
Why matter matters to neo-Aristotelian teleology in mechanics

Por qué es importante la materia para la teleología neo-aristotélica en la mecánica

ANDREW PINSENT

University of Oxford
Faculty of Theology and Religion
OX1 3LD Oxford (Reino Unido)
andrew.pinsent@theology.ox.ac.uk

Abstract: Simple mechanical systems involving feedback can easily manifest teleonomy, but it is still widely believed that there is no place for genuine teleology in metaphysical naturalism. In this paper, I argue that chaotic systems do, in fact, provide examples of irreducible neo-Aristotelian teleology in mechanics, but only if their behavior is considered in terms of changes to extended objects in a phase space, with aspects that can be mapped to notions of form and matter.

Keywords: Chaos, teleology, matter, neo-Aristotelian.

Resumen: Los sistemas mecánicos simples que incluyen feedback fácilmente pueden manifestar teleonomía, aunque es ampliamente aceptado que no hay lugar para una genuina teleología dentro de una metafísica naturalista. En este artículo sostengo que los sistemas caóticos, de hecho, proveen ejemplos de teleología irreducible neo-aristotélica en mecánica, pero sólo cuando su comportamiento es considerado en términos de cambios de objetos extensos en un espacio de fase, con aspectos que pueden ser mapeados a las nociones de materia y forma.

Palabras clave: Caos, teleología, materia, neo-aristotélico.

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1. INTRODUCTION

Surveys of the term ‘teleology’ in academic publications rapidly reveal the continuing and seemingly intractable controversy over the meaning and status of final causation. Drawing from the work of contemporary philosophers of Aristotle, with whom the defense of an end (*telos*) as a distinct cause is most closely associated, the eminent biologist Ernst Mayr argued that the acknowledgement of end-directed phenomena does not have to imply the endorsement of unverifiable theological or metaphysical claims, a rejection of physico-chemical explanations or anthropomorphism.¹ Nevertheless, many biologists continue to regard teleological descriptions of nature as merely nominal, variously treated as convenient, substitutory metaphors for the effects of other kinds of causation or as dangers to rational thought, vestiges of Aristotelian thinking that should be driven out of science.²

Decades of work on complex systems and self-organisation have nevertheless produced an unexpected revival of teleological language in science and even a few advocates for a revival of the Aristotelian four-cause system.³ Less controversially, and setting

1. E. MAYR, *The Idea of Teleology*, “Journal of the History of Ideas” 53/1 (1992) 122. Mayr cites in particular the work of M. GRENE, *Aristotle and Modern Biology*, “Journal of the History of Ideas” 33/3 (1972) 395-424 who is careful to distinguish Aristotelian end-directed action generally and purposeful action.

2. Adept communicators of biological ideas, such as R. DAWKINS, *The Extended Phenotype: The Long Reach of the Gene*, rev. ed. (Oxford University Press, Oxford, 1999), frequently resort to teleological descriptions of biological processes, but even these convenient metaphors have been subject to criticism. See, for example, D. HANKE, *Teleology: The Explanation That Bedevils Biology*, in J. CORNWELL (ed.), *Explanations: Styles of Explanation in Science* (Oxford University Press, Oxford, 2004) 143-156; J. REISS, *Not by Design: Retiring Darwin's Watchmaker* (University of California Press, Berkeley/London, 2009).

3. For a recent review of trends in the philosophy of science that argue for a return to some version of Aristotelian final causation, see M. CHASE, *Teleology and Final Causation in Aristotle and in Contemporary Science*, “Dialogue” 50 (2011) 511-536. Chase highlights in particular the work of R. THOM, *Aristote et l'Avènement de la Science Moderne: La Rupture Galiléenne*, in A. SINACEUR (ed.), *Penser Avec Aristote. Études Réunies Sous La Direction De M. A. Sinaceur* (Éditions Erès, Toulouse, 1991) 489-496, I. PRIGOGINE, *La Nouvelle Alliance: Métamorphose de la Science* (Gallimard, Paris, 1986²) and R. ROSEN, *Life Itself: A Comprehensive Inquiry into the Nature, Origin, and Fabrication of Life* (Columbia University Press, New York, 1991). Besides biological phenomena, instances of self-organisation in chemistry, such as Bénard Cells, have influenced this re-evaluation.

