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Dossier

Biology and complexity: Edgar Morin and Henri Atlan★

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Abstract – This article considers the important contribution made by Edgar Morin and Henri Atlan – both members of the Groupe des Dix – to the theorisation of life and information. They have both played a major role in challenging the dominant determinist, mechanistic paradigm of molecular biology that emerged in the 1960s, and which has continued to influence thinking on biology up to the present day. The article will show how they explored key concepts, such as the principle of order from noise, in order to reorient thinking on life and information in terms of a new paradigm of complexity that stood as a radical challenge to the determinist paradigm. A key insight in this respect was the relationship between life, information and meaning.

Keywords: research / technology / biology / complexity / information

Résumé – Biologie et complexité : Edgar Morin et Henri Atlan. Cet article porte sur les contributions décisives d'Edgar Morin et d'Henri Atlan (tous deux membres du Groupe des Dix) dans le domaine des théories du vivant et de l'information. Ils ont tous deux joué un rôle déterminant dans la remise en cause de la formulation déterministe et mécaniste prédominante dans le cadre de la biologie moléculaire, qui émergea dans les années 1960 et qui continue encore aujourd'hui d'influencer la pensée sur la biologie. Cet article propose d'explorer l'usage qu'ils font de concepts-clés tels que le principe d'« ordre » qui émerge du « bruit », afin de réorienter le débat (en matière de théories du vivant et de l'information) autour du nouveau paradigme de « complexité » qui représente un défi radical au concept déterministe. L'une des perspectives-clés en ce domaine fut la relation entre les concepts du « vivant », d'« information » et de « sens ».

Mots clés : recherche / technologies / biologie / complexité / information

The concepts of complexity and emergence have gained a wide intellectual and popular currency since their initial formulation in the 1960s and 1970s. In his influential survey *Complexity. The emerging science at the edge of order and chaos* (1993), M. Mitchell Waldrop suggests that this new paradigm can help to account for a variety of social, political, economic and natural phenomena that appear to defy conventional explanations. These include the remarkably rapid collapse of the Soviet Union and the Eastern Bloc in the late 1980s, the stock market crash of 1987, the emergence of complex living organisms, the evolution of intricate structures such as the human eye and kidney, and the fact of consciousness (Waldrop, 1993, p. 10-11). The idea of complexity as a way of thinking about these phenomena refers not simply to the fact that they are self-evidently "complex" in the common sense of the term, but rather that they demonstrate emergent properties of spontaneous self-organisation. As Peter Coveney (2003, p. 1058) explains, complexity is the study of the collective behaviour of a large number of basic interacting components in a system: "The complex phenomena that emerge from the dynamical behaviour of these interacting units are referred to as self-organizing". The fact that these phenomena emerge entirely from local interactions, without any reference to the global structure, indicates that complex systems have a form of coordination that is distributed rather than being localised in any centre of operations. Also, in a technical sense, self-organisation

★ Voir dans ce numéro les autres contributions au dossier « Le Groupe des Dix, des précurseurs de l'interdisciplinarité ».
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occurs in systems that are "dissipative" and "nonlinear": that is to say, unpredictable ("non-trivial") structures and functions emerge in the productive zone that is at the so-called edge of chaos. This is "the constantly shifting battle zone between stagnation and anarchy, the one place where a complex system can be spontaneous, adaptive, alive" (Waldrop, 1993, p. 12). In many ways, thinking on complexity and emergence reverses the polarity of first-order cybernetics as an ontological exploration: rather than looking at the ways in which life has machine-like characteristics, complexity explores the ways in which a variety of complex structures – natural, societal, geographical – behave like organisms.

This focus on the way in which systems are, as Waldrop puts it, "alive" highlights the importance of biology and biological concepts in the early formulation of complexity. This article draws on research presented in papers delivered at a panel on the Groupe des Dix – held at the Society for French Studies Conference and at the University of Exeter in July 2012, and subsequently at the University of Cambridge in September 2013 – in order to focus on the centrality of biology for Edgar Morin and Henri Atlan in their important contributions to the field of complexity. Referring in particular to Morin's *Le paradigme perdu : la nature humaine* (1973) and two key publications by Atlan, *Entre le cristal et la fumée. Essai sur l'organisation du vivant* (1979) and *La fin du « tout génétique »* (1999), the article will explore the way in which their work converged around an innovative interpretation of the post-war molecular biology paradigm, challenging what they saw as the overly linear, mechanistic and reductionist framing of DNA and its role in the reproduction and development of living systems. This framing of molecular biology drew heavily on the growing importance of first-order cybernetics and information theory in the post-war era which, in very broad terms, identified information – in addition to matter and energy – as a fundamental dimension of the natural world. The effect of information theory on the theorisation of life was twofold. First, it appeared to offer a resolution to the thorny issue of vitalism. That is to say, it was no longer necessary to think of living matter as containing some kind of animating vital spark: in short, life was matter plus energy and information. Second, first-order cybernetics explored the idea that life might have machine-like qualities. Morin and Atlan developed the concepts of complexity, emergence and self-organisation precisely in order to take these initial cybernetic insights further. For them, initial thinking on life and information had offered ways of explaining reproduction and inheritance in non-vitalist terms, but it had had little to say about, for example, the emergence of consciousness. Such complex phenomena can only be understood, they argued, by exploring the capacity of living systems to self-organise in response to external stimuli and growing complexity. For these reasons, they explored ways of understanding information not simply in terms of transmission, but also as the construction of meaning within systems. For Atlan, a core preoccupation throughout his work has been the attempt to mobilise cybernetics and information theory in order to provide a materialist account of consciousness and intentionality. This article will look in particular at his sustained challenge to genetic determinism ("*le tout génétique*"). It will also look at the ways in which, for Morin, complexity provides a conceptual frame for a reformulation of human "nature". This project began to take shape for Morin in the 1970s, and it was influenced not only by his engagement with molecular biology but also, as the article will show, by new thinking in diverse fields such as anthropology, ethology and evolutionary theory.

