambiguous, insofar as there exists, under this term, a range of positions from complex sciences to holism

The opposition *reductionism / holism* is found, in specific forms, in many disciplinary fields. In all case, it prevents, disadvantages or hijacks the adoption of the concepts of the complex, and the recognition of the fundamental role of non-linearity. This is why the sciences of the complex are still obliged to take refuge in specialized institutes (such as the institutes of complex systems,) instead of being entwined in the disciplines, as happens in mathematics, or in statistical physics.

[197] Accumulation made possible by the use of sophisticated high-throughput methods and machines opening the field of the so called “big data”..

III-4-2 Complexity and dialectics: what articulation?

The sciences of the complex have therefore forged (and will presumably continue to forge) new scientific concepts. What I have called complex thinking is a method of thinking that is based on and benefits from the fact that these concepts are generic and transdisciplinary.

The materialist dialectics (and here again I will rely on the books of Lucien Sève[198]), is both a method of thinking and a logic (thus a branch of philosophy), different and complementary to formal logic. (What Seve calls a methodo-logic). Scientific concepts are, as far as possible objectives, *ie* enunciating properties which, if they need the scientist to be highlighted, remain true, in the absence of the observer or at least for any other observer in the same conditions. Philosophy deals with categories which "« *étant par essence des concepts de rapport entre nous et le monde ont explicitement une dimension double : ontologique et gnoséologique, objective et subjective »*[199.] Thus « *Le passage du philosophique au scientifique ne peut jamais s'opérer de façon valide sous forme de « déduction ». Le passage du scientifique au philosophique ne peut jamais consister en une simple généralisation...*»[200] It is important to keep these differences in mind when being interested in the relationship between complexity and dialectics: the later can not be used to prove or justify a particular scientific theory.

But since the sciences of the complex allow to overcome the contradictions of scientific thought such as the opposition reductionism / holism, one can wonder if the knowledge of dialectical logic is still useful as it was for J.B.S.Haldane or M.Prenant ? There is more than one answer to this question.

Generally speaking, as stated by F.Engels *« On peut y parvenir sous la pression des faits qui s'accumulent dans la science de la nature ; on y parvient plus facilement si l'on aborde le caractère dialectique de ces faits avec la conscience des lois de la pensée dialectique*»[201]. Marcel Prenant said nothing else.

At first, even if it is not automatic, a knowledge of the materialistic dialectics can help to overcome the epistemological obstacles that face the sciences of the complex, help to understand all the interest of these approaches, not to mix up complexity thinking and holism, thus not to underestimate the importance of non-linearity. This seems to be the case of the palaeontologist Stephen Jay Gould, speaking of *autoorganised adaptive complexty*[202]

198 Lucien Sève et *alii* . 2005 *op.cit.* p105-108

199 Lucien Sève et *alii, 2005 op.cit.* p107 "*Being in essence concepts of relationship between us and the world they explicitly have a dual dimension: ontological and gnoseological, objective and subjective*"

200 *ibid.* p 108."*The passage from the philosophical to the scientific can never be valid in the form of "deduction". The passage from science to philosophy can never consist of a simple generalization ...* "

201 Friedrich Engels, *Anti-Dühring*, cité dans Gouz (*JBS Haldane, la science et le marxisme*) *op.cit.* p 436. "*It can be achieved under the pressure of facts accumulating in the science of nature; it is more easily achieved if we approach the dialectical character of these facts with the consciousness of the laws of dialectical thinking* "

202 Stephen Jay Gould, *the structure of the evolutionary theory* Harvard University Press, 2002

Conversely if dialectical logic, as we can see it today, enables us to think the sciences of complexity, is it not necessary for this scientific revolution to enrich (dialectically) the dialectical logic?

III-4-3 the "*dialogics*".

In elaborating his *pensée compelxe* (complex thought), Edgar Morin needed a logic different from Cartesian logic, but he gradually abandoned the dialectics he used at first for the *dialogics* he created. This transition is well marked in his book *Sciences avec conscience* published in 1982 that also contains earlier writings. He associates the dialectics with the overcoming of antagonistic contradictions (which he does not want) and creates the dialogic that stresses the unity of the opposites. *« Le terme de dialogique veut dire que deux ou plusieurs logiques, deux principes sont unis sans que la dualité se perde dans cette unité »*[203]. But one can note that this is exactly what Lucien Sève has named a non-antagonistic contradiction. Among so many other possible citation let me give one more *« Ce n'est pas le déterminisme qui est d'une « richesse fascinante », ce n'est pas non plus le hasard. Isolés, ils sont chacun d'une pauvreté désolante. La richesse fascinante, le véritable objet de la connaissance scientifique, c'est la (les) relation(s) ordre/désordre, hasard/nécessité. C'est la réalité de leur opposition et la nécessité de leur liaison* [204]*».* This need is often expressed by Edgar Morin by the addition of a third term*: order / disorder / organization* for example.

Another concept created by Morin, the *recursion*, by which the produced object is producer of the subject that produces it, that recalls the positive feedback loops of the NLDS, also recalls (and enriches) the dialectical contradiction *cause / effect*, and seems to me very close to Sève's embryogenic contradiction.

Finally, what Morin calls his *hologrammatic principle*[205], does not really differs from the dialectical notion of the unity of opposites, while enriching it with the thickness of the complex.

His erroneous (but frequent) conception of dialectical contradictions reduced to antagonisms may have led Morin to refuse that his work may enrich the "i*mmense heritage" of dialectics*[206] which probably also led Marxist or Marxian thinkers to underestimate the important contribution of his work. As a commentator of Edgar Morin writes « *Le « dialogique » est abordé comme l'instrument approprié pour penser et articuler des domaines radicalement inséparables et constituant un réel indissociable et complexe. Le dialogisme permet à Edgar Morin d'éviter le mot*

203 "*The term dialogical means that two or more logics, two principles are united without the duality being lost in this unity*.

204 Edgar Morin *Réponse à René Thom op.cit.* p 114. *"It is not determinism that is of a" fascinating wealth ", nor is it chance. Isolated, they are each of a desolate poverty. The fascinating wealth, the true object of scientific knowledge, is the relationship (s) order / disorder, chance / necessity. It is the reality of their opposition and the necessity of their liaison.*

205 see chapter II-2 *Complexity thinking*

206 Lucien Sève 2005 *op cit*

de dialectique, c'est-à-dire lui permet de faire porter sa réflexion sur la notion de contradiction sans avoir à penser son dépassement ce qui conduirait à une synthèse ou à un retour à l'unité. En un mot il permet à Edgar Morin de se dégager de la tradition hégélienne et marxiste qui avait pu animer ses premiers travaux ».[207]

In many respects, I consider dialogics as a work of articulation between part of the dialectical logic and part of the sciences of the complex. It might be interesting to incorporate it's contributions to the legacy of dialectics, if that proved possible.

III-4-4 A great challenge ahead.

Since dialogic did not, could not complete the task of articulation between the concepts of the complex and the categories of the materialist dialectical logic, this task, initiated by Lucien Sève in the collective work of 1998 and continued by him in that of 2005, is not fulfilled. It is a major undertaking, which will require transdisciplinarity. It could prove essential in order for the dialectics, thus updated with categories that fully reflect the current relations between the objective and the subjective in the knowledge, to participate in thinking the revolution of the complex in the multiplicity of its dimensions, which would in turn help the development of the complexity revolution, faced with the many obstacles that hinder it.

This will also better define the relationship between complexity thinking and dialectical thinking. Of course, complexity thinking is elaborated in a multiplicity of ways, emerging from the many currents of the sciences of complexity, and perhaps never will achieve as unified a formulation as the *complex thought* of E. Morin. However, is it not conceivable, if the awareness of what dialectics can bring to the complexity thinking diffused among scientists at the same time as the sciences of complexity are imposed in the academic universe and in society, that a "dialectical thought of the complex" can be achieved?

We have seen here the epistemological obstacles, which often present themselves as dogmatic oppositions, when they are in fact dialectical contradictions. In the next two chapters, we will review the economic and ideological obstacles. And we will see how closely these three aspects are in fact interdependent.

[207] Christianne Peyron Bonjan, http://peyronbonjan.free.fr/complex2.htm . *Dialogic is approached as the appropriate instrument for thinking and articulating radically inseparable domains constituting an inseparable and complex real. Dialogism allows Edgar Morin to avoid the word dialectics, that is to say, allows him to focus his thinking on the notion of contradiction without having to think about its overcoming which would lead to a synthesis or a return to unit. In a word, it allows Edgar Morin to free himself from the Hegelian and Marxist tradition that was animating his early work.*

Chapter IV the economic and political context.

> *Ainsi nous avons comparé les principaux problèmes techniques et physiques de cette période avec les recherches en physique à l'époque et nous arrivons à la conclusion qu'ils étaient déterminés principalement par les enjeux économiques et techniques que la bourgeoisie montante plaçait au premier plan [...*] *Les universités féodales luttèrent contre la nouvelle science avec une force identique à celle qui opposait les relations féodales agonisantes aux nouvelles méthodes progressistes de production.* B Hessen[208]

The industrial society, resulting from the industrial revolution of the nineteenth century, is taking more and more rapidly a new form, resulting from what has been called successively a scientific and technical revolution[209], then an informational revolution[210], (and also sometimes computational, numerical, cognitive...) which evokes a rupture in the evolution of our civilizations due to the recent developments of sciences and techniques in the field of information. The current period has also seen the birth of the term technoscience, which means that science and technology are totally intertwined and indissociable[211]. Among them, the New Information Technologies (NIT) [212] play a key role in these transformations, be it for the production of goods (which remains however mostly in the commercial and capitalist domain) or for personal life .

The sciences of the complex are involved at several levels in these developments, well beyond the development of computers, which has certainly played a leading role in the development of these disciplines. But it is only one element in the interactions between these and current economic and social transformations. There are strong reciprocal relations between the revolution of the complex and the information revolution, which have moreover manifested themselves nearly simultaneously, and are also concomitant with the emergence of neo-liberal financial capitalism. They exert a direct influence on the scientific policies of the developed countries, without fundamentally changing the relations of production, that is to say the forms of ownership and domination.

208 Boris Hessen *op.cit.* p 98-99.*Thus we compared the main technical and physical problems of this period with physics research at the time, and we came to the conclusion that they were determined mainly by the economic and technical stakes that the rising bourgeoisie placed in the foreground. Feudal universities struggled against the new science with a force identical to that which opposed the dying feudal relations to the new progressive methods of production.*

209 Yvette Lucas, *la révolution scientifique et technique,* Éditions Sociales, 1983 (this term arises from the work of the tchec researcher Richta)

210 Jean Lojkine, *La révolution informationnelle,* Paris PUF, 1993 : *Une autre façon de faire de la politique,* Le temps des cerises, 2012 ; Paul Boccara, et*« révolution informationnelle, dépassement du capitalisme et enjeux de civilisation »,* Revue Économie et Politique, 626-627, 2006 ; Gérard etVerroust . 1994/1997 *Histoire, épistémologie de l'informatique et Révolution technologique* -http://www.epi.asso.fr/revue/89/b89p165a.htm .

211 It also implies that the current purpose assigned to research by the political and economic powers is to favour technological inventions designed to increase the competitiveness of enterprises, called innovations.

212 The term technology, which originally meant "study of techniques", was subverted to refer to techniques with a strong scientific component, or derived from techno-sciences.

It is therefore necessary to analyse the role of these relations of production on the development of the sciences of the complex, and what is their articulation with the information revolution. We will see how socio-economic obstacles, that slow down, deflect or even distort development of the sciences of the compelxe, are added and articulated to the epistemological obstacles.