aside trivially ‘teleomatic’ processes such as stones rolling down hills, it is widely accepted today that goal-directedness can be introduced into complex systems by the operations of programs exploiting feedback mechanisms, a simple example being the equilibrium temperature of a room produced by a thermostat linked to a heating system. A process that owes its goal-directedness to the operation of such a program is what Mayr defines as a ‘teleonomic’ process, the program being coded or prearranged information that contains, in some manner, the blueprint of the goal and instructions how to use the information of the blueprint.⁴

Despite the vast difference in complexity between biology and idealized Newtonian physics, there is no doubt that the behavior of simple, non-teleological, two-body systems has strongly influenced commitments to determinism, an understanding of time as symmetric and space-like, and the widespread use of machine metaphors to describe living things.⁵ In a parallel manner, the more recent modelling of teleonomical behaviour in simple and programmable electro-mechanical systems involving feedback has arguably permitted a cautious expansion in the variety and sophistication of end-directed phenomena that are today deemed acceptable to metaphysical naturalism generally and biology in particular. Mayr makes it clear that a paradigm for this kind of goal-directedness is genetic programming, the feedback in question being provided by the operation of natural selection.⁶

Advocates of teleonomy, including Mayr, have been cautious in adopting the word ‘teleological’ to describe such phenomena, however, partly because of the notorious ambiguity and connotations of this word, but also because it is questionable whether teleonomy can be equated to what Aristotle meant by advocating a *telos* or ‘end’

4. The term ‘teleomatic’ is from E. MAYR, *op. cit.*, 125-126. In regard to more sophisticated modes of end-directedness, the fact that complex machines can exhibit such behaviour by means of feedback mechanisms was recognised as early as the 1940s; see N. WIENER, *Cybernetics; or, Control and Communication in the Animal and the Machine* (J. Wiley, New York, 1948).

5. Newton’s role in the rise of the machine metaphor is covered in M. RUSE, *Science and Spirituality: Making Room for Faith in the Age of Science* (Cambridge University Press, Cambridge, 2010) 50-53.

6. E. MAYR, *op. cit.*, 126-130.

as the fourth foundational cause of the natural world. As Leunissen has argued, a final cause does not exert a “mysterious pull” from the future, the apparent characteristic that has often seemed bizarre and objectionable about teleology.⁷ Nevertheless, for Aristotle, a final cause is still distinct and irreducible, the key question being, in Gotthelf’s influential interpretation,

“Is the development of a living organism the result of a sum of actualizations of element-potentials, or is it primarily the actualization of a single potential for an organism of that form, a potential the actualization of which involves the actualization of element-potentials, but is not reducible to them?”⁸

In simplified terms, the first part of this question could be re-phrased as, “Is a thing the sum of its parts?” provided the word ‘part’ is understood to refer to a element, the behaviour of which can be fully characterized within the organism the same way as it would be in isolation or in another organism. In the case of programmable electro-mechanical systems, the answer would appear to be ‘yes,’ insofar as the behaviour of each transistor, step of a program, cog or pulley would be the same if embedded in a different system or no system at all, and the behaviour of the whole is the sum of these behaviors. If any end-directed systems exist for which the answer is ‘no,’ then there is a further, irreducible cause of the whole, and it is this that is properly called a ‘nature’ or ‘final cause’ in the Aristotelian sense.⁹

How do so-called ‘chaotic’ systems fit into this picture? Based on a serendipitous discovery involving models of complex weather systems, equations capable of generating chaos have also turned out

7. M. LEUNISSEN, *Explanation and Teleology in Aristotle’s Science of Nature* (Cambridge University Press, Cambridge, 2010) 220.