A new paradigm: "*la fin de l'humanité insulaire*"

Edgar Morin is one of the first thinkers to attempt to summarise and theorise the emergence of a new paradigm of complexity that challenged and expanded the deterministic, mechanistic focus of science by emphasising nonlinearity, disequilibrium, disorder and interaction. For Morin, complexity constitutes nothing less than a challenge to the central ontological and epistemological assumptions of the established paradigm of Western scientific rationality, which constructs knowledge according to principles of order, reversibility and linear causality, operating according to a clear epistemological distinction between subject and object. Although classical science has achieved major success by discovering the "simplicity" of basic elements at the microscopic level, this methodology must now be supplemented with a willingness to engage with the nature of the complex and dynamic relations that exist between these elements. Along these lines, Morin has consistently explored the role of chance, disorder, and complex recursive causality, and he has argued that the world consists primarily of open systems that are characterised by flux and disorder: all living systems are threatened by disorder but are at the same time nourished by it (Morin, 1973, p. 129). In contrast to classical science's drive to eliminate subjectivity in favour of a rigorously objective approach to scientific knowledge, complexity draws on second-order cybernetics to emphasise the importance of the role of the observer. As far as the figure of the human is concerned, scientific rationality places the human subject in a privileged position in relation to the natural world. Both Christianity and humanism are built on the assumption that it is possible to escape or transcend, either in death or life, the constraints of the natural world (Morin, 1973, p. 20-21). In this respect, Jacques Monod's influential framing of the significance of molecular biology, *Le hasard et la* *nécessité* (1970), remains squarely within the classic paradigm of scientific rationality. For Monod, molecular biology provided a final confirmation that humanity was alone in the universe, condemned to the absurd Sisyphean task of creating meaning in the absence of any transcendental power[1]. Furthermore, he emphasised that the "animist" – as he put it – tendency to project human values onto the natural world was illusory. In short, the figure of the human was entirely isolated. So, although molecular biology strips "life" of any metaphysical dimensions, reducing it to physico-chemical interactions, the human subject maintains a position of splendid, if tragic, isolation. Although, as Morin emphasises, we may accept that – after Darwin – we are descended from primates, and also that – after molecular biology – our bodies are complex multicellular machines controlled by genes, we still accord a privileged position to the human as being somehow outside of nature. Complexity, in contrast, has sought to conceptualise the human as part of the natural world, forging a "new alliance" (Prigogine and Stengers, 1979) with nature that finally draws the human out of its peculiar conceptual isolation. As Atlan acknowledges, this challenge to the insularity of the human has much in common with Michel Foucault's (1966, p. 398) prediction, in *Les mots et les choses*, that "man" might be on the point of disappearing, like a "face drawn in the sand" (Atlan, 1979, p. 133). Whereas Foucault, writing at the height of structuralism's intellectual influence, placed his faith in language as the area in which this breakthrough would take place, biology offered itself as a more fruitful area for thinkers like Morin and Atlan. The task, as they saw it, was to place the human squarely in the natural world without being drawn into the sort of biologism that has characterised, for example, sociobiological views of human behaviour as being primarily genetically determined.

As the article will show, this attempt to break down the conceptual insularity of the human is the main aim of Morin's *Le paradigme perdu : la nature humaine* (1973). This was an important publication for Morin in that it constituted an attempt to summarise the period of intense reflection on biology, culture and evolution that he had undertaken in previous years. It also pointed forward to the long-term project of bringing together biology and the human sciences in a highly ambitious, conceptually coherent synthesis. The book grew directly out the international conference on "*L'unité de l'homme*" held at Royaumont in 1972 that was in large part inspired by Morin's friendship and intellectual dialogue with the eminent French molecular biologist Jacques Monod (Morin and Piattelli-Palmarini, 1974). The overall aim of the conference was to explore the links between "biological invariants and cultural universals", and it brought together researchers from a wide variety of fields, including molecular biology, anthropology, ethology, physics, cybernetics and sociology. As Claude Fischler emphasises in a piece written thirty-three years later, the conference marked a pivotal moment in transdisciplinary dialogue and signalled a shift away from the dominant approaches of structuralism and Marxism in French intellectual life (Fischler, 2005; 2006). In raising fundamental questions concerning culture and nature it inspired Morin to set out a conceptual framework for human evolution that incorporated new insights in the fields of molecular biology, cybernetics, ethology and anthropology.