IV-1 The "informational revolution": the progress of the productive forces that allows and requires the revolution of the complex.

We have seen the importance of computers in the development of the sciences of the complex. This development has also been the cause and consequence of a profound change in society. Issued from a command of the US military during the war, computers were developing slowly at first. Then their progressive miniaturization allowed them (from the middle of the 80s), to invade the entire economic sphere (automation of management and production) and the whole society. This generalization led to a societal and economical mutation which has been called *Information Revolution* by several authors[213]including Jean Lojkine, on the work of whom I will rely here.

Lojkine speaks of an unprecedented societal revolution in the history of humanity, at least as important, if not more so, than the conception of the manual tool or the invention of writing. With the *Information Revolution* comes automation: mass production is no longer a manual phenomenon but an entirely mechanical phenomenon: the multiplication of the gesture by the machine is infinite, more precise, faster, more reliable. Which means that the worker no longer works with his hands and that the machine has recovered a certain number of the cognitive functions of the human, making possible and necessary an entirely new type of dialogue between man and machine. Moreover, with computer science, the capacity to process huge masses of information (storage and calculation) is infinitely multiplied.

With cybernetics, robots and the expert systems, we are entering a new era *« La machine n'est plus un support aveugle de la seule force motrice, mais un substitut d'intelligence, qui émet également de l'information et avec qui l'homme peut dialoguer »*[214] The role of the human in the production can change fundamentally. And since the numerical control of the machine can be done remotely, the coordination of the fabrications can be realized in a diversity of places, the unity of place as a field of economic action disappears, scattering the cultural coherence (language, history, geography, practices, referents) of groups and peoples. Indeed, the *Information revolution*

[213] See note 190

[214] *op.cit.* p 118 "*The machine is no longer a blind support of the only driving force, but a substitute for intelligence, which also emits information and with which man can interact*"

potentially modifies all the economic interactions, by replacing the fixed hierarchical organizations of the industrial revolution, by organizational networks, at the level of a company, or at the level of the globalized multinationals. It also requires trained staff not only in computing and robotics but in the science of the global operation of networks.

In other words, the very notion of a process going from design to distribution to production is blurred by the simultaneity of ancestral functions: the researcher and the designer rely more and more on the real production and consumer situations that become their laboratories; phenomena of large numbers enter the theoretical field, together with randomness, probability and risk, and the multiplication of interactions...Labour corresponds less and less to a logic of linear organization and more and more to that of a complex system operating with retroactive control loops.

Here we see the double relationship between the revolution of the complex and the *Information revolution*. First in both cases a material relationship due to the central place of computers. Because of this place, the economy develops the computer more and more quickly and these technical advances favour those of the sciences of the complex. And secondly a conceptual relationship of perhaps even greater advantage: computerization and automation bring about changes in society that make it more and more complex. From the local level of the enterprise, to the global levels of nations and the "*world-system*"[215] society tends to become a network of interacting complex systems. The result is a clear need for study and understanding of these changes, a need for complex sciences, concomitant with the development of the instruments necessary for this development. Entirely embedded in the *Information revolution*, the sciences of the complex should flourish as much as possible in these new economic and social conditions.

But. For there is a But and even several ones.
First, the commercial criteria of labour are challenged by this transformation, because the market value itself may lose its relevance. Indeed, the value (of use) created is more and more constituted of ideas and information. But the idea escapes market logic: if you sell an idea to a third party, you continue to own it. Nowadays we are seeing all sorts of tricks developed to turn the barriers of intellectual property, at the same time as the practice of free software[216] is developing. But this is opposed to capitalistic property and great efforts are being made by the economic powers to limit as much as possible these processes of circulation and information sharing, from the level of the enterprise to that of scientific research, where the proliferation of patents is opposed to the free flow of ideas, yet necessary for all research.

[215] To take up here the expression launched by Ferdinand Braudel and developed by the school of the Annales cf Immanuel Wallerstein op.ci

[216] Free software is much more than gratis. It is a work that becomes obligatorily collective as soon as each user can seize it to improve it. It is therefore also a complex object, arising from multiple interactions, non-commercial because volunteers.

But there is more. As Lojkine also showed, automation is not simply the replacement of the human by the machine. To be effective, it must be an articulation between human and machine, which requires an increasingly educated workforce, thus more and more able (and willing) to take part not only in the operation but in the business management. The unskilled workers of the Taylorized plant are rapidly replaced by technicians trained at “baccalaureate plus three”. At the same time, technical potentialities no longer require the unity of place, and companies move from a hierarchical organization to an organization in decentralized networks, which could go towards self-organization. This is why the *information revolution* carries within it the potentialities of a true civilisationnal revolution. The computer can become *un instrument de transformation du monde, matériel et humain*[217]. But it is also why it opposes even more frontally capitalistic logic, based on the ownership of the means of production, thus the complete separation between the direction / decision-making and the execution, therefore the hierarchy. « *L'irruption des NTI et les exigences nouvelles de décloisonnement et d'accès direct à toutes les informations circulant dans l'entreprise risquent de se heurter aux verrous de la direction stratégique qui n'entend pas partager sa « vision d’ensemble » de la politique de l’entreprise...*»[218].

Thus the revolution of the complex is part of a macro system in crisis because the functioning of society at the level of the planet is based on a scientific, technological, economic system continuously complexifying, but based on a unique and outdated principle: merchant exchange, simplistic, reductive and hierarchical, opposing the societal reality in progress. We are indeed at the heart of the contradiction already seen by Marx between the progress of the productive forces, which generate and require the complexity within the firm itself-horizontality, the multiplicity of multilateral interactions, sharing-and the maintenance of the all-merchant and of the production relations braced on the conservation of these past values - hierarchy, verticality - while seeking to recover as much as possible the considerable profits that these new technologies can bring. This is one of the bases of the systemic crisis we are experiencing.

Lojkine studied how, in the companies, the maintenance of the hierarchy, related to the will of omnipotence of the directions and the will of power of the intermediate hierarchy, as well as the pressures for an immediate yield of the work, prevented or very strongly minimized the changes in organization made possible and necessary by automation and computerization, which already led, in 1990, to contradictions (whose current exacerbation has been reflected in France by a wave of suicides of employees). Two apparently contradictory movements are emerging today that rely on systemic. The "*Lean management*" is based on a global conception of the company to "optimise" it

217 *op.cit.* p 44.*an instrument of transformation of the world, material and human*

218 *op.cit.* p 160. "*The emergence of NTI and the new requirements of decompartmentalization and direct access to all information circulating in the company may run up against the locks of the strategic direction that does not intend to share its" overall vision "of company policy* “.

in terms of time (tight flow) and staff. The "*liberation management*" aims at gaining efficiency by giving the most possible initiatives to the staff, excluding, of course, strategic decisions. In this instance, systemic can help training the staff to take into account new data, to manage the malfunctions of the organization, « *pour changer, changeons le relationnel »* [219] without questioning the overhanging role of top management. In the same way, among the potentialities opened by the new methods, Lojkine also showed that it is especially those related to the processing of masses of data, rather than those related to the entirety of the dynamic processes that are favoured, which we also noted as a drift of the sciences of the complex.

Thus, the potentialities of the *information revolution* come in deep contradiction with capitalist property and the market. « *Les mutations socio-techniques sont[...]des potentialités contradictoires et non des ... conséquences automatiques d'une évolution linéaire* [220]». Therefore it has become necessary, in order to maintain the capitalist economy, to bridle (distort) the *information revolution*, to keep it within limits (inevitably unstable and conflicting[221]) where it is useful to this economy without harming it at least on the short term. Science in general and the revolution of the complex in particular, are *de facto* at the heart of this contradiction.

Scientific research was already part of Marx's definition of the productive forces, but we now note, as we have seen, a considerable increase in the interrelationship between science and production (techno-science)[222]. Scientific research has become a major economic issue in developed countries and is the subject of direct steering by the economic powers. What are the consequences on the sciences of the complex?

To understand it I will rely on scientific policies in Europe and France

IV -2 The knowledge society and economy

During the so-called "Golden Thirties" period in France, basic public scientific research[223] was independent of the industry, both by its funding coming almost exclusively from the state and by the research policy, led by the French National Council for Scientific Research (CNRS), an organization reorganised after the war and, at that time, democratically managed by scientific workers. The underlying ideology was that "science finds and industry applies". However, industrial research[224] was somewhat underdeveloped in France, which was the cause of industrial

219 Arlette Yatchjnovsky *op.cit.* p 99. "*To change, let's change the relationship*"

220 Jean Lojkine *op.cit.* p 19."*Socio-technical changes are [...] contradictory potentialities and not automatic consequences of a linear evolution*".

221 A conflict that sometimes results in the suicide of workers or executives caught in a complexity that they no longer have the means to manage. See for example Vincent de Gaulejac, *Travail, les raisons de la colère,* le seuil 2011.

222 Science tends to become a "direct" productive force.

223 With regard to so-called applied public research entrusted to large organizations such as CEA (Center for Atomic Energy), INRA (National Institute of Agronomic Research), INSERM (National Institute of Health and Medical Research)), etc., things are more complicated, but their detail does not matter here.

224 It may be useful to note that in France the engineers and managers of the industry are trained in specialised schools, whereas the research was carried out mainly in the universities.

leeway. From around 1975 (again this same decade 70-80!), Successive governments endeavoured to overcome this hindrance by developing relations between public research and industry. This has been achieved in particular by a gradual decrease in recurrent credits[225] of laboratories, forcing them to seek financial resources through contracts with industry, or by public contracts requiring association with industries - thus on projects of interest to theses industries. The same process took place in the various countries of Europe in different forms and at different rates The model was supposed to be the USA[226].

In year 2000, the Lisbon European Council launched the concept of the *knowledge economy* and created the ERA (European Research Area) to implement it. The objective was to "«*devenir, (d'ici à 2010), l'économie de la connaissance la plus compétitive et la plus dynamique du monde, capable d'une croissance économique durable accompagnée d'une amélioration quantitative et qualitative de l'emploi et d'une plus grande cohésion sociale*»[227]. It was a matter of formalizing and systematizing what had begun over the last twenty years and accelerating these transformations by turning the various strategies of resistance of scientists, attached to the autonomy of science. To this end ERA has used an already existing tool, the Framework Programs (for research and development) (FP). In 2002, FP6, which had become the preferred tool for the construction of the ERA, was launched for the implementation of the European research policy, as defined in Lisbon.

FP 6 is an enormous text, divided into seven themes, most of which concern the "hard" sciences. It includes the creation of *networks of excellence* (very large groupings of European scientists around defined themes) and calls for tenders for integrated programs. These research programs, developed by the commission under the supervision of industrial lobbies, were intended to become models in Europe. The aim was to control and enlist knowledge, (essentially identified with science, technology and scientific research) under the banner of the economic warfare of capitalist enterprises, which they call competitiveness. The list of the projects contained in these calls for tenders gives an overview of the directions that the European Commission wants to give to the research.

Admittedly, these programs represented only a small part of the funds allocated to research in each country (at the time of the launch of FP6 these sums represented about 5% of research funds in France). But their influence was already much greater. First, symbolically, there was the impact of the laboratories selected to be part of the *networks of excellence*. They constituted a label, granted by opaque commissions of experts, which allowed the lucky ones to apply for large sums

[225] Credits allocated regularly to the laboratories according to the number of researchers.

[226] But in the US, almost all research labs benefit from a dual source of funding, a public source by two major national funding agencies and a private source via contracts with industry, which invested much more massively than in France in "knowledge". And the funding for research was very high.