8. A. GOTTHELF, *Aristotle’s Conception of Final Causality*, “The Review of Metaphysics” 30/2 (1976) 235.

9. On the limitations of naïve reductionism in characterizing the behaviour of ‘things within things,’ see also B. LONERGAN, *The Collected Works of Bernard Lonergan: Insight: a Study of Human Understanding: 003*, ed. by F. E. CROWE and R. M. DORAN (University of Toronto Press, Toronto, 1992, 5th rev. ed.) 283-284.

to be surprisingly simple, just as teleonomic feedback systems can be surprisingly simple. Moreover, as is well known, chaotic systems also exhibit end-directed behaviour. Although errors in setting initial conditions inflate exponentially, a characteristic that inspired the name ‘chaos,’ points in the phase space of a chaotic system can also converge on, and subsequently remain in, the general vicinity of a specific region called a ‘strange attractor.’ This attractor is not a point, however, as in the case of a representation of a stone coming to rest at the base of a hill, but has the peculiar characteristic of being a fractal. How should this end-directed behaviour be classified? Clearly, the system is not what Mayr would call teleomatic, but is it reductively teleonomic or irreducibly teleological? To address this question, it is first necessary to review briefly how chaotic systems are currently understood and the challenge of finding an adequate classification of their behaviour.

2. THE PROBLEM WITH POINTS

The invention of the computer enabled the simulation of the time-evolution of complex systems without algebraic integrals by means of numerical integration. By such means, Edward Lorenz first explored the unusual properties of what are now known as the ‘Lorenz equations.’¹⁰ For the system defined by these equations, repeated numerical integration from any starting point in the three-dimensional phase space produces a trajectory that moves towards and then remains in the vicinity of two interconnected regions, a characteristic shape known as the ‘Lorenz butterfly’ (Figure 1):

10. E. LORENZ, *Deterministic Nonperiodic Flow*, “Journal of the Atmospheric Sciences” 20 (1963) 130-141. As a paradigm and pioneering example of a chaotic system, this paper takes as its model the kind of chaotic system exemplified by the famous Lorenz equations describing a simplified model of convection, although many other chaotic systems are known today. For a general and accessible account of the development of chaos theory, see J. GLEICK, *Chaos: Making a New Science* (Vintage, London, 1998).

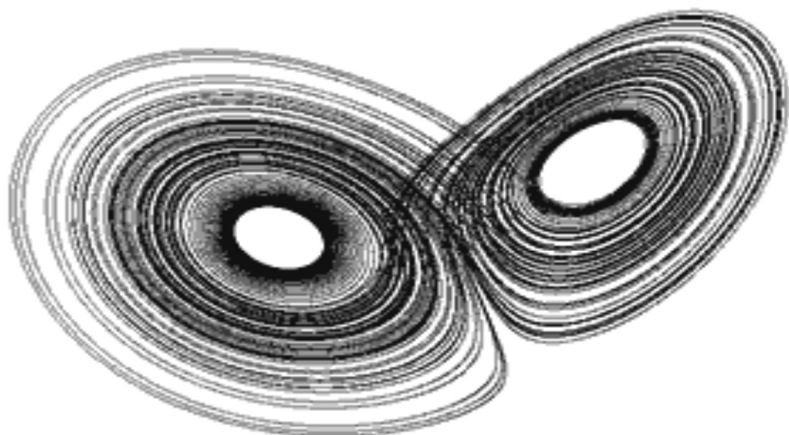


Figure 1

A plot of the Lorenz 'butterfly' showing how trajectories in the phase space group together in the general vicinity of the two wings of the strange attractor

Since all trajectories in the phase space gravitate towards the butterfly, this is called an 'attractor,' a term borrowed from a similar phenomenon in classical mechanics. For example, a pendulum dissipating energy will spiral, in a phase space defined as position versus velocity, towards a central point of rest, the attractor of the system.¹¹ The Lorenz butterfly, however, is not the result of dissipation of energy and, although occupying a fairly well-defined area of a phase space, does not have a precise and analytically definable boundary like the point attractors, limit cycles, and torii of classical systems.

These peculiar characteristics have led such attractors to be called *strange attractors*, but chaotic systems are so-called for another reason, namely that any change in the starting point of the temporal evolution of the system in the phase space, no matter how small, inflates exponentially. To give a dramatic example proposed by Peter Smith, suppose that two identical computers using pre-

11. J. POLKINGHORNE, *The Metaphysics of Divine Action*, in R. RUSSELL, N. MURPHY, and A. PEACOCKE (eds.), *Chaos and Complexity: Scientific Perspectives on Divine Action* (University of Notre Dame Press, Indiana, 1996²) 153, points out that "the infinitely variable paths of exploration of this strange attractor are not discriminated from each other by difference of energy." The attractors of chaotic systems are not the outcome of energy dissipation, unlike classical attractors.

cisely the same algorithm, start with points that almost exactly identical in the phase space within a small error difference Δx . Suppose also that both computers always calculate that the point is on the same wing of the Lorenz ‘butterfly’ up to time T but then diverge. By how much should the difference Δx be reduced to ensure that both computers produce the same result after $100T$? The answer is an extraordinary forty orders of magnitude, roughly equivalent to shrinking the entire distance from Earth to the edge of the observable universe down to the size of a proton.¹² For all practical purposes, there is a breakdown of all predictive power with respect to even the smallest change in input conditions.