Molecular biology: a dogmatic paradigm

As indicated already, a key component of the context of Morin and Atlan's attempts to formulate a new paradigm of complexity was the natural philosophy associated with molecular biology. Crick and Watson's discovery of the double-helix structure of DNA and Jacob and Monod's work on gene regulation had been incorporated into a linear, mechanistic account of the three main dynamics of life: the reproduction of hereditary characteristics from generation to generation; the development of living organisms from conception and an embryonic phase through to adulthood; and the overall process of evolution. These phenomena which had previously been explained in terms of the enigmatically vitalist properties of living matter and the direct influence of environmental stimulus, could now be described exclusively in physico-chemical terms. That is to say, DNA is inherited from the genome of each parent, and the nucleotide bases that make up DNA macromolecules act as coded information that is translated into sequences of amino acids, which in turn specify the structure and properties of proteins in the cell. Crucially, molecular biology quickly formulated its own so-called "central dogma", according to which the information flow in the cell does not permit for any transfer of information back from protein to DNA (so-called "backtranslation"). According to this model of information transfer there can be no direct influence exerted by the environment on DNA during the lifetime of an organism. The concept of the central dogma was formulated in the 1950s by Francis Crick, who asserted that once information has passed into a protein "it cannot get out again" (Crick, 1958, p. 153).

[1] Monod uses a lengthy quotation from Camus' *Le mythe de Sisyphe* (1942) as an epigraph – along with a quotation from Democritus – for *Le hasard et le nécessité*. The quotation closes as follows: "*Cet univers désormais sans maître ne lui paraît ni stérile ni futile. Chacun des grains de cette pierre, chaque éclat minéral de cette montagne pleine de nuit, à lui seul forme un monde. La lutte elle-même vers les sommets suffit à remplir un cœur d'homme. Il faut imaginer Sisyphe heureux*".

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Consequently, as far as the evolution of life is concerned, molecular biology was integrated into a broadly neo-Darwinian model, according to which evolutionary change results from random genetic mutations producing phenotypic variations that are subjected to environmental pressures. Evolutionary change occurs by virtue of the steady accumulation of new features that allow for adaptational advantages: the vast scale of evolutionary time means that the random generation of genetic difference has the effect of sculpting organisms in minute detail. In summary, this model is rigidly gene-centric and selectionist rather than instructionist, in that no environmental effects on the phenotype can be fed back into the germ-line in heritable form.

Morin and Atlan argued that the theorisation of this new field by its main practitioners limited its potential as the basis for a new natural philosophy. For them, molecular biology misrecognised its own potential, effectively locking itself into an inadequate and anachronistic determinist paradigm. The preoccupation with defeating vitalism had pulled it down a mechanistic route, preventing it from exploring the full potential of the new paradigm of complexity that lay before it (Atlan, 1979, p. 195). Morin likens molecular biology's accidental discovery of complexity to Columbus who, in looking for India, actually found America (Morin, 1973, p. 28). In order to properly explore the new continent that molecular biology had uncovered Morin and Atlan sought to expand on what they regarded as molecular biology's limited understanding of cybernetics and information theory. Rather than focusing on the linear transmission of information, they considered the ways in which information functions to facilitate meaning and interpretative dynamics in complex systems. In this sense, they sought to replace the rather loosely-defined concepts of "code" and "programme" favoured by molecular biology with models that draw on the emerging conceptualisation of the brain as a complex distributed system. As the article will show, in addition to self-organisation, the concept "order from noise" was central to this reassessment of molecular biology.

Complexity and molecular biology

Morin's critical engagement with molecular biology emerged from what was a particularly intense period of intellectual development for him, as he explains in the foreword to *Le paradigme perdu : la nature humaine* (1973). He emphasises that fundamental questions relating to biology had always informed his thinking in a variety of ways up to this point. Initially, he says, these were the sort of naïve reflections that occur in childhood and adolescence, but these basic questions concerning the relationship between the human and nature took on a new significance for him when he was exposed to a series of new intellectual influences in the late 1960s. A key phase in Morin's thinking on biology and complexity began in 1968, when Jacques Robin invited him to join the Groupe des Dix. Then, in 1969, Morin was invited by Jonas Salk and Jacques Monod to spend a year at the Salk Institute in California, where he developed further his thinking on biology, ecology, information and systems theory. He continued this line of research when he returned to France, at which point he was particularly influenced by François Jacob's analysis of the evolution of biological concepts in *La logique du vivant* (1970), and he was introduced to the principle of "order from noise" by Henri Atlan[2], who also pointed him to Von Neumann's theory of automata (Fischler, 2008, p. 165). In addition to this, he spent time at MacGill University in Montreal, where he avidly read new material on self-organising systems that was unavailable in France at the time (Morin, 1973, p. 12-13).