[227] Declaration of the Lisbon European Council March 2000." T*o become (by 2010) the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic growth accompanied by a quantitative and qualitative improvement in employment and greater social cohesion"*

allocated to integrated programs, thus constituting a "scientific aristocracy" according to the criteria of Brussels. Secondly, many finacial backers (the regions for example) required the laboratories to submit programs similar to those in FP6. States and especially regions were indeed encouraged to use FP6 as a model to design their research policy. In France a whole arsenal of structural reforms of research has been set up for this purpose, which, piece by piece, led to a putting of public scientific research under the supervision of private companies, (including with their management criteria), in line with the recommendations of the ERA (which themselves are in line with those of the OECD): teaching reform (LMD), which has weakened the national network of higher education; then, under the five-year rule of President Sarkozy, the law called University Autonomy (LRU), which greatly increased this fragility and pushed universities to seek financial support from regional industries; recurrent research funding continuously decreasing in favour of various contracts, then almost eliminated and replaced by contracts (between research laboratories and companies) and by public tenders, the majority of which are targeted towards research-innovation, launched by a National Agency for Research (ANR) created in 2005; and lastly, a method of evaluating laboratories based on the number of publications, patents and innovation prospects, and which makes the laboratory note, and therefore the career of their researchers, depend on the proper implementation of these criteria which are all but scientific. This is the establishment of scientific supervision by authorities, that designate them, through increasingly opaque ways, such as the ANR, which handles a large part of public funds for research. It works through calls for tenders for relatively short projects and for the most part focused on the interests of what is now called- without defining it - research-innovation[228]

In this way, science policy assigns the role of profit-seeking to public research through innovation[229], (the term research-innovation has now replaced the term research in all discourses and official texts dealing with research). Meanwhile, moreover, some major industrial research and development laboratories have been closed. Public research has lost a great deal of its autonomy in steering, while time for free research (basic research not explicitly linked to an innovation perspective) was shrinking.

Certainly the European Commission has created a European Research Council funding the best basic research, that is to say, issued mainly from large laboratories with many resources from research-innovation. Similarly the ANR used to propose, until 2013 non-targeted projects, called white, But they represented a small proportion of credits allocated and do no longer exist.

The very nature of the research has been profoundly modified with these practices imposing short projects (not exceeding 4 years on average), instead of the, sometimes very long-term, themes

[228] Thus in 2007 there 90% projects funded were from thematic projects.

[229] An analysis of the uses of this term can be found in "*la science pour qu*i? "edited by J. Guespin-Michel and Annick Jacq. The Croquant, publisher 2013.

of baic research. It also ensues in most scientific fields, a phenomenal waste of researchers' time, dedicated to writing responses to calls for tenders, at the same time as they are asked to increase their productivity (in terms of publications or patents), not to mention the very low rate of success (less that 10 % of the applicants get granted). Worse still, researchers are being asked to predict the results they expect from their work, which forces them either to cheat or to confine themselves to research of which all complexity is excluded.

Whether at the European level or at the French level, there is a double movement that may seem contradictory. Taking into account the place of knowledge in economic development leads to a logic of development and the EU advocates (but without precise instructions or means to achieve this), to bring the research effort to 3% of GDP. Not only has this never been achieved, but the crisis of 2008 stopped to this ambition, and the current restriction measures impair the development of research. On the other hand, the EU also advocates a (very effective) limitation of the scope of development of research to the stakes of a market economy: innovation is conceived as the weapon of the economic war for the conquest of new markets. Thus a logic of development (very relative) is contradicted and hampered by a narrow vision of the role assigned to the development of knowledge and by the imperative need to reduce the cost to enterprises (and now to the State) of investment in research.

But these projects and tenders, written by expert committees that include scientists chosen by the government and representatives of industrial lobbies, make it possible to know what the objectives these companies, through governments and European Commission, do assign to research to ensure business competitiveness. The study of the programs thus financed is therefore a good indication of how the current economic and political context affects research trends. The analysis of the content of calls for tenders (compared to that of freer research projects), gives an indication of the direct impact of the liberal economy on scientific development and, as far as we are concerned, on the revolution of the complex. The ways used to corset and brake what hampers, while developing what seems useful, are diverse and not always easily detectable. They affect all aspects of the development of knowledge, quantitative of course (funding, posts), but also qualitative, simply by the title of the calls for projects. It will therefore be necessary to study this obstacle/development aspect in a rather detailed and qualitative way because it does not consist only in a significant reduction of the over all basic research effort in favour of a relative increase in the applied research effort, but has a profound impact on the nature of researches. Indeed basic research is privileged in areas where it is likely to lead to rapid applications. It is therefore necessary to ask whether the choices made by these committees relate only to the questions asked to the research, or if they also imply an epistemological interference, particularly with regard to the sciences of the complex?

Insofar as biology entered the era of techno-sciences at the time of the launch of *knowledge economy*[230], it is on examples from this discipline that I concentrate first in this chapter[231] by studying the way in which representatives of the European markets have interfered in the epistemological debate concerning a reductionist discipline[232], molecular biology. Then I will question the French tenders to try to directly evaluate the impact of the economic interference in the development of the sciences of the complex.

IV-3 Economic pressures on scientific paradigms: the case of the biology

IV-3-1 the rise of the "all genetic" (1975-2000)

We can distinguish three phases in the history of molecular biology from the 1970s to the 2000s, which illustrate the growing involvement of economic pressures in the epistemological debate in favour of the “all genetic”, the advanced point of reductionism in biology.

Between 1975 and 1989, molecular biology developed at breakneck speed thanks to the discovery of what is called genetic engineering techniques. Until then, genetic studies had mainly concerned bacteria, yeasts and vinegar flies. From now on we could short-circuit the slow in vivo studies, based on phenotypic differences and directly study the genes and their expression (that is to say the production of proteins), in higher organisms, and soon in human. This has resulted in unexpected and fascinating discoveries that have obviously focused the attention of scientists and the general public on genes and prompt to forget that a protein does not correspond to a function[233], and even less to a functioning. The considerable and indisputable success of these methods has quickly turned into a victory of a more and more narrow reductionism in the life sciences. This first phase is mainly epistemological.

But the discovery of these techniques has also almost immediately given rise to what has been called biotechnologies (by diverting the meaning from an already existing industrial branch). It involved using techniques to isolate genes for expression (functioning) in other organisms, which are now called GMOs, to obtain at a lower cost, products with high added value, for the pharmaceutical industry (insulin, or growth hormone produced by bacteria for example), or the agri-food industry.

There has been a tremendous financial appeal, huge profits have been made, including by the American academic authors of these discoveries, and even higher profits have been suggested by scientists who, wishing to have their share of the pie, started surfing the venture capital system. To convince markets, to put them in motion, it was necessary to have a convincing, therefore simple,

[230] The real birth, not its officialisation by the EU in the 1970s.

[231] In doing so I will rely mainly on the collective work « *le vivant entre science et marché : une démocratie à inventer* » *op.cit.*

[232] Thus, as stated in the previous chapter, opposed to complexity

[233] A biological function generally requires several proteins and can often be performed in several different ways (i.e. with different sets of proteins).

theory. The “all-genetic” perfectly fulfils this function. Thus was justified a research policy directed essentially to studying genes with the hope for rapid fallout in terms of cost-effective drugs. Companies have thus favoured a type of scientific development, but without interfering in the epistemological aspect. In the same vein, the scientific equipment companies made considerable progress drastically shortening the duration of the experiments, allowing to accumulate an impressive number of data usable or at least marketable by the biotechnologies, which illustrates the reciprocal interrelations between science, technology and industrialization.

In France the development of molecular biology techniques to the detriment of other lines of research in biology was carried out drastically in the 80s, in the sections of life sciences from the CNRS, then at INSERM[234]. Significant scientific results were also at the rendezvous and this scientific policy found its justification. Thus, when the concepts of complexity began to take form, as modelling techniques begin to emerge, the living, that eminently complex object, escaped almost entirely these investigations.

The story culminates around 1990, when scientists began to persuade decision-makers of applied and financial interest (one spoke of health as the possibility of sources of new profits) of embarking on a job that was at that time rather titanic, the sequencing of the human genome[235]. The gigantism of the project gave rise, quite logically and justifiably, to international cooperation between public research in the industrialized countries (including the United States) and the multinational firms concerned: *the public consortium*. The aim was to put this knowledge in the public domain to be able to share it and to pool the efforts.

The story got carried away when Perkin Elmer, a manufacturer of DNA sequencing apparatus, decided, under the influence of a researcher, Craig Venter, to seize on its own (through the sequencing project "Celera"), the huge profits expected, by filing patents on the sequences obtained. We then saw this bewildering fact, that, to prevent Celera from appropriating a large number of sequences of the human genome by patenting them, the states of all the participating party countries of the public consortium, instead of prohibiting the patenting of such sequences, have engaged in a speed race with Celera. It was proclaimed that it was a matter of ethics, in order to put the raw data in the public domain, but it is only to see how the European Commission gave in, on the problem of the patenting of human DNA, to realize that ethics has been, for some, a mere pretext. In this race for sequencing, there has been a tremendous diversion of public research funding (and in France also charitable funds) in favour of a single goal, prevent Perkin Elmer and

[234] The Comité National de la Recherche Scientifque, and the Institut national pour la Santé Et la Recherche Médicale, were respectively harbouring basic and medicine oriented research.

[235] The techniques used became more and more efficient (the sequencing speed increased by a factor of 100), but at the beginning, it must be realized that the sequencing had to be done from DNA fragments of about 100 pairs of bases! And once the order of the base pairs on the molecule was found, it still had to be interpreted, *ie* locate the genes, which was also a huge job.

Craig Venter from appropriating the results of sequencing of this genome, and leave their share to other multinationals! Certainly, the sequence of the human genome has been almost completely deciphered nearly five years before the scheduled date. Admittedly, the tremendous accumulation of data constituted by this sequencing and that of many other living beings has considerably advanced techniques and knowledge in bioinformatics and molecular biology.

But, for almost 10 years, a huge fraction of research funding, positions, biology efforts have been (at the level of the world's great powers) concentrated in one direction, which has hampered research opportunities in the other necessary directions[236], and this for a very long period, because of the diversion of "human resources"[237]. Yet the most important immediate success was to show that knowledge of the genome was by far insufficient to understand the organism. Who does not smile nowadays of the assertion of Walter Gilbert (1991) *« quand nous aurons totalement séquencé le génome humain, nous saurons ce que c'est que d'être humain »*[238]

Of course this could only be done with the consent of a large part of the community of scientists involved in the decisions. The interpenetration of economic and epistemological dimensions is particularly evident here. It is now well known (thanks to the knowledge of the sequences of many genomes) that a gene can express several proteins, that the structure of these proteins can depend on the environment and that each function depends on several proteins and the environment, cellular or other... The reductionist paradigm of the "all genetic" is moribund, as brilliantly explained by Henri Atlan[239] in 1999, showing that a new paradigm had become necessary. This new paradigm to discover, to invent, could it not be precisely the sciences of the complex? One would then have expected to see a multiplicity of approaches and attempts to move towards what would have been the biological branch of the scientific revolution of the complex.

Instead, the third phase is related to the "prolonged coma" of reductionism, to the good care of the European Commission through the programs of the 6th (since the 7th) FP.

IV-3-2 Intervention of the European Commission in support of reductionism.

Atlan's book was published in 1999. However, as we will see, the 6th FP (2002-2006) has still supported through funding, networks of excellence and national or regional research pressures, a frame of thought that has reached its limits of effectiveness. It has, therefore, allowed proponents

[236] Such as those necessary against the consequences of climate change, including agriecology.