The task of clarifying precisely what is meant by ‘chaos’ in this context has not proved easy, however, and there is even a lack of agreement over whether such systems are philosophically significant, beyond offering extraordinary challenges to calculation. The early tendency to define such behaviors simply on the basis of their lack of predictability proved inadequate for a reason that Smith has highlighted, namely that lack of predictability with respect to small changes in the initial conditions can also be found in classical and perfectly integrable systems.¹³ By Batterman’s criterion, “No adequate definition of chaos for classical dynamical systems can allow an integrable classical system to be chaotic,” unpredictability therefore fails as a definition.¹⁴ Moreover, although terms like ‘unpredictability’ and ‘chaos’ suggest that these systems generate epistemic disorder, this description fails to capture what is arguably the most intriguing aspect of these systems, namely that any starting point of a trajectory in the phase space will end up somewhere in the vicinity of the strange attractor, even though it rapidly becomes impossible to predict precisely where in this vicinity a particular

12. P. SMITH, *Explaining Chaos* (Cambridge University Press, Cambridge, 1998) 54-55.

13. P. SMITH, *op. cit.*, 58. Smith gives a very simple example of how unpredictability is insufficient for defining chaos: a particle travelling on a straight line whose position at time t is given as $x_0(1 + t)$. Even this simple linear relation will eventually inflate any finite precision in the initial conditions past any finite measure of success in the predictability of the system.

14. R. BATTERMAN, *Defining Chaos*, “Philosophy of Science” 60/1 (1993) 62.

point will be found at a given time.¹⁵ Hence, it is possible to consider chaotic systems as generating rather than destroying order, insofar as a random scattering of initial points in the phase space will end up being in a more ordered rather than less ordered state as they converge on the attractor.

This peculiarity raises the question of the perspective from which chaotic systems have generally been studied. Descriptions of such systems invariably begin by presenting the following model: a point moving in a phase space.¹⁶ This choice of model is not accidental, being in the Newtonian tradition of representing everything that is important about the dynamics of an extended moving body, such as a molecule or a planet in orbit, in terms of a single point, the centre of mass. Such a point is, of course, a mathematical abstraction, and a problematic way of representing any material object given that points, by definition, lack volume or internal structure. Indeed, points even need to ‘borrow’ space from other things, such as dots and ink marks that are not dimensionless, to be represented visibly on paper or computer screens.¹⁷ Nevertheless, the abstraction is successful in Newtonian mechanics because the relation of the extended object to the centre of mass is maintained over time, or changes only in ways that are unimportant to the dynamics under consideration. A material object can be treated therefore as a mathematical point-mass, and the position, momentum and the forces acting on this point-mass in space at a particular time enables these parameters to be calculated at future times, unifying disparate phenomena and providing testable predictions of the position of the extended object itself.

Chaotic systems, however, do not respond well to this treatment. As has been seen, the reliability with which the position of a point can be predicted quickly degenerates, but there are also more

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15. For claims of randomness or apparent randomness being the standard characteristics of chaotic systems, see, for example, M. TABOR, *Chaos and Integrability in Nonlinear Dynamics: An Introduction* (Wiley-Blackwell, Hoboken (NJ), 1989) 34, and S. RASBAND, *Chaotic Dynamics of Nonlinear Systems* (Wiley-Interscience, Hoboken (NJ), 1997), 1.
 16. R. RUSSELL, N. MURPHY, and A. PEACOCKE, *op. cit.*, 15.
 17. See R. TALLIS, *On Points*, “Philosophy Now” (London, Dec. 2011).