This intense period of research, conversation and reading was clearly a pivotal episode in Morin's thinking, orientating him towards a general method of complexity. His diary entries in *Journal de Californie* (1970), written throughout his time at the Salk Institute, provide fascinating insights into the ways in which biology was of central importance to the development of his thinking. In a preface to the 1983 edition of the book he reflects in a general sense on the fact that the intellectual atmosphere of California allowed him to make connections between life and ideas in ways that were not possible in France, where a radical disjunction between the two categories was the norm (Morin, 1970, p. 7). A key preoccupation for Morin is the relative isolation of biology as a discipline, and the possibility that it may now be possible to make new connections between biology, anthropology, sociology, etc. (Morin, 1970, p. 42-43). Morin's thinking draws him towards the possibility of exploring the links and articulations between the different systems that comprise life, as well as the different logics of structure and event (Morin, 1970, p. 54-57). In what he recognises as a significant breakthrough in his thinking, he arrives at the formulation of "*la vie comme système événementalisé*": a system capable of responding to both internal and external chance events and of integrating them into a flexible structure (Morin, 1970, p. 58). Life, he claimed, can be described as a dialectical relation between conservation and evolution (Morin, 1970, p. 107). The significance of Morin's engagement with molecular biology is emphasised by Jacques Robin, writing about the Groupe des Dix sessions with Monod and Jacob in the early 1970s. Robin remembers these as "*soirées exaltantes*", marked by a

[2] Morin talks in Brigitte Chamak's *Le Groupe des Dix* (1997) about the importance of his time at the Salk Institute and about his friendship with Jacques Monod. He also mentions that his association with Atlan dates back to the early 1960s (Chamak, 1997, p. 227).

certain liberty of expression and robust intellectual exchanges. At this time, he recalls, the new, apparently all-conquering field of molecular biology confidently asserted a determinist perspective, according to which a line of linear causality ran from DNA, through proteins, to characteristics in the organism. Morin, however, inspired by his time in California, surprised the group by expressing serious reservations about this overly "linear", determinist paradigm. He warned against over-simplification, predicting that the genome would come to be seen as much more complex than this approach suggested (Robin, 1990, p. 85).

Henri Atlan (1979, p. 13-27) was also questioning the reductionism and finalism of molecular biology, and he summarises his thinking on this subject in a short chapter in *Entre le cristal et la fumée*, "Dogmes et découvertes cachées de la nouvelle biologie". Like Morin, he challenges Jacques Monod's neo-Darwinist, reductionist framing of molecular biology in *Le hasard et la nécessité* (1970). Having dismissed vitalism, Monod's core thesis is that teleological explanations of heredity relying on final causes can now be replaced by the concept of teleonomy. Heredity and evolution as teleonomic processes, Monod argues, only give the appearance of being governed by final causes: they are in fact the realisation of a genetic programme, contained in the genome, which has been sculpted over time by the dual forces of random mutation and natural selection. For Atlan, this mechanistic framing does not ultimately address the issues raised by the notions of code, information and programme associated with the conceptualisation of molecular biology. Instead, these cybernetic concepts open up profound questions of an ontological, not to say metaphysical, nature. Atlan suggests that the finalism observed in biology can be explained by drawing on new ways of thinking about living systems as complex and self-organising. Greater levels of complexity in living systems would allow them to react to environmental stimuli and to develop in ways that are not pre-programmed into genetic material. Atlan points to the importance of the work of Paul Glansdorff and Ilya Prigogine (1971) on the self-organising properties of far-from-equilibrium systems, his own work on order from noise, and the parallels that Jean Piaget (1967) explores between biological systems and the self-organising nature of learning.