[237] If it had taken twice as many years to obtain this sequence, there would have been no delay in the applications for health, because, if none of the therapeutic promises on which the advertisement was based was held during at least the ten following years, one may think that it is because the indispensable complementary researches were not carried out in parallel. On the other hand, large financial profits have been made from these promises, for biotechnology companies did not need, at least initially, to have concrete results to sell. This is called the economy of pledge.

[238] Cited in Richard. Lewontin, *la triple hélice*, 1998, traduction française, Le Seuil coll science ouverte, 2003. "*When we have completely sequenced the human genome, we will know what it is to be human"*

[239] H. Atlan, *La fin du tout génétique, vers de nouveaux paradigmes*, Éditions de l' INRA, 1999.

of an outdated paradigm to continue to hold the upper hand and divert to genomics an undue proportion of research funding.

It is “therapeutic relentlessness”! The tendencies of these programs are sometimes referred to as post-genomics, especially with the so-called "high throughput" techniques which make it possible to gather data in very large quantities and at a very high speed thanks to more and more sophisticated equipment grouped in technological platforms. This led to the lack of resources to look elsewhere, for example to develop complex approaches to non linear dynamics. And things have not changed from this point of view in the next program, the 7th PCRD 2007-2013[240]. However, despite the lack of incentives, such researches have started to emerge, even in biology[241]. Then very quickly, system's biology, came from the US, implementing high-speed technologies, which exploit through huge data banks, the results obtained thanks to the knowledge of the sequences of DNA. This systems biology is often presented as a complex (systemic) approach. In fact, the use of often impressive computer resources makes it possible to compile an impressively growing number of data (the famous *big data*), corresponding to the global cellular or organism scale. But this leads most often to build linkage maps between hundreds of genes whose expression is increased or decreased during a particular process. But these networks are entirely static, and for instance, no feedback loop can be observed. They differ from the networks studied in the previous period only by the number of genes involved, that continuously increases due tu miniaturisation improvement. The complex has given way to the complicated, for the greater benefit of the manufacturers of molecular biology equipment.

And this is not limited to cell biology. In addition to the big data fashion, that of neurosciences may seem to contradict my statement and give full scope to complexity. An example will show how necessary it is to be careful. In educational science, to determine the effectiveness of educational methods (software) for learning to read, measurements of the activity of neuronal zones by MRI imaging have been used instead of simple reading tests, (which in addition led sometimes to results unconnected with the desired learning capacity). The very expensive use of large instruments, replaces here simple, effective and really complex methods[242].

Although the situation seems to evolve more rapidly now, attempts to resist this trend, and studies of complex dynamic systems (which can be simple) remain difficult. Laboratories, networks, institutes of integrative biology, or of integrated systems that flourished here and there,

[240] with the following topics: health; food, agriculture and fisheries, and biotechnology; information and communication technologies; nanosciences, nanotechnologies, materials and new production technologies; energy; environment (including climate change); transport (including aeronautics); socio-economic sciences and humanities; space and security. This program also integrates new joint technology initiatives.

[241] Roger Lewin op.cit, This american popularization book introduced to the general public, the possibilities of studies of the complex in biology.

[242] *Neurobullshit: Good practices and mischief in neuroscience*” Franck Ramus, directeur de recherches au CNRS, Laboratoire de Sciences Cognitives et Psycholinguistique (ENS Ulm, Paris) talk at lSC-PIF for *open cognition and education* january 2018

have more or less quickly disappeared or have been diverted, in France at least, for lack of support or credits. Biologists are still very few in the National Network of Complex Systems.

All this shows that European research policy had epistemological repercussions, at least in the field of life sciences. What about other disciplines?

I browsed French calls for tenders in search for complexity thematics.

I found a narrow complex often reduced to the complicated, devoid of concepts of non-linear dynamics, which are marginalized, a complex which is far from evoking a scientific revolution . A complex that takes refuge mainly in the human sciences, (where the sums allocated are the weakest).

Obviously, it would be simplistic to conclude that this situation is solely due to economic constraints and that the epistemological obstacles analysed in the previous chapter are not at stake! It would also be naïve to try to estimate the respective responsibility for epistemological obstacles and economic obstacles, since they reinforce each other (and also since the ideological obstacles are equally important, as we will see in the following chapter). But the result is there: in the current capitalist society, the revolution of the complex is slowed down and distorted. The complexity thinking obviously does not suit the knowledge economy, which does not reject it explicitly, but leaves it thrive in a meagre territory, between the technical mastodons of big data and expensive devices.

The absence of these concepts in teaching programs is particularly conspicuous. If we compare with biotechnologies, whose birth is contemporary with the emergence of the complexity sciences (around 1975), the difference is flagrant, since the latter are taught from high school, while the complex must wait for specialized university lectures, in mathematics, physics or social sciences! (see chapter VI)

IV-4 The sciences of the complex and society in the twenty-first century.

Major societal issues came to the fore at the turn of the twenty-first century, the issues of sustainable development and the environment, climate, biodiversity, have joined those of hunger, water, democracy... They impose themselves more and more, in frontal contradiction with capitalism, despite attempts of “green washing” capitalism.

Thus, if global warming and energy are among the priorities of EU-funded research in the current Framework Program for Research and Innovation Horizon 2020, this is part of a vision that the following formulation crudely highlights " « *tout le long de la chaîne de l'innovation débouchant <u>uniquement</u>*[243] *sur l'apport au marché de produits et de services innovants* »[244] For example, the use of agricultural resources to produce biofuels intended to limit greenhouse effect

[243] highlighted by me

[244] Framework program (horizon 2020) for research and innovation. . *all along the innovation chain leading <u>only</u> to bringing innovative products and services to the market*

has first led to a very serious food crisis, then, with palm oil, to very serious ecological problems[245]. This illustrates the limits that capitalism has reached to solve vital questions[246]. Most of the time, the damage caused by green capitalism comes from the fact that, to make a profit, it sees only one aspect of the issue.

Yet what characterises these issues is their global nature, transnational and interdisciplinary, and the fact that they always involve multiple transformations and interactions. Cereals used for biofuels are also used for other purposes, biodiversity does not generate profits[247]. These are, almost by definition, complex issues that, given the dramatic global consequences that may result from neglecting them, deserve a huge effort in the development of the complexity sciences, including, basic research. So far, the effort does not live up to the stakes.

Let's go into more detail with an example of research on agricultural seeds[248] . Bonneuil and Thomas1[249] analysed how research aimed at meeting productivist industrial criteria focused on plant genetics to produce the seeds most suited to these criteria. They showed that this reductionist strategy, however, corresponds to a neoliberal economic bias implicit and most often unknown to researchers. For his part, Hugh Lacey[250] has studied the evaluation and selection of agricultural seeds in agro-ecological research in Brazil, where they are considered in the context of a food production system. Are then taken into account the impact on biodiversity, social relations, territory, *i.e.* the entire network of interactions in which this production is taken. This strategy (also called contextualised) is clearly complex, with a social bias. In general, applied or finalized research carried out with a social bias is not less scientific than that conducted with a liberal bias, but must include a multiplicity of interrelated factors and therefore belong *de facto* to the realm of complexity. They should benefit from the methods of the sciences of the complex which they should in turn help progressing, if they were not disadvantaged, even criticized as unscientific, by the liberal policies of the research and their supporters.

To sum up this chapter, the development of the productive forces[251] made possible the *informational revolution*, which relies on, and requires, the development of the sciences of the complex. But the capitalistic relations of production slow down and divert the whole process,

[245] Diverting food resources to fuels allowed speculation on wheat leading to famines, while growing palm trees for oil necessitates tu burn native forests.

[246] It is no question here of developing this point, which has been addressed in many books, for example Hervé Kempf, *pour sauver la planète, Sortez du capitalisme,* Le Seuil, 2009.

[247] At least for the moment, but laws in preparation, or already implemented in some countries, which allow, on the model of the carbon tax, to buy the right to destroy the biodiversity, let fear the worst.

[248] *see la science pour qui ? op.cit.* pp 85-90.

[249] Christophe Bonneuil andFrédéric Thomas, *Gènes, pouvoirs et profits : Recherche publique et régimes de production des savoirs de Mendel aux OGM, publishers* Quae, and Fondation pour le progrès de l'Homme, 2009.

[250] Hugh Lacey *Values and objectivity in Science : the current controversy about transgenic crops.* Lexington books (Rowman and Littlefield publishers inc. 2005.

[251] I use this term rather than techniques, because it encompasses not only the techniques but the processes that result and the changes in the relationship between men and the machines they involve.

including by interfering at the epistemological level. These production relationships generate conditions that can be globally dramatic for human civilizations, and notably prevent to face the full complexity of the great ecological and societal challenges facing the planet. The revolution of the complex is at the heart of the contradictions between the development of the *informational revolution* and the relations of production, and between these and the survival of our civilizations.

Chapter V the ideological context

> *La situation économique est le fondement. Mais le développement des théories et l'œuvre individuelle d'un savant sont affectées par diverses superstructures, telles que les formes politiques prises par la lutte des classes, et les résultats, l'écho de ces luttes dans les esprits des participants : théories politiques, juridiques, philosophiques, croyances religieuses, ainsi que leur développement en systèmes de dogmes.* Boris Hessen[252]

The hegemony of the neo-liberal ideology, after the degeneration then the implosion of the "socialist camp", is what we call the *unique thought*, the fatalism, the idea that this neo-liberal economy is the only possible one. This includes rejection and discredit of anything reminiscent of Marxism[253], the class struggle, materialism, as well as any attempt at global explanations, disqualified under the terms of *grand narrative* or utopia. But it is the dialectics, this logic of transformations that is particularly banned, while a static, simplistic and disjointed form of thinking remains dominant.

This ideological context in which the revolution of the complex has developed has certainly contributed to the underestimation of the interest and even the existence of a *complexity thinking*, emerging from it and destined to spread well beyond. On the one hand, because the decried materialistic dialectical logic is a privileged tool for thinking the complex, as we saw in Chapter III. On the other hand, because the dominant ideology is based on and reinforces a way of thinking in which Cartesian rationalism has been frozen in a static, simplistic and linear form, as opposed to any thought of complexity. This way of thinking permeates media communication as well as a large part of education and thus sterilizes in return the development of the *complexity thinking*, and more profoundly of the sciences from which it emerges and for which it ensures coherence.

The recent awareness of the systemic crisis of capitalism has resulted in a certain return of Marx and in the multiplication of reflections and experiences that form a sort of post-capitalistic movement, by which complexity is more and more recruited[254]. Without constituting (yet) a new ideological context, it nevertheless makes it possible to envisage its occurrence.

[252] *op.cit.* p 118 « *The economic situation is the foundation. But the development of the theories and the individual work of a scholar are affected by various superstructures, such as the political forms taken by the class struggle, and the results, the echo of these struggles in the minds of the participants: political theories legal, philosophical, religious beliefs, as well as their development into systems of dogmas".*

[253] Rejection which, starting from the caricature of Marxism which reigned in the USSR, extends, without any distinction, to all the forms of Marxism and communism, thus preventing from knowing them and justifying the uselessness to know them.

[254] See for example *Le monde qui émerge : les alternatives qui peuvent tout changer*. C.Aguiton et G.Azam ed les liens qui libèrent 2017

V-1 Materialism and idealism in the sciences of the complex.

> «*De quelque façon que les savants veuillent se situer, ils sont dominés par la philosophie. La question est seulement de savoir s'ils veulent être dominés par quelque mauvaise philosophie à la mode ou par un mode de pensée théorique reposant sur la connaissance de l'histoire de la pensée et de ses acquis.*» (Engels[255])

V-1-1 Proof by emergence.

If you wish to witness a feverish debate among scientists, launch the word *emergence* in an assembly of researchers interested in complexity.