subtle philosophical problems with using points to represent these systems. First, an abstract point can no longer be an adequate and unproblematic substitute for representing any extended material object since any extended object, no matter how small, will have spatial dimensions that are magnified exponentially to the extent that the object ends up stretched and folded around the general vicinity of the attractor. Second, a key characteristic of these systems is the strange attractor, the shape of which gradually takes on visible form by means of the trajectories plotted on a computer screen. Although the trajectory of a point migrates towards the general vicinity of the attractor, it never reaches a stationary position or an orbit represented by some well-behaved analytic function. Indeed, no monadic point, or a set of points described by some well-behaved analytic function, could ever represent the strange attractor adequately, since this is a fractal. So there is an apparent distinction of kind, and not merely of degree of precision, between the way in which the system is usually characterized, namely the trajectory of a point, and the kind of thing that constitutes its end. The philosophical problems with points, which can be safely set aside in Newtonian mechanics, cannot be evaded in the chaotic case.

3. CHAOTIC SYSTEMS AS NEO-ARISTOTELIAN ENGINES

Although there has been renewed interest in Aristotelian causation in recent decades, and the range of acceptable end-directed phenomena within a naturalistic framework has expanded, it is uncommon to find the end-directed behaviour of the type of chaos studied in mechanics expressed or evaluated in explicitly Aristotelian terms.¹⁸ The essential insight to the nature of the process involved in chaos can be seen in an influential early article,

18. As an example, the following excellent overview of many aspects of the philosophy of chaotic systems does not mention the possibility that they might be characterized in terms of Aristotelian causation: R. BISHOP, *Chaos*, in E. N. ZALTA (ed.) *The Stanford Encyclopedia of Philosophy* (Fall 2009, accessed May 4, 2013, <http://plato.stanford.edu/archives/fall2009/entries/chaos/>).

“The stretching and folding operation of a chaotic attractor systematically removes the initial information and replaces it with new information: the stretch makes small-scale uncertainties larger, the fold brings widely separated trajectories together and erases large-scale information. Thus chaotic attractors act as a kind of pump bringing microscopic fluctuations up to a macroscopic expression. In this light it is clear that no exact solution, no short cut to tell the future, can exist. After a brief time interval the uncertainty specified by the initial measurement covers the entire attractor and all predictive power is lost: there is simply no causal connection between past and future.”¹⁹

The key issue here is that the operation of a chaotic attractor is described as systematically removing initial information and replacing it with new information, but what is the initial information? If treated in terms of the projected future position of a monadic point in space, the classical Newtonian approach for centre of mass dynamics, then it is true that this information is quickly lost, as the authors claim.

Consider, however, what happens if the initial information of the system is not that of a monadic point, but some structure delineating a region of the phase space. Table 1 below shows examples of initial shapes demarcated by a configuration of points and then how these shapes are changed if each point of each structure is transformed by the operation of the Lorenz equations:

Example initial states



Settled state

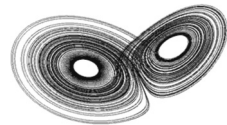


Table 1

Examples of initial configurations of a system of points demarcating a region of the phase space and how these configurations are transformed by the Lorenz equations.

19. J. P. CHRUTCHFIELD, J. D. FARMER, N. H. PACKARD, and R. S. SHAW, Chaos, “Scientific American” 254/12 (Dec. 1986) 46-57.

With these examples, what is clear is that *any* extended object demarcated by a set of points of the phase space, configured in any form whatsoever, will be transformed into the wings of the Lorenz attractor. Indeed, the last example of an initial configuration shown in Table 1, intended to represent a random set of points, is also transformed into the Lorenz attractor. What is striking in this instance is relative order *increases* rather than decreases, bringing order out of chaos rather than vice versa.²⁰

Considered from the perspective of extended objects, it is clear that this initial information is removed systematically and replaced with new information, but the claim that all predictive power is lost is incorrect, as noted previously, since the attractor infallibly emerges no matter how many times the process is repeated and whatever the initial structure. Moreover, it is not true that there is “no causal connection between past and future,” as suggested in the passage above. Each point within or on the boundary of the initial extended object will eventually map onto *some* point in the general vicinity of the attractor. Although points are dimensionless, if the standard heuristic is adopted of labelling a subset of initial points within the initial object and their corresponding final points with tiny identical dots and ink marks that are not dimensionless, the overall volume of dots or ink used will be conserved between the initial and final states. If the number of labelled points is halved at the beginning, half as many will be present at some future time, although the strange attractor will continue to be visible as long as the marks are sufficient to demarcate the general trajectories of the orbits. The shape is only rendered invisible in the limiting Newtonian case, when the system is modelled as a single point in the phase space at the start of the process and a single point without a visible trail at future times.