In "Finalité du complexe", an article written in 1990, Atlan revisits the issue of finalism and intentionality in biology in the light of more recent models of evolution. He looks in particular at the concept of the "selfish gene", associated primarily with Richard Dawkins. Although the principle of final causes is apparently challenged by the idea that the evolution of phenotypic forms is simply a by-product of the drive of genes to ensure their own replication, the concept of the selfish gene retains a strong sense of intentionality. Genes apparently "choose", for "egotistical" reasons, the phenotypical expressions that are best adapted to their programme of reproduction (Atlan, 1990, p. 242). For Atlan, the selfish gene is the biological substrate of sociobiology, which he dismisses as a drily one-dimensional materialist view of evolution. He suggests that, rather than slipping into theories of intentionality by using ill-advised metaphors, it would be more productive to take a cue from recent work in ethology, behavioural biology and artificial intelligence (AI) and to acknowledge the unavoidable fact of intentionality. These fields show that intentionality is an emergent property, and AI is crucial in this respect because, as Atlan emphasises, the fact that a machine can replicate aspects of intentionality and consciousness makes it more difficult to sustain idealist notions of these properties (Atlan, 1990, p. 244). He suggests that the idea of non-intentional play ["*le jeu*"] constitutes the best model within which to understand the emergence of intentionality at certain levels of complexity. So, rather than seeing evolution and the development of individual organisms as being in some way programmed or as unfolding according to a pre-established plan, the idea of play conveys the way in which a nondirected dynamic can lead to emergent properties of intentionality. Crucially, this is a game in which the rules are constantly changing (Atlan, 1990, p. 245-246). Atlan recalls a conversation – presumably at one of the Groupe des Dix sessions devoted to molecular biology – that captures in summary form the way in which the Groupe was exploring ways of thinking that challenged the assumptions of the molecular paradigm (Atlan, 1990, p. 245). François Jacob replied to a question regarding final causes in the natural world by saying that the "dream" of a bacterium is to make two bacteria, to which Morin apparently responded in turn by suggesting that the dream might simply be to "enjoy [*jouir*] its metabolism". Atlan provided a slightly different perspective which, in his opinion, avoided any trace of finalism: organisation in living organisms can only be described in terms of physico-chemical interactions. The "dream" of a bacterium is simply to achieve thermodynamic equilibrium: in other words, to die (Atlan, 1990, p. 245). Death, in this sense, is synonymous with disorder and noise which, Atlan emphasises, lies at the heart of vital processes. He summarises this view by means of a neat reversal of Bichat's vitalist definition of life as the set of functions that resist death. For Atlan, in contrast, life is the set of functions capable of using death (Atlan, 1979, p. 278).

Self-organisation and order from noise

Atlan's emphasis on disorder and noise leads him to formulate the principle of order from noise, which is central to the understanding of self-organisation. In a broad sense, disorder can be defined as any phenomenon that cannot be predicted deterministically or mechanically, and noise refers to any perturbation that interferes with the transmission of information (Morin, 1973, p. 127). However, the concept of order from noise and its relation to self-organisation requires a somewhat more technical explanation. Atlan's challenge to the metaphorical uses of information theory is based on a critique of Claude E. Shannon's highly influential probabilistic theory of information. Shannon defines information as a particular arrangement of elements that is distinct from all other possible arrangements and that can be transmitted as a sequence. The process of transmission can be disrupted by random perturbations, *i.e.,* noise. Redundancy, in the shape of repeated elements, can help to protect the fidelity of the transmission against the disruptive effects of noise, although redundancy of this kind necessarily entails a cost. The main problem with Shannon's formulation, according to Atlan, is that it neglects the issues of meaning and the creation of new information. For Shannon, whose primary focus was the preservation of the message, noise is destructive and redundancy is a cost that is paid in order to protect against noise. From the perspective of self-organisation, however, noise actually creates new information, and a certain amount of redundancy is required to facilitate change: "Redundancy for communication engineers is a burden. It is a bonus for biologists" (Atlan and Cohen, 1998, p. 712). Atlan explains this principle in *Entre le cristal et la fumée* by means of a simple model of a system S comprising two subsystems A and B. As far as the overall quantity of information in the system is concerned, the optimum level of operation for the system as a whole entails a degree of transmission between A and B, but also a certain number of errors (Atlan, 1979, p. 46-47). The positive effects of noise are maximised in a highly complicated system with multiple direct and indirect connections between subsystems: "*Cette augmentation peut être alors utilisée pour la réalisation de performances plus grandes, notamment en ce qui concerne les possibilités d'adaptation à des situations nouvelles, grâce à une plus grande variété des réponses possibles à des stimuli diversifiés et aléatoires de l'environnement*" (Atlan, 1979, p. 49).

In this way, noise is a necessary stimulus to a dynamic of self-organisation that can only function in open systems, since closed systems are inevitably subject to entropy when noise occurs in the system. Self-organising systems, in contrast, function both despite and with noise (Morin, 1973, p. 127-128). They are able to do this because they are open systems, which have the capacity to constantly retrieve organisation from a state of disorganisation: in fact they require a "nourishing disequilbrium" in order to maintain this state of stability and continuity (Morin, 2005, p. 30). Living systems can overcome the entropy that is produced within the system by responding to the forces of disorganisation that come from the environment. Consequently, open systems must be considered in the context of the environment that is both part of the system whilst remaining exterior to it (Morin, 2005, p. 32). The capacity to use noise also depends upon the fact that complex systems can, as it were, observe themselves. What appears to be redundancy or noise at one level of organisation can be seen as entirely coherent from the point of view of a higher-level observer. That is to say, the role of observer can be undertaken by a higher level of organisation within the system. So, from the perspective of a cell, any noise that occurs in the transmissions of information that constitute the cell is necessarily negative, but from the wider perspective of the organ within which the cell functions this noise is positive, in that variety potentially increases the overall regulatory performance of cells in the organ (Atlan, 1979, p. 69-70). The idea that meaning is generated by the capacity of a system to observe itself means that complexity theory is able to develop the rather loose linguistic metaphors of molecular biology in a more nuanced manner. Atlan argues, for example, that the self-organising capacity of the human immune system functions like a conversation: a dynamic process that adjusts to constantly changing circumstances: "These changing requirements are abstracted into the chemical language of the immune system. The ongoing integration of germline and somatic information in one's body is the essence of the self" (Atlan and Cohen, 1998, p. 717).