The divergent definitions of this term will flourish and, each holding fast to its own, no consensus can be reached, no sensible discussion even can be reached. The closest to a consensus that I witnessed during a conference, was the replacement of the word emergence by a humorous *beep-beep* recalling the impossibility of a dialogue about this term. However, meetings around this topic have been frequent in recent years: dedicated symposia of philosophy of science, round tables during scientific symposiums on complex systems, or discussions on the occasion of a scientific presentation, their forms have varied, but not their inability to lead to any agreement. And that does not date from today : "*en avril 1995. A la fin de ce colloque, plus personne n'osait prononcer le mot « émergence » parce qu'il était apparu que chaque participant accordait à ce mot une signification différente »*[256]

The violence and the recurrence of such controversies suggest that philosophical and metaphysical options, conscious or not, are at the origin of the discord. I will use the various meanings of the term emergence here, as a thread to follow the reciprocal influences between science and philosophical or ideological positions, and to suggest a possible role of materialistic dialectics.

The already ancient term of emergence, which refers to the transition from the parts to the whole, refers to the idea that a "whole" is more than (or not "equal to") the sum of its parts. This sentence characterizes, as we have seen (Chapter III), the reductionist positions (which refute it) and the holistic (or globalist) positions which affirm that understanding a whole does not require to know the parts which constitute it. Present in many disciplines, the term emergence has taken, in the context of complexity and non linear dynamic systems, a "youthful look", inasmuch as a certain number of phenomena appearing in complex systems, such as self-organization or bifurcations of

255 Friedrich Engels, D*ialectique de la nature* ,Traduction française Éditions Sociales, 1975, p 211. "*In whatever way scientists want to situate themselves, they are dominated by philosophy. The question is only whether they want to be dominated by some fashionable bad philosophy or by a theoretical mode of thinking based on knowledge of the history of thought and its achievements.* "

256 Brigitte Chamak, *Le groupe des Dix*, Éditions du rocher, 1997, interview de Jacques Sauvan p 115 *April 1995. "at the end of this conference, nobody dared to pronounce the word "emergence" because it had become clear that each participant was gibing the word a different meaning "*

non linear dynamic systems, or transitions between organizational levels are characterised as emerging.

For some researchers, emergence and complexity are mutually defined (Chapter I). But this renewed interest is accompanied by deep polemics and disagreements about the meaning of this term, disagreements which, it is my hypothesis, are of ideological origin. To the extent that scientists have been deprived of a coherent philosophical culture[257], their philosophical position is often implicit, sometimes to the point of refusing to recognize it when suggested.

The materialistic dialectics, strongly politically connoted, meets a real ideological denial even among those scientists who practice it spontaneously. Non-dialectical materialism[258] is also widespread among scientists, and we will see that this impacts their relationship to the complex. Currently, four groups of different positions regarding emergence can be schematically distinguished.

The dialectical materialist position considers that emergence corresponds to the appearance of new global properties that result from non-linear or complex interactions between the parts, whether we understand them or not, whether we foresee them or not. It thus distinguishes a collective property (such as the pressure of a gas), which results from the observation or measurement of a collective phenomenon on a global scale, from an emergent property which represents the existence of a new property on a global scale. This property is not present in the constituents since it depends on their organization, and it appears moreover only in certain conditions. For those who share this concept, the taking of the mayonnaise even though we can predict and explain the process, is an emergence as well as life which is not yet understood. The proponents of this conception, whether they know it or not, whether they accept it or not, are not only materialists, but also, to a greater or lesser extent, they are dialecticians: they consider transformations as a material property, they place more importance on interactions (relations) than on isolated elements, they study the global behaviours due to the interactions between the elements and the dialectical category *qualitative leap*, is familiar to them even if they do not know it formally. For them, emergence is inseparably epistemic and ontological. *« Nous appelons émergence l'existence (et pas seulement l'apparition vue comme un processus temporel, ce que le vocable pourrait suggérer) de qualités singulières d'un système qui ne peuvent exister que dans certaines conditions»*[259].

[257] In France in any case
[258] For a study of the differences between these two types of materialism see Lucien Sève 2015 op cit.Chapter III
[259] Janine Guespin-Michel and Camille Ripoll in Lucien Sève *et alii* 2005, *op.cit.*"*We call emergence the existence (and not just the appearance seen as a temporal process, which the word might suggest) of singular qualities of a system that can exist only under certain* conditions"

In addition « *La théorie des systèmes dynamiques contient des concepts qui permettent d'expliquer, au moins pour certains types de systèmes, pourquoi les interactions non additives donnent lieu à des propriétés qualitativement différentes des propriétés des parties*[260]»

But for some scientists and many philosophers of science, emergence occurs only when unexpected, surprising processes occur. The supporters of this meaning can be divided into 3 groups.

There are those for whom emergence is ontological: the unexpected is a fundamental property that characterizes life in particular. Either emergence means that life has an unknowable core, be it called the vital impulse or intelligent design: it is vitalism; or it means that one can not understand a level of organization (a whole) by taking an interest in its parts (holism). In both cases the emergence (the transition from the parts to the whole) is an absolutely unknowable property. These are clearly idealistic positions.

There are those for whom emergence does not exist. This term would designate only ignorance and when the unexpected disappears, there will be no more emergence. The most radical in this position are the hard reductionists for whom the whole is equal to the sum of the parts and who are convinced that it is a lack of knowledge that makes believe that something new and unexpected is emerging. They of course, reject the revolution of the complex as a whole in the name of a materialism remaining mechanistic, that is to say, overlooking transformations.

But the majority admits the emergence, but only as an epistemic property, related to the consideration of levels made by the observer. The weak reductionism[261] admits that the whole results not only from the sum, but from the interactions between the parts that can, when these interactions are not linear, give rise to astonishing properties. But by knowing these interactions, the unexpected, the non-understood disappears and with them the emergence, which is therefore a purely epistemic property. Correlatively, they do not accept to call emergent phenomena studied by the physics of non-linear systems such as self-organization, bifurcations... since they are now well understood.

One might think that it is ultimately only a question of a definition of little scientific importance, even if the underlying ideology, materialistic but ignoring the transformative properties of matter, is just as reductive materialism as hard reductionism. But excluding the NLDS from emergence, leads to a definition of the complex which underestimates the importance of non-linearity and thus lends itself to confusion between complex and complicated.

260 Maximilian Kistler *La réduction, l'émergence, l'unité de la science et les niveaux de réalité* in *Matériaux philosophiques et scientifiques pour un matérialisme contemporain,* Marc Silberstein . Éditions Matériologiques, 2013. "*The theory of dynamic systems contains concepts that explain, at least for certain types of systems, why non-additive interactions give rise to properties qualitatively different from the properties of the parts."*

261 *Le vivant entre science et marché op.cit*., chapitre V Janine Guespin-Michel et John Stewart, p 155.

Variations of this last position distinguish a weak (or epistemic) emergence and a strong (or ontological) emergence. But these two terms refer to different concepts according to the authors. For the computer scientist Hughes Bersini « *Le long de cet axe interprétatif, situant l'émergence quelque part entre un premier extrême, essentiellement épistémique, émergence n'existant que dans le regard et dans la tête de l'observateur humain, et l'autre extrême, essentiellement ontologique, émergence témoignant d'un phénomène réel, fondamentalement réel, autonome par rapport aux parties qui le constituent dans un sens qui reste à définir, et qui échappe à la science classique, les physiciens et les chimistes se concentrent tous sur l'extrémité épistémique de l'axe»*[262]. For him, weak emergence, the one defined by the NLDS in particular, is epistemic, because it consists only in a change of level of the gaze of the observer from the parts towards the whole, this change enabling to detect new properties that do not exist *per se*. For him ontological emergence also requires an observer, who, for a materialist, can only be natural selection.

« Nous allons montrer par la suite qu'un phénomène émergera lorsqu'un ensemble d'objets en interaction propose une fonctionnalité collective nouvelle, aux « yeux » non plus uniquement d'un observateur humain, mais surtout et avant tout de la sélection naturelle, qui trouve dans ce phénomène de quoi doter l'organisme qui l'héberge d'une meilleure valeur adaptative »[263].

This is indeed a philosophical position which, to be materialistic, ignores the materiality of transformations, hence here again the dialectics, and does not know how to distinguish a collective property that statistically summarizes interactions and requires an observer, from an emerging property that reveals new global behaviours whether or not they are observed.

Another dispute concerns *downward causation*, or reciprocal action of the whole on the parts that H.Bersini, for example, refutes in the name of materialism and almost without explication; « *Cette influence du tout sur les parties est impossible si on choisit de s'en tenir à la vision des sciences de la nature endossée par l'essentiel des physiciens et des chimistes ... la causalité descendante serait , dans le rayon de la mauvaise science...»*[264] . This form of causality between the whole and the parts is the only one recognized by the holists, but it is also admitted by the RNSC for example, as one of the fundamental properties of complex systems. « *Non seulement les caractéristiques émergentes supérieures des systèmes complexes sont issues des interactions des niveaux inférieurs, mais les comportements globaux qu'elles créent affectent à leur tour ces niveaux*

[262] Hugues Bersini, *Qu'est-ce que l'émergence?* Ellipses, 2007 p76 *« Along this interpretive axis, emergence is situated somewhere between a first extreme, essentially epistemic, emergence existing only in the look and in the thought of the human observer, and the other extreme, essentially ontological, emergence testifying of a real phenomenon, fundamentally real, autonomous with respect to the parts that constitute it in a sense that remains to be defined, and which escapes classical science, physicists and chemists all concentrate on the epistemic end of the axis.*

[263] *ibid.* p 106."*We will show later that a phenomenon will emerge when a set of interacting objects proposes a new collective functionality, to the" eyes "not only of a human observer, but above all of natural selection, who finds in this phenomenon what endow the organization which hosts it with a better adaptive value* " .

[264] ibid. p 91 and following *"This influence of the whole on the parts is impossible if one chooses to stick to the vision of the sciences of the nature endorsed by the essential of the physicists and the chemists ... the downward causality would be, in the department of the bad science..."*

inférieurs, -une boucle de rétroaction parfois appelée immergence »[265]. We will see below that such a downward causation can be thought of (and therefore accepted) in an explicitly materialistic framework of dialectical logic.

These ideological / philosophical conceptions have a direct scientific influence. Indeed, since the scientific practices consist in seeking answers to questions we ask, it is clear that we will not ask the same questions depending on our philosophical position. For example, it is only if we think that there is a downward causation that we will be looking for examples of it- and they have been found[266].

The endless debate between the supporters of the different meanings of the word emergence has been underpinned since its origin by different philosophical positions, a different ideology. As Laurent Jaudoin notes « *Le concept d'émergence a d'abord été élaboré afin d'obtenir un compromis entre deux ontologies extrêmes : une ontologie moniste et matérialiste, donc réductionniste, où il n'y aurait que des éléments matériels et leurs propriétés, et une ontologie dualiste, donc antiréductionniste, où il y aurait la matière mais aussi l'esprit [...] Il y a donc plusieurs questions épistémologiques associées à la notion d'émergence. [...] Il va donc de soi que les débats à propos de la notion d'émergence ont été nombreux et se poursuivent encore aujourd'hui* [267]».

My position, however, is that there is a monistic and materialistic non-reductionist ontology associated with the notion of emergence.

Scientists generally are materialistic in their practice, but, refuse or ignore the dialectics, often for ideological reasons[268]. Thus they are easily drawn to reductive positions on complexity.