This conservation suggests some principle of continuity, therefore, between initial and final states, but this continuity has the peculiar characteristic that an answer cannot be given to the question of

20. The phrase “order out of chaos” also forms the title of Ilya Prigogine’s book, presenting a positive re-assessment of Aristotelian thinking in the light of new developments, especially in biology and chemistry: I. PRIGOGINE, *Order Out of Chaos: Man’s New Dialogue with Nature* (William Heinemann Ltd., London, 1984).

what this principle is, if an answer is required in the customary manner of mathematical objects, such as a numerical value, a position in space, or a some determinate geometric form. As Gianfranco Basti has proposed, one heuristic for thinking of this principle is as a volume of space bounded by some limit, such that the limit and the volume that it encloses are conceptually separated, but there is a subtlety.²¹ In the case of a well-defined geometric object, all that is required to answer the question of what the object is can be obtained from the formal definition of the object; for example, a cube in a mathematical space can be defined simply as a symmetrical three-dimensional shape contained by six equal squares, and nothing more needs to be said. The need to distinguish a further principle only arises when the initial form is eliminated and replaced with a new form, but there is some underlying continuity, heuristically understood and imagined as a volume of space, but not a *particular* bounded volume since all such particularity is formal. Such a principle appears to correspond closely to how Aristotle describes *hyl* ('matter'), namely as that which is in itself "neither a particular thing nor of a certain quantity nor assigned to any other of the categories by which being is determined," but which is known by means of the continuity through the generation and corruption of particular, determinate beings.²²

If this correspondence is correct, then chaotic systems exhibit something akin to hylomorphism, with 'matter' being the principle of continuity between transformed states. With this identification, it also becomes possible to assign various elements of such systems to the fourfold causes. The final cause (also equated with what Aristotle calls the formal cause in the case of biological systems) is the strange attractor; the efficient cause is the process by which the attractor is generated and the matter is the principle of continuity between the initial and final states, imagined heuristically as a

21. G. BASTI, *Filosofia Della Natura e Della Scienza*, vol. I (Lateran University Press, Rome, 2002) 328-329.

22. Aristotle, *Metaph.* VII, 3, 1029a20-21. The translation is that of Sir David ROSS in J. BARNES, ed. *Complete Works of Aristotle: The Revised Oxford Translation* (Princeton University Press, Princeton, 1984) 1625. In *Metaph.* IX, 8, 1050a15, Aristotle adds that matter exists in potential state to receive a form, and in *Physics* II, 3, 194b23-24 he describes this cause as that out of which a thing comes to be. In all these cases, matter is highlighted as a distinct principle by reference to substantial change.

volume but lacking a formal definition, by definition. Having established this conceptual framework, it is then also possible to adapt Gotthelf's criterion for Aristotelian teleology. In the case of biology, the crucial issue was whether the development of a living organism is the result of a sum of actualizations of element-potentials, or primarily the actualization of a single potential for an organism of that form. The question might be adapted for the chaotic system in mechanics as follows. Is the final form the 'sum,' that is, some formal relationship, of the initial form of the system? To put this question another way, is a description of the final state of the system formally reducible, at least in principle, to the initial state, as is the case with Newtonian mechanics acting on idealized point-masses? The answer appears to be 'no' for at least two reasons. First, the initial form is systematically broken down by the action that generates the attractor, an action described in the citation above as a "pump bringing microscopic fluctuations up to a macroscopic expression," the action of this pump magnifying uncertainties and overwhelming predictability. Second, the particular initial form seems irrelevant, as noted previously, since any shape or configuration of points generates (or appears to generate) the same outcome regardless of the starting configuration. The only contribution the initial form makes to the final form is the 'matter,' namely the principle of continuity that remains under formal change.