Atlan: *La fin du tout génétique*

Throughout his career Atlan has challenged the idea of a genetic programme, and he summarises his objections, particularly in the light of new developments in the field of epigenetics, in *La fin du « tout génétique »* (1999). The reductionist *tout génétique* paradigm has held wide currency for the past three decades or so, and it culminates, at the very end of the twentieth century, in the Human Genome project, which conceives of the genome as the "essence" of life: the basic idea that "everything is in the genes". This essentially preformationist notion that genes contain a programme for the organism – a programme for life – has been reinforced by a reductionist mode of scientific practice that has operated according to the "streetlight effect". Like the proverbial fool who looks for his keys under the streetlight, although he knows that he lost them elsewhere, because "this is where the light is", genetic research has sought "genes for" any number of characteristics and behaviours. This type of research is favoured, Atlan claims, precisely because it avoids the problematic analysis of multiple, interrelated determinants (Atlan, 1999, p. 58). The properties of pleiotropy, redundancy and complexity that have been revealed by genomic research challenge the core assumptions of molecular biology. Pleiotropy refers to the fact that the same gene can have different functions in a variety of organisms and at different stages of development. Redundancy was identified as early as the 1970s in the shape of repetitive DNA sequences that are noncoding and the function of which is unknown. At a later stage, repetitive coding sequences were also identified. In a more general sense, the interaction between the genome as an overall structure and the state of expression of the genes has been shown to be more complex than the determinist paradigm would suggest (Atlan, 1999, p. 20-21). Genome sequencing has, for example, shown that there are significant similarities at the genetic level between very different species (Atlan, 2010, p. 104-105). Also, experiments with "knocked-out" genes have produced either no apparent effect in phenotype or have led to significant and unexpected changes. In short, the way in which a gene is expressed in an organism cannot be deduced in any straightforward way from knowledge of the DNA sequence (Cohen *et al.*, 2016, p. 3).

Atlan has highlighted the growing recognition of the significance of epigenetic inheritance and embryonic development. Both depend upon phenomena that are already known and observed, but have tended to be neglected within the dominant molecular paradigm. In the case of epigenetic inheritance, it is clear from the differentiation of somatic cell lines that, at the moment of cellular division, it is not simply the DNA sequence that is transmitted, but also the state of activity of the sequence. Despite the fact that this phenomenon is, of course well-established, since it facilitates the development of the differentiated somatic cells, it was thought unlikely that it might apply to germ cells. However, there is evidence that certain states, such as DNA methylation, can be transmitted (Atlan, 1999, p. 38-39; Atlan, 2011, p. 109). Research has also revealed what appear to be mechanisms of epigenetic inheritance at work in human populations. For example, the children and grandchildren of women who experienced the "Dutch hunger winter" of 1944-1945 have suffered a high number of pathologies and developmental issues. As Atlan suggests, epigenetic inheritance of this kind calls into question the central Weismannian tenet of neo-Darwinist genetics, according to which there is a strict distinction between *soma* and *germen*, preventing the inheritance of acquired characteristics (Atlan, 2010, p. 111). As far as embryonic development is concerned, Atlan points to the fact that, in *Drosophila*, it has been shown that maternal RNA directs the initial development of the embryo before the genome expresses itself (Atlan, 1999, p. 41-44). Cloning techniques have also called into question the notion of a genetic programme, since they have shown that the nucleus of an adult cell can be reprogrammed epigenetically (Atlan, 2010, p. 103).

Rather than fetishising DNA as the essence of life, it should be seen, Atlan suggests, as a "dead" molecule, which has no autonomous power to reproduce and make copies of itself or, for that matter, anything else. The presence of active molecules – proteins and RNA – is required for any activity to take place (Atlan, 1999, p. 54). In light of this, the idea of the genetic programme is, Atlan argues, a metaphor that has outlived its usefulness, and it should now be supplemented with a new model of genomic DNA as data within the distributed system of the organism. Whereas a programme is a plan for a sequence of events, a blueprint for a specific set of tasks to be completed, biologists working in the field of molecular biology are all too aware that the genome is "ambiguous, incoherent and indefinite", and that it is neither autonomous nor "complete" in the sense of a programme (Cohen *et al.*, 2016, p. 2). Similarly, DNA does not have significant syntactical or semantic language-like properties (Atlan, 1999, p. 24). It might more usefully be thought of as a vocabulary: that is to say, a reservoir of information that mutates and evolves over time, and which is transmitted from generation to generation. Expanding the metaphor further, a vocabulary – like DNA – can be expressed in different ways to generate meaning, but individual language users are required to carry out this process (Cohen *et al.*, 2016, p. 7). Locating DNA within a complex distributed system marks a significant break with the central dogmas of molecular biology: there appear to be molecular bearers of information that are not entirely reducible to DNA. At the macro-level of evolution Atlan challenges the neo-Darwinian tenet that evolution improves the genome by the steady accumulation of small errors. Rather than generating improvement, evolution accumulates complexity and thus generates new information (Cohen *et al.*, 2016, p. 6).