Conversely, scientific practice can also influence ideological positions. Thus, although my observations have no statistical value, I have observed that physicists (who study non-linear dynamical systems), highly claim the concept of emergence in the sense that I characterized as dialectical and materialistic. Among computer scientists, on the other hand, it is those who

265 RNSC http://rnsc.fr/tiki-index.php "*Not only are the higher emergent characteristics of complex systems derived from the interactions of lower levels, but the global behaviours they create, in turn affect these lower levels -a feedback loop sometimes called immergence".*

266 It has been shown, for example, that the shape of a cell (global level) can influence the regulation of some genes (molecular level)

267 Laurent Jaudoin, *L'émergence et la réalité des états compatibles inobservables,* In M*atériaux philosophiques et scientifiques pour un matérialisme contemporain*. op.cit. P 328." *The concept of emergence was first elaborated in order to obtain a compromise between two extreme ontologies: a monistic and materialist ontology, therefore reductionist, where there would be only material elements and their properties, and a dual ontology, thus anti-reductionist, where there would be the matter but also the spirit [...] There are therefore several epistemological questions associated with the notion of emergence. [...] It goes without saying that the debates on the notion of emergence have been numerous and continue today. "*

268 Including the fact that most of them do not know it, because of the absence of this branch of philosophy in the studies, for purely ideological reasons. (seeLucien Sève, *penser avec Marx aujourd'hui* tomme III *la philosophie ?* Ed La dispute, 2014)

manipulate computer simulations of complex systems that are most likely to link emergence and unexpected (and indeed what they discover on their screens is most often unexpected). These will neglect simple non linear systems, considered non-emergent and not complex, in favour of very complicated complex systems where the unexpected will be at the rendezvous on their computer.

V-1-2 From the spontaneous dialectics to the controlled dialectics.

If the debate is keen between scientists who discuss (or argue) about emergence, it is also that their philosophical positions, strong though they are, are spontaneous, that is to say that, having been deprived of of a sufficient philosophical culture, they are most often unable to specify the source of their thought and to know the philosophical position to which it relates. In the best cases, they will quote important philosophers like Kant or Descartes, even Aristotle or Buddha, but they ignore Hegel and (due to dominant ideology) despise Marx and Engels. The philosopher Lucien Sève showed how dialectics allows us to think of emergence in a truly materialistic way without needing a distinction between weak and strong emergence. This is the Hegelian dialectical category of *qualitative leap* that allows one to think le *paradoxe de l'émergence : « dans le passage non additif, non-linéaire des parties au tout, il y a apparition de propriétés qui ne sont d'aucune manière précontenues dans les parties et ne peuvent donc s'expliquer par elles* [269]*».* To Hughes Bersini, who needs the gaze of the observer to think of the transition from the parts to the whole, Sève opposes the Hegelian concept " *tout et parties ne forment qu'un seul et même concept : celui du rapport tout/parties* **"** [270]that he transposes, of course, with Marx, from the ideal field of Hegel into the realm of reality.

It is the same for the notion of downward causation which Bersini discarded peremptorily. Sève, in the same book, analyses the long article by the Danish philosopher Claus Emmeche who, starting from the definition that C. Lloyd Morgan gave in 1923 of the emergence as "*creation of new properties*", strives to purge the concept of all its finalist and theological connotations to include it in a scientific vision of the reality extended to the dynamics of non linear systems. These authors however, reject the downward causation on the grounds that the superior can not modify the laws of the lower level. To which Sève answers that, without modifying the laws, the superior can modify the form of their application, it is the dialectics of the levels which makes it possible to consider each level in the specificity of the transformations which it implies. *« Un capital renversement dialectique s'opère ici, où la détermination générale du supérieur par l'inférieur doit s'accommoder d'une détermination particulière de l'inférieur par le supérieur. C'est justement la compréhension de ce renversement qui nous fait passer d'un matérialisme simpliste, enfermé dans*

[269] *paradox of emergence:Lucien Sève et alii 2005, op.cit. p 58 "in the non-additive, non-linear passage of parts to the whole, there is the appearance of properties that are not in any way pre-assembled in the parts and can not therefore be explained by them.*

[270] *ibid.*, p. 77. « *The whole and it's parts form one and the same concept: that of the relation whole/ parts* »

une unilatéralité d'entendement, à un matérialisme complexe, faisant place à toutes les dialectiques de l'action réciproque»[271] .

Here we find again the necessity (and the premises) of a vast trans-disciplinary work intended to articulate the concepts of the complex and the categories of dialectics, which I mentioned in chapter III.

V-2 Individualistic ideology, obstacle to the revolution of the complex.

We have seen how the philosophical positions related to the dominant ideology intervene in the interpretation of the concepts of the complex thus in the resulting researches. But another ideological component contributes to curbing, or misleading, the rise of the sciences of complex systems, often to the profit of reductionism, it is individualism, which we perhaps did not expect in this context.

I will take as an example the success of the theory of the selfish gene[272], proposed by Richard Dawkins, which illustrates the closeness between reductionism and neo-liberal individualist icideology. In the preface of the first edition, published in the USA in 1976, Dawkins presents this message: « *Nous sommes des machines à survie, des robots programmés à l'aveugle pour préserver les molécules égoïstes connues sous le nom de gènes* ». In the first chapter, he adds, « *l'argument de ce livre c'est que nous, ainsi que les autres animaux, sommes des machines créées par nos gènes* ». Finally, in the preface of the second edition (1989), he specifies the hyper-reductionist character of his message: « *La théorie du gène égoïste » c'est la théorie de Darwin exprimée d'une autre manière ... Plutôt que de se focaliser sur l'organisme individuel, elle prend le point de vue du gène sur la nature* » [273]. The message is therefore the reduction to the extreme of the individual to his genes, correlated of course to the total disappearance of the social. Although it has been listen to mainly in the US (the first French edition dates back to 1990), the speed with which this theory, which the author himself describes as extreme, has spread (especially in the textbooks that are usually very slow to incorporate the novelties), is somewhat puzzling. In 1989 Dawkins writes: « *cela fait bientôt douze ans qu'est sortie la première édition du Gène égoïste, et le message qu'il*

[271] *ibid.* p 139."*A capital dialectical reversal takes place here, where the general determination of the superior by the inferior must be accommodated by a particular determination of the inferior by the superior. It is precisely the understanding of this reversal that makes us move from a simplistic materialism, locked in an unilaterality of understanding, to a complex materialism, giving way to all the dialecticss of reciprocal action.* "

[272] Richard Dawkins, The Selfish Gene, 1976, French translation 1990, Odile Jacob, 1996. The criticism I make here must not obscure the fact that the success of Dawkin's ideas has also contributed to the fight against the fierce US opponents of Darwinism, the supporters of intelligent design.

[273] "*We are survival machines, robots programmed blindly to preserve selfish molecules known as genes*" ; "*The argument of this book is that we, as well as other animals, are machines created by our genes*" ; "*The theory of the selfish gene" is Darwin's theory expressed in another way... Rather than focusing on the individual organism, it takes the point of view of the gene on nature.* "

véhicule fait à présent partie de tous les manuels »[274] . In contrast, the complexity's theories, although much older, are not yet reflected in most textbooks! My hypothesis is that he theory of the selfish gene has been so quickly established in the United States because it corresponded to an ideology that was part of a wider current that it helped to extend. It is indeed a message that is addressed, beyond the geneticists of evolution, to the entire American society, glorifying extreme individualism and competition.

It must be noted that reductionism, long before the invention of the term itself, has often been related to the conception of the individual. As Canguilhem indicated with humour[275], when, in the mid-nineteenth century, the controversy around the cell theory raged in biology, it was difficult to know if one was republican because one was a proponent of the theory or a proponent of this theory because one was republican. Thus he noted how much the republican conception of the individual in his relations with the State, is in phase with the cellular theory. Haeckel writes for example, in 1899,« *Les cellules sont les vrais citoyens autonomes qui, rassemblés par milliards constituent notre corps, l'État cellulaire*»[276] and Canguilhem insists on « *l'unité latente et profonde chez un même penseur des conceptions relatives à l'individualité, qu'elle soit biologique ou sociale*[277] ». At that time, the ideology supporting the cell's theory was, in France, liberal and republican.

The accentuation of individualist ideology in the current neo-liberal phase, can be summed up in the difference between Haeckel's quotation, where the assembled cells constitute our body, and that of Dawkins, where the individual organism itself disappears (as an actor of evolution), in front of the gene.

By contrast, complexity thinking is compatible with an entirely different conception of the individual: an individual engaged in multiple interactions with his or her social and natural environments (which leads to the idea of sustainable environment and society); an individual both autonomous and part of a collective whole whose characteristics emerge from the interactions between the individuals (present and past) and retroact on them (which moreover meets the definition of Marx: « *l'essence l'homme, dans sa réalité, c'est l'ensemble de ses rapports sociaux*[278]). An individual as actor and subject of non linear dynamics, on which he can act.

But beware, even though complexity thinking is compatible with such behaviour, it is by no means a sufficient condition.

274 *"It has been almost twelve years since the first edition of the Selfish Gene came out, and the message it conveys is now part of every textbook"*

275 Georges Canguilhem, *op.cit.*

276 *ibid. p 70."The cells are the real autonomous citizens who, gathered by billions constitute our body, the cellular state*

277 *ibid.* p 66. "*The latent and profound unity within the same thinker of conceptions relating to individuality, whether biological or social*

278 Karl Marx *6e thèse sur Feuerbach.* French trnaslation par Lucien Sève dans *penser avec Marx aujourd'hui tome II l'Homme ?* La Dispute, 2008, p 64."*The essence of man, in his reality, consists in all his social relations* "

V-3 The obstacle of the dominant way of thinking.

Finally, the strongest ideological obstacle lies in what is sometime called Cartesian thought, which Edgar Morin describes as simplifying thought and which is also the dominant thinking form[279]. Indeed Cartesian rationalism gradually became common sense, largely overflowing the academic sphere and thus losing much of the philosophical thought of Descartes. Particularly influential in France, where it pervades the way of thinking taught at school, this rationalism of Cartesian ascendancy, has become a major obstacle to the development of the revolution of the complex, by opposing the complexity thinking. It is an ideological as well as an epistemological obstacle, not only because this way of thinking is quite general, but also because it is currently a support for the ideology of fatalism, of TINA (Thatcher's *There is No Alternative)*. And as such it is maintained and strengthened in the same way and by the same processes (teaching, media) than the dominant ideology. So what is precisely this obstacle?

It is what Jean Lojkine calls the *mechanistic paradigm*, of which he emphasizes the always dominant character, « *l'impact de la cybernétique et plus largement des traitements de l'information n'ont pas mis fin pour autant au paradigme mécaniste qui continue à dominer entreprises et administrations dans tous les pays capitalistes développés*»[280]. The developments in physics and other sciences have not undermined this paradigm, which has simply lost its most mechanistic aspects. This form of thought is also moulded, of course, in the linear vision, of which we have discussed at length in Chapter III. It still predominates in both the sciences and politics and, becoming *common sense*, it is transformed into simplistic, dualistic, eventually Manichean thought... As Edgar Morin writes « *Une tradition de pensée bien enracinée dans notre culture, et qui forme les esprits dès l'école élémentaire, nous enseigne à connaître le monde par « des idées claires et distinctes » ; elle enjoint de réduire le complexe au simple c'est-à-dire de séparer ce qui est lié, unifier ce qui est multiple, d'éliminer tout ce qui apporte désordre ou contradictions dans notre entendement* [281]*»*

Some great principles apparently obvious are nevertheless fraught with danger. The principle of *excluded thirds*, which comes from Aristotle and is the basis of formal logic, seems unavoidable to us and is obviously very often so. However this principle makes it extremely difficult to think transitions otherwise than "all or nothing". We are reluctant to embrace the moments when precisely

279 I call dominant thought the mode (or form) of thinking most widespread in the population, propagated by the media and by the school. It is not equal to the dominant ideology that concerns the content.