Le paradigme perdu : la nature humaine

The article will conclude with a brief consideration of the way in which Morin attempts, in *Le paradigme perdu : la nature humaine*, to apply the principles of complexity and self-organisation to evolution, and in this way to challenge the dominant association of a reductionist molecular biology with a rigidly neo-Darwinist view of evolution (the so-called modern synthesis). Biological and cultural evolution are considered as interconnected processes that are conceptualised in terms of the interaction of open systems, the interplay of order and disorder, the principle of order from noise, and the dynamic of growing complexity. In the course of his argument Morin seeks to overturn established causal

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relations in a number of ways. In a general sense, it is not simply the case that the development of a larger brain facilitates the emergence of more sophisticated human culture, but also that the emergence of culture itself promotes the development of a larger brain. Morin describes his nonlinear, non-mechanistic approach as a form of a complex – in both the common and technical sense – diagramme, an anti-model, of the hominisation process (Morin, 1973, p. 104).

As Atlan notes in his detailed assessment of *Le paradigme perdu*, Morin's focus on new capacities that emerge in the process of evolution, and which are effectively activated at a later stage when they become adaptationally advantageous, draws directly on the self-organisational principle of productive redundancy, and of order from noise (Atlan, 1979, p. 203). Morin is attempting to recover and reconstitute the scattered pieces of "human nature" which has up to this point been fragmented by the opposition between nature and culture (Atlan, 1979, p. 192). Philosophically, the idea of a human nature has, Morin suggests, been relegated over time to that of a kind of material substrate, a "*matière première*" that is moulded by the forces of culture and society: an inherently conservative phenomenon that must be modified in order to achieve progress and social change: "*Ainsi, de toutes parts, vidée de vertus, de richesse, de dynamisme, la nature humaine est devenue un résidu amorphe, inerte, monotone : c'est ce dont l'homme s'est soustrait et nullement ce qui le fonde*" (Morin, 1973, p. 20). Although there have been serious philosophical attempts to theorise the human in terms of the natural world and natural processes, notably by Marx, Spencer and Freud, the general tenor of anthropology has been to separate culture from biology (Morin, 1973, p. 23-24).

Morin argues that, as well as directing biological understanding to the micro-level of the physico-chemical realm, molecular biology also, somewhat counterintuitively, points to the importance on the macro-level of the cultural and anthropological realms. So, in contrast to the neo-Darwinist model of evolution driven by genetic mutation and adaptive selection, he describes the process of hominisation as one of complex morphogenesis in which genetics, environment, culture, individual and species interact in a variety of ways (Morin, 1973, p. 64-67; p. 102-103). Whereas, for Lamarckian or Darwinian models of evolution the environment is simply a formative or selective "*moule géo-climatique*", he conceives of the relationship between a living system and an ecosystem as a co-productive dynamic between two open systems (Morin, 1973, p. 30-32). In the course of elaborating this model of human evolution Morin uses ideas taken from complexity to challenge the basic assumption that both cultural and biological evolution are processes of emerging order and rationality. So, for example, hominisation only appears to be logical and orderly because the disorder of the process of evolution, in the form of blind alleys, redundancies and periods of stasis, is forgotten (Morin, 1973, p. 102).

Morin begins his survey by considering on what was, in the early 1970s, relatively recent research on primates (chimpanzees, baboons, macaques), which showed that anthropoid social structures were more complex than had previously been thought. For Morin, this social complexity emphasises the pervasive presence of "noise" – in the shape of uncertainty, indeterminacy and conflict – in forms of society that must have predated human societies in evolutionary terms (Morin, 1973, p. 37). These anthropoid societies demonstrate the "Brownian motion", or noise, of the incomplete integration of individuals, unresolved aggression and generalised conflict that provides a certain "metabolic richness" (Morin, 1973, p. 45-46). In this way, Morin suggests that humans have not only inherited biological features from primates, but also cultural features. He also draws on research carried out in the late 1960s and early 1970s that revealed previously unsuspected linguistic capacities in chimpanzees. As well as showing that chimpanzees can use a basic gestural language in order to enter into dialogue with humans, the research demonstrated a sense of self-identity and reflexive, logical thinking associated with high-level language skills. Morin concludes that, in evolutionary terms, chimpanzees do not lack the cerebral capacity for language, but rather the purely physical glottal aptitude and the environmental influence of social stimulation required to promote the development of a more highly developed linguistic system (Morin, 1973, p. 52-54).

He then moves on to a general outline of the humanisation process, which comprises three main dynamics: cerebralisation; juvenilisation and culturisation. With the move to the savannah an increasingly complex relationship develops between the ecosystem and the hominid (Morin, 1973, p. 70). The emergence of language as a complex meta-system constitutes a crucial evolutionary leap, facilitating the development of culture as a source of complexity. Sociocultural evolution and the development of the brain are mutually supportive, in that sociocultural "complexification" maximises the use of brain capacity, which in turn favours mutations that produce new cerebral aptitudes (Morin, 1973, p. 94).

The large brain of *Homo sapiens* functions as a system which generates both order and disorder, and the "madness" of *Homo sapiens* provides a creative source of noise. The evidence of burial tombs and paintings indicates emergence of a profound, complex consciousness of time. This, in turn, gives rise to a growing realism and the development of myth and imagination (Morin, 1973, p. 109). Uncertainty and ambiguity concerning the relationship between the brain and environment now become crucial. The necessity of selecting between solutions and approaches introduces the possibility of error. Error, in short, is part of human nature (Morin, 1973, p. 120). The development of *Homo sapiens* is also marked by a psychological and affective eruption of violence: "*La violence, circonscrite chez les animaux à la défense et à la prédation alimentaire, se déchaîne chez l'homme, hors du besoin*" (Morin, 1973, p. 122). In summary, the evolution of *Homo sapiens* is characterised by a massive increase in disorder. Darwinism and anthropology cannot adequately account for the development of these characteristics: "*L'homme est fou-sage. La vérité humaine comporte l'erreur. L'ordre humain comporte le désordre*" (Morin, 1973, p. 126).

The key to understanding the process of hominisation is the "complexification" of the brain, and the qualitative leap that constitutes the emergence of *Homo sapiens* opens up a realm of hypercomplexity. As a hypercomplex system the human brain is characterised by high levels of flexibility in terms of hierarchy, specialisation and centralisation, and it is orientated primarily towards heuristic and strategic activity (Morin, 1973, p. 130). As the brain achieves a certain degree of autonomy from the constraints of genetics, it is able to respond to chance events and incorporate noise. At the same time, its own internal functions become more "disordered": in short, it is prone to error and disorder. The brain is "*le centre fédérateur-intégrateur*", which mediates systemic links between the biological, cultural and spiritual spheres. These spheres are not compartmentalised orders organised in a hierarchy, but rather profoundly interconnected systems. Consequently, there are intimate and surprising connections between aspects of human life that appear to be entirely unconnected and irreducible. So, for example, sexuality, which appears to be the "most genetic" sphere, is also profoundly symbolic and cultural. Morin claims that Freud is, in this sense, one of the great analysts of complexity, in that he explored the encroachment of sexuality on all mental activity and the reciprocal effect of the superior cortex on sexuality (Morin, 1973, p. 146). The growing influence of the brain as a mediating centre means that cerebral "noise" is projected onto society. In contrast to the idea of a process of human "enlightenment", Morin emphasises the unstable, volatile nature of the development of human consciousness: "*La conscience n'est pas la lumière qui éclaire l'esprit et le monde, mais c'est la lueur ou le flash qui éclaire la brèche, l'incertitude, l'horizon. Elle tend à éliminer l'erreur, mais pour illuminer l'errance*" (Morin, 1973, p. 153).

Although Atlan admires the attempt to trace the contours of a new paradigm of complexity in *Le paradigme perdu*, he suggests that Morin has a tendency to privilege the creative possibilities of disorder, and consequently neglects the importance of stabilising mechanisms of repetition and reproduction. Atlan detects in this respect the influence of the radical politics of the 1960s and early 1970s (Atlan, 1979, p. 200-201). He points in particular to Morin's "fascination" with human error towards the end of the book as the point at which Morin equates the removal of constraints with hypercomplexity in contrast to the more subtle analysis of the complex relations between autonomy and dependence that characterised the earlier parts of the book (Atlan, 1979, p. 212). Morin responded to Atlan's critique by further refining and developing his own distinctive interpretation of order from noise in the first two books of his multi-volumed *Méthode* (Morin, 1977; 1980).

Conclusion

Morin and Atlan have made a highly significant contribution to the shift away from reductionism in biology towards a paradigm of complexity. They challenged the inherent reductionism of the dominant paradigm of molecular biology that was formed in the 1950s and 1960s. They did this by emphasising the importance of noise as a source of order, and by reframing the notion of information in the context of sense and interpretation. Information, as Morin explains, only exists when it is interpreted by living beings, and is in this way inseparable from life (Morin, 2005, p. 145). Their conceptual development of the relationship between life, information and sense continues to resonate in the field of biology. The notion that organisms always exist in an environment from which they receive information is now commonplace, as is the idea of emergent properties that cannot be predicted from a knowledge of the linear, mechanistic interactions between the constituent components of a system. Contemporary neuroscience, for example, is predicated on the assumptions that the brain is a complex, nonreducible system in which interactions occur both upwards and downwards between multiple levels, and that consciousness is an emergent property of these processes. For Morin in particular, this engagement with biology in the late 1960s and early 1970s proved to be pivotal in the overall development of his thinking on complexity. This "*tournant biologique*" allowed him to address the fundamental question of what he saw as the reductive opposition between nature and culture. *Le paradigme perdu* attempted to understand human evolution as both a cultural and a natural phenomenon, and he drew extensively on the theory of self-organisation in order to avoid the pitfalls of molecular reductionism.

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