280 Jean Lojkine, *La révolution informationnelle, op.cit.* p133 "*The impact of cybernetics and more broadly information processing have not extinguished the mechanistic paradigm that still dominates companies and administrations in all developed capitalist countries"*

281 Edgar Morin, *La Voie F*ayard, 2011 p 147.*"A tradition of thought deeply rooted in our culture, and which trains minds at elementary school, teaches us to know the world by 'clear and distinct ideas'; it enjoins us to reduce the complex to the simple, that is, to separate what is bound, to unify what is multiple, to eliminate all that brings disorder or contradictions in our understanding."*

we are still in the old while being already in the new, when we arrive in the new, while still being impregnated with the old. The idea of a scientific revolution, for example, implies for some people a disappearance of the old for the benefit of the new, whereas it is often an incorporation of the old as a particular case of the new, (as the linear with respect to the non-linear). The refutation of this famous principle (not in the absolute, but in cases where it prevents thinking) is the work of the dialectics which postulates the unity of opposites. Heraclitus said « *vivre de mort, mourir de vie* [282]» The emergence that states that a whole is both composed of its parts and differs from the sum of these parts is therefore one of those cases that contravene the excluded third.

Moreover, the excluded third often leads to a binarism that analyses the world in the form of binary oppositions, which lead to choices in "either/or": the thing or the movement, the matter or the spirit, true or false, science or letters, intelligence or stupidity, innate or acquired, good or evil ... Whereas not only is it often necessary to choose between several options: Which job ? Which friends? Which Europe ? but that the two terms rarely exist without each other: the NLDS, with their solutions that can be multiple or can turn indefinitely, are particularly alien for a thought shaped by binarism. This mindset makes it as difficult to understand dialectics than the systemic, and their search for the plurality of causes of all phenomena and all (rarely binary) interactions.

Then since analysis, the study of the parts, is the foundation of Cartesian critical thinking, the very choice to consider everything within the system of interactions to which it can belong does seem to oppose rationality. Not to mention that the immobile thing, result of the analysis, takes precedence over the processes of transformation so that the dominant way of thinking does not easily takes into account the processes, the dynamics. There is on one side the matter which divides almost to infinity, on an other the movement and on a third side the form. It is therefore difficult to think that matter is inseparable from the movement from which its form originates, a strong idea of the materialistic dialectics. It is difficult to think of emergence as a property that makes something different from the sum of its parts, while depending on these parts. Thus the analytical approach of the dominant mind set represents a powerful obstacle to dialectical as much as to complexity thinking from scientists to laymen.

Finally, as we have seen (Chapter III), dominant thinking has developed in the context of a linear epistemology (proportionality and additivity of causes and effects) which leads to the decomposition of processes into a chain of successive events. Depending from a first, initial, unique cause (the scapegoat?), and with the idea that the effects are necessarily proportional to the causes. In this context, the idea of circular causality seems to involve the disappearance of causality.

[282] *"Live from death, die from life" and Henri Atlan, who denies yet to be a dialecticsian« la vie est l'ensemble des fonctions capables d'utiliser la mort ». (life is the set of functions capable of using death). Entre le cristal et la fumée, op.cit.*

We can therefore think that, if the sciences of the complex have suffered from ideological obstacles (in addition to and combined with epistemological and economic obstacles), it is because the complexity thinking which directly opposes the dominant way of thinking, is laminated by the latter. This may be why many of the scientists grouped within complex systems institutes do not realize or admit that their scientific practices generate this new mindset, which in turn could be a great help in implementing the coherence of their practices.

V-4 Complexity thinking versus "pensée unique".

But the strength of dominant thought is not just that of habit. It is the best ally, even a necessary condition of the dominant ideology, the so-called ideology of the *pensée unique*, the deterministic fatalism of the neoliberal capitalist society as the end of history. During his speech at the conference of Cérisy on *determinisms and complexities*, Michel Rocard noted « *On peut à cet égard se demander si la force étonnante du paradigme de Milton Friedman, c'est-à-dire la pensée économique et financière qui depuis vingt ans gouverne le monde pour son malheur, ne tiendrait pas pour l'essentiel à l'extrême simplicité de son expression et à son refus absolu de toute complexité. L'équilibre du marché est optimal*[283]»

Simplism, dualism, immobility, disjunctions, are all ingredients that fuel fatalism and submission to the existing order (there has always been... so there will always be) and oppose the complexity thinking. Inversely, the complexity is a powerful critical instrument, which can provide, (together with materialistic dialectics), tools to think the transformations without being locked in false sterilizing simplifications. It is therefore not surprising that so much is done in today's society to prevent or at least delay its development and dissemination.

Let's be clear. There is not a great inquisitor who decides to ban sciences of complexity from the intellectual landscape. Everything works like a complex self-organized system, with a series of feedback loops. On the one hand, there is common sense, reinforced by the teaching of (formal) logic, linear mathematics and the absence of complexity sciences in school curricula[284].

Those responsible for the programs, have not received any order to that effect, at least I do not think so, because it is not necessary, for the most part they share the dominant ideology and therefore have not reticence against the dominant thought, but they have some against complexity thinking, almost as much as against materialistic dialectics or they ignore both of them. As for mathematicians, who could prepare minds for non-linearity, they do not feel the need to do so insofar as, for them, non linear dynamic systems are a mathematical object among many others, of

[283] Colloque de Cérisy *op.cit.* p 342."*In this respect one may wonder whether the astonishing force of Milton Friedman's paradigm, that is, the economic and financial thought which for twenty years has governed the world for its misfortune, would not be essentially it's extreme simplicity of expression and absolute rejection of all complexity. The market balance is optimal* »

[284] In comparison, we can see that biotechnologies, which have also developed since 1975, that is roughly at the same time as the sciences of the complex, have been taught even in high school for almost twenty years.

which total mastery requires high-level mathematical tools. They are not aware of the particular role this object might have on the way of thinking.

Thus (except in a few cases) scientists who arrive in laboratories and universities are not aware of this so different way to understand their discipline or the world. They do not measure how much the official programs are deficient from the point of view of the sciences of the complex, or this very deficiency suggests to them that these approaches are not very interesting. They do not incorporate it (or so little) in their teaching programs... A first feedback loop comes from the fact that the complexity being little taught seems uninteresting and strange, so is little taught. A second feedback loop comes from the fact that the complex is not very present in the research programs (as we saw in Chapter IV, concerning tenders), it is little practised, so little required, so little taught. But the third feedback loop is even more important, because it comes from the very mechanism that contributes to making the dominant class ideology the dominant ideology. The techniques to perpetuate this shelving, are well known: a shrug, a contemptuous pout and, worse than all, silence. We do not talk about it, so it does not exist. And then, when it can no longer be avoided mentioning it, which is more and ore the case nowadays, it is disfigured, either by caricaturing it, or by falsifying it, as I mentioned with the confusion between complex and complicated.

The complex is both, and I will say indissolubly, a scientific issue and an ideological issue. This is the issue of rationality and rationalism.

Chapter VI Transmitting complexity thinking.

> *« L'un des défis les plus difficiles à relever sera de modifier nos modes de pensée de façon à faire face à la complexité grandissante, à la rapidité des changements et à l'imprévisible, qui caractérisent notre monde »* le directeur Général de l'UNESCO[285]

Our century appears as the century of every dangers, where a speed race between the degradation of the planet and the implementation of measures to face it is played out[286]. As we have seen (Chapter IV-5), these measures require a global vision based on a complexity thinking, not only on the part of scientists, but also that of the rulers, and the citizens. Speaking at the colloquium of Cérisy "*determinism and complexity*" in 2004, as a former member of the *groupe des dix*[287], Michel Rocard portrayed a political staff faced with two tasks, both incompatible with the complex: to govern with the help of specialized experts and therefore unfit to master the complex, and to get elected by an electorate formatted in particular by media pushing charisma and sensational, so impervious to all that is complex. And he adds : « *Ce qu'il y a de commun dans toutes ces attitudes est que, pour l'essentiel des politiques, la référence à la pensée complexe est dans une large mesure un handicap. Et je ne pense pas que ce que l'on appelle très improprement la classe politique puisse en sortir seule. Les paradigmes centraux de la pensée scientifique moderne, les théories du chaos déterministe et de la complexité doivent maintenant être enseignés dans les lycées et les universités, ainsi que dans les centres de formation de journalistes pour que les politiques puissent s'y référer et s'en servir sans risquer l'ironie, la marginalisation ou l'incompréhension*[288] "

I can only subscribe to such a statement, adding, however, that what was wishful thinking (or failure) in the words of a former French Prime Minister deserves to become a political objective. It will also require from now on, an important work of pedagogy and didactic, to know how these concepts can be incorporated in the teachings, (in what disciplines, at what levels and with what progression?) and also in popular education and lifelong learning.

As early as 1975, in his book, The Macroscope, Joel de Rosnay was concerned with what he called *systemic education*[289]for which he made pedagogical recommendations. But the sciences of

285 *"One of the most difficult challenges will be changing our ways of thinking to cope with the growing complexity, rapid change, and unpredictability that characterize our world."* UNESCO general director

286 See for instance Jared Diamonds C*ollapse How Societies Choose to Fail or Succeed:*2005 by Viking Penguin

287 : Brigitte Chamak, *Le groupe des Dix ou les avatars des rapports entre science et politique*, Éditions du rocher, 1997,

288 Michel Rocard,*" Responsabilité du politique face aux complexités"* in *Colloque de Cérisy op.cit.* p147."*What is common in all these attitudes is that, for most policies, the reference to complex thought is to a large extent a handicap. And I do not think that what is very improperly called the political class can come out alone. The central paradigms of modern scientific thought, the theories of deterministic chaos and complexity must now be taught in high schools and universities, as well as in journalism training centers for policy to be referred to and to use it without risking irony, marginalization or misunderstanding"*

289 Joel de Rosnay, op cit, chapter 3 *systemic education*. He notes that education is "*desperately analytical, focused on a few disciplines, like a puzzle whose pieces do not fit into each other. It does not prepare us for the global approach to problems, nor for the interplay of their interdependencies.* "He advocates an open-ended teaching based on 5

complexity were then beginning, the obstacles that I have detailed above obviously concern just as much the teaching as the research, and didactic researches were not undertaken. It may seem that some of his recommendations have been heard, ways of teaching are changed (institutionally if not always in practice) but it is not formalized, it is the scattering of examples to the case by case, without the theoretical framework necessary to appropriating this way of thinking in order to be able to transpose it to any other subject.

Does this mean that we must give up promoting this form of thinking, both at the level of initial education and at the level of adult education? Certainly not, quite the contrary, but we must find the means to achieve it, and first clarify the questions. For example, is the teaching of the sciences of the complex necessary and sufficient to train the teachers, then the students to a complexity thinking, as M. Roccard advocates, or does it have to be integrated into a systemic education as proposed by Joël De Rosnay?

And if teaching of the sciences of the complex is necessary, at what level should it be done and how? And if a systemic education is necessary, can it be implemented in the current educational system, or must there be changes and which ones? And encompassing all this, how to train the trainers to a complexity thinking, can we directly convey this form of thought, and how?

VI-1 What are the obstacles to teaching the sciences of the complex?

The teaching of sciences considered as part of the sciences of the complex, are currently limited, as we have seen, to some end-of-studies courses, notably in mathematics, statistical physics, and in certain branches of the sciences of engineering but also economics, management, sociology, psychology, care (although often in a simplistic form with a fragile conceptual basis).

Some of the academics and researchers in these disciplines are aware of implementing a new form of thinking, especially if they have encountered obstacles, but others see it merely as a methodology. difficult enough, which justifies it being taught only late. Therefore if the teaching of these disciplines may have brought students into contact with some of the concepts and methods of complexity, these students may not have had their attention drawn to the importance of the new form of thinking that this allows or entails. The interest or usefulness of making the effort to teach these concepts more broadly, earlier in university curricula, or even earlier, is not often perceived by scientists who practice and teach these sciences. Other disciplines whose study objects are

principles; "*Avoid the linear or sequential approach, returning several times, but at different levels on what needs to be transmitted ...; to avoid too precise definitions ...; highlight the importance of mutual causality, interdependence and the inherent dynamics of complex systems ...; use themes of vertical integration ...; and finally the acquisition of facts can not be separated from the understandings of the relations existing between them.*

"ontologically" complex systems; biology, ecology, sociology... still often have reductionist practices and attitudes. True enough, a complex system can be studied by analytic methods, whose dominant reductionist attitude prevents appreciating their limitations. Those teachers who, in these disciplines, are aware of these limitations and implement the approaches and concepts of the complex, are not always aware of using a new form of thinking, and most importantly, are they able to pass it on to their students? I think, but it is a hypothesis that should be tested in collaboration with teachers, that the teaching of a science of the complex is necessary but not sufficient to allow the acquisition of the complexity thinking. This does not mean that it is impossible to convey this form of thinking in current disciplinary teaching, but that it may be necessary to show students at every stage in what respect what they learn is a new form of thinking that opposes (while encompassing) the reductionist form of thought[290]. An epistemological formation dedicated to the mindset, to the meaning of complexity, should be part of the scientific training, at least in the present state where most of the teachings remains reductionist. But should the current absence of such teaching represent an impassable barrier to teaching complexity? This is a problem of "the chicken and the egg", a feedback loop where you have to act at all possible levels simultaneously because there is no "first" cause at the moment.

This in turn raises the question of the level of education at which we start this type of education, and what training of teachers will be necessary if we admit, as I think, that we must start as soon as possible? This requires to launch a vast program of didactic research and experimentation, which is particularly difficult in the current situation of teaching. Most publications dealing with the relationship between complexity and education deal with "how complexity can help to understand, manage and improve the educational system or methods of education" rather than "how to teach complexity now[291] "

VI-2 training in complexity thinking

The relationship between education and complexity has been at the heart of Edgar Morin's work. whose last book on the subject is « *enseigner à vivre, manifeste pour changer l'éducation* [292]». However, he stands upstream of the didactic or pedagogical questions, presenting general principles such as those detailed since 1999[293], regardless of how to implement them in teaching. The first

[290] What E. Morin calls "*the knowledge of knowledge*", but applied to each teaching in ways that deserve a didactic effort.

[291] *complexité de la formation et formation à la complexité* Jean Clenet et Daniel Poisson l'harmattan 2005 ; *Complex Systems in Education: Scientific and Educational Importance and Implications for the Learning Sciences* Michael J. Jacobson and Uri Wilensky The journal of the learning sciences 2006 15, 11–34. *Complicity : an international Journal of complexity and education*

[292] T*eaching to live, manifested to change education* Ed Actes sud 2014

[293] *Enseigner La connaissance de la connaissance, la condition humaine, l'identité terrienne, la compréhension, l'éthique du genre humains, affronter les incertitudes* in *Les sept savoirs nécessaires à l'éducation du futur publication de l'uneco* op cit.1999 *Teaching Knowledge of knowledge, the human condition, earth identity, understanding, the ethics of human kind, confronting uncertainties in the seven knowledge necessary for the education of the future*

round table of the *World Congress for Complex Thought* held under the auspices of UNESCO in January 2017 in Paris, was titled *education and the learning to live together* The aim was *"thinking in complexity" the challenges of education in the 21st century*[294] .

But is it possible if the teachers themselves are not trained to *think in complexity*? Which leads to asking how one can appropriate *complex thought* or *complexity thinking*? This question concerns as much the training of the teachers as the necessary formation of the citizens. Starting from the etymology of the word “complex” (woven together), a current emphasizes the "reliance"[295]. Forging links between disciplines would then be the basis of training in and through complexity[296]. It is indeed a component, but I see it more as a result than as a starting point, insofar as the disciplines are heterogeneous, and it is precisely a thought of the complex that makes it possible to detect the coherence, thus to weave these links [297]. It is a demanding job, which requires a mastery of complexity thinking in addition to the bases of the disciplines, otherwise one is condemned to remain in the superficial and sprinkling, which is likely to cause more harm than good.

For it's not easy! In addition to the ideological obstacles, there is the fact that a form of thought is not transmitted as a cooking recipe, nor even as a theorem.

South African sociologists have come up against this problem while conducting action research in socio-ecology[298]. They realized that their research required a complexity thinking that their stakeholders had to share in order for collaboration to lead to effective decision-making. “*Complexity thinking is increasingly being embraced by a wide range of academics and professionals as imperative for dealing with today’s pressing social–ecological challenges. In this context, action researchers partner directly with stakeholders (communities, governance institutions, and work resource managers, etc.) to embed a complexity frame of reference for decision making. In doing so, both researchers and stakeholders must strive to internalize not only “intellectual complexity” (knowing) but also “lived complexity” (being and practising)”*

And since this was not the case, they investigated the methods that allow this difficult sharing of complexity thinking. *« Fostering a change in people’s frame of reference is much more*

294 https://www.reseau-canope.fr/congres-mondial-pour-la-pensee-complexe/programme.html#bandeauPtf."*Education actors are at the forefront of thinking about the global challenges of humanity because they do not stay at the door of the school. The call for contributions ... is an invitation to all - teachers, directors, trainers, parents, inspectors, heads of schools, students, school partners ... - to "think in complexity" the challenges of the education in the 21st century, share looks and explore avenues of action”*

295 *Relier, c’est-à-dire pas seulement établir bout à bout une connexion, mais établir une connexion qui se fasse en boucle. (Connect, that is, not just establish an end-to-end connection, but a connection that is feedbacked*) Edgar Morin, *La stratégie de reliance pour l’intelligence de la complexité,* in Revue Internationale de Systémique, vol 9, N° 2, 1995

296 Jean Clenet et Daniel Poisson *op cit*

297 An example of positive feedback

298 *Fostering Complexity Thinking in Action Research for Change in Social–Ecological Systems* Kevin H. Rogers, Rebecca Luton, Harry Biggs, Reinette (Oonsie) Biggs, Sonja Blignaut, Aiden G. Choles, Carolyn G.Palmer and Pius Tangwe *Ecology and Society* **18**(2): 31. http://dx.doi.org/10.5751/ES-05330-180231

than just adding to their knowledge base, it implies changing their mindset and behaviour ...in a process of "transformative learning ». They have been led to establish and propose a working method to achieve this. As a first step, all partners need to become aware of their own thinking since it is usually implicit and deeply rooted in their personality. For that, it is useful to confront reductionist and complex forms of thought in a process that is necessarily slow and requires mutual trust. But this is not enough. They also propose an integrated (complex) framework for learning complex thinking through a transformation of the frames of reference and finally they stress the additional level required to move from knowledge to action. They also stress the importance of psychological aspects, which they call mental habits, such as open-mindedness, sensitivity to the conditions of the situation, the ability to stop and take a step back. Finally « *the learning and understanding processes that lead to transformation are not complete without experience of, and feedback from, application. »* It seems logical that a way of thinking that emanates from practices must be transmitted in the context of practices, be they management, research or teaching.

All this seems to me very useful, but requires a lot of work to be transposed for example at the level of teacher training.

These questions, touched on here, are at the heart of the problems facing humanity at the beginning of the twenty-first century. Teaching, conveying a complexity thinking to make it available to future citizens, is it not a priority objective that could and should be seized by the scientific community of the complex?

Conclusion: Towards a renewal of rationalism.

To conclude I would like to address a particularly important issue at the moment, that of rationalism. The disarray linked to the economic, ecological and human disasters of neo-liberal capitalism has contributed to open the Pandora box of irrationality: sects, fundamentalisms, racisms, intelligent design, are its most visible forms. This rise of irrationality represents a major danger, for the sciences first, that are often accused of the evils caused by an unscrupulous application of their discoveries in the name of irrational principles. But far beyond, for all our civilization.

This is why it is necessary to maintain the principles of rationalism inherited, say, from "*les lumières*". Cartesian rationalism has two aspects, which it is now important to dissociate. On the one hand, it is a rationalism: it tells us that the world is knowable by the human mind, without calling on divine interventions. It will be remembered that Boris Hessen emphasized the ideological difference of Descartes with Newton, who needed God to launch his movements. As such, rationalism is valuable, even more so in our period of rising irrationalisms of all kinds.

But Cartesianism presents another aspect, because for Descartes, this knowability went through the analysis of the objects of the world in their constituent parts, and rested on the exclusively mechanical physical knowledge of his time. Those who struggle against the (major) danger of irrationality, have not always been careful that this aspect of rationalism, to the very extent that it impregnates and is impregnated with, the dominant form of thinking which opposes the complexity thinking, prevents us from understanding the complexity of reality, and thus becomes an open door to irrationality.

This will lead either to repudiate as irrational, or to recruit under the banner of irrationalism, such notions as uncertainty, order from disorder, deterministic chaos, self-organization, emergence... and contradictions. Even the reduction of complexity to the only notion of uncertainty can lead directly to irrationality. Without integrating a real thought of the complex in all its dialectical richness, classical rationalism is no longer able to effectively counter the irrationalisms associated with binary and linear thinking: sects and fundamentalism are based on the opposition between Good personified by a guru or a book, and the Evil that is opposed to him; racism and xenophobia, and all the nuances of populism are based on a static dualism (us and the others). As for the intelligent design, this sophisticated American form of vitalism takes advantages of the flaws of linear rationalism unable to understand emergence, to claim to demonstrate the inevitability of a divine action in the evolution of living species.

Therefore, one may wonder if linear and simplifying thinking is still rational? That it was so when the knowledge did not allow better, seems certain. But now? Is it rational to believe that the effects are always proportional to the causes? Is it rational to separate things from their transforming context, their futures? Is it rational to believe that the future is determined towards a single possible? The indispensable struggle against irrationality can not be successful, in my opinion, in a dogmatic and fixed way, on pain of falling into another form of irrationality.

Faced with the rise of irrationalisms we need, not to retreat into eighteenth-century rationality but to build a rationality enriched by scientific advances and innovative thinking. Here again, complexity thinking and dialectical thought are candidates, not opposed but complementary.

Recently, there has been a shiver of renewal, this return of Marx that I have already mentioned. But the junction is not made, or hardly, between complex sciences, yet powerfully dialectical, but of which the most famous thinkers reject (and often ignore) Marx for reasons generally ideological and political, and a dialectical thought that is gradually being reconstituted but, often ignoring the complexity thinking, does not succeed in renewing itself to meet the challenges of... the complexity of the current world. The disjunction is, again, at work!

Another deleterious disjunction seems to me to be the still so active separation, in France at least, between the so-called exact sciences and the human and social sciences. If the latter feel concerned by the future of humanity and can feel authorized to work towards the construction of this new rationalism, the former believe they are obliged to lose interest in it, in the name of a conception of scientificity that we saw in Chapter IV that it is maintained by economic and I would add ideological pressures. But what can a rationalism that does not take into account the totality of the scientific knowledge mean at the moment? The sciences of the complex have, in my opinion the duty to get involved in this construction and they will have everything to gain in return.