There are some possible challenges to these claims, however. First, it may be that the apparent loss of the initial form of the matter is an illusion, so that the information is severely scrambled in the attractor but still available, at least in principle. If this were the case, then the final state could be calculated, at least in principle, from the initial state and the forces described by the Lorenz equations. In response, the Lorenz system has been studied extensively and mathematicians have concluded that there are no analytic solutions for the domain in which the strange attractor is generated.²³ Hence it is not possible to express the final state as some finite set of terms of the initial state.

23. See, for example J. LLIBRE and CLÀUDIA VALLS, *Formal and Analytic Integrability of the Lorenz System*, "J. Phys. A: Math. Gen." 38 (2005) 2681-2686.

Nevertheless, the very fact that a computer can generate a representation of the strange attractor based on the initial state and the Lorenz equations might appear to raise a counter-challenge. A computer generates a final state by means of rule-based calculations, and the very fact that the computer *can* generate the final form by a long series of calculations based on the initial conditions suggests that it is possible to overcome the apparent irreducibility. Moreover, a question might be also raised about the fact that although the initial state information in a computer simulation is broken down quickly by the spreading and sensitive dependence of the Lorenz equations, it does not appear to be lost immediately. If reducibility appears possible over small time-slices, why should it suddenly become impossible when the time interval is increased? In a continuous process, why should the metaphysics change simply because of the length of time over which the process operates?

To respond to these challenges it is necessary to consider briefly what is meant by the kind of numerical integration that computers perform in calculating the action of the Lorenz equations. Methods such as the Runge-Kutta algorithm do not solve differential equations but generate an approximate value for the state of the system at time $T + \Delta T$ based on the state at time T assuming that the differential part of the equation can be treated as invariant across this small interval ΔT . At the end of the time interval a new value of the differential part is calculated and this new value is similarly approximated as constant over the next small interval. There are many refinements to such algorithms to improve precision, but the essential fact remains that the computers do not 'solve' the equations over any time interval, no matter how small. All they do is plot an approximate trajectory through a series of stepwise iterations using an approximation of the equations that is amenable to calculation. By increasing computer power it is possible to achieve arbitrarily closer approaches to the solution by decreasing the time slice. Nevertheless, there is never true reducibility since there is always an 'aetiological gap.' No matter how small the time slice ΔT , the state of the system at time $T + \Delta T$ cannot be reduced by some finite analytical equation to the state of the system at T since the true equations, as opposed to their approximations, are just as irreducible over small time slices as over large ones. So whether

considered theoretically or in terms of the practical realizations of chaotic systems in computer systems, what is generated is only ever an approximation.

Moreover, the aetiological gap between what is amenable to calculable by numerical techniques and that which is being approximated in each step of the calculation is also characteristic of the final form itself. Although the trajectories of points converge towards and remain in the vicinity of a general region of the phase space, forming a discernible shape on a computer screen, this shape has the peculiar characteristic of being a fractal, lacking a definite boundary. All that any simulation will do is to delineate gradually the approximate region of the attractor, but the attractor itself cannot be fully characterized by any finite, formal mathematical description. For this reason also, therefore, the final cause cannot be reduced to the other causes of the system. Hence by the criterion of irreducibility, the chaotic system is properly characterized not merely as teleonomical, but teleological, the operation of which can be likened to an neo-Aristotelian pump or engine for breaking down and systematical replacing any information that is present initially by a final form.

4. CONCLUSIONS AND IMPLICATIONS

The Aristotelian metaphysics of chaotic systems ought not to be unexpected, given that the work required to assess the nature of causation in such systems has been available for decades, but the implications of this work are surprisingly unfamiliar to philosophers at the present time. Some of this oversight may be due to a lingering distaste for what Francis Bacon described as the 'defilement' of philosophy by final causation, combined with an insufficient appreciation of the kinds of end-directed action that are possible without immediate intervention by a purposeful agent.²⁴ Another explanation may be simply due to the well-known challenge of hyper-specialization, erecting barriers to the free exchange of ideas between,

24. F. BACON, *The New Organon, or True Directions Concerning the Interpretation of Nature*, trans. J. SPEDDING, R. ELLIS, and D. HEATH, *The Works of Francis Bacon Vol. 8* (Longmans, Green, Reader, and Dyer, London, 1857) Aphorism XLVIII.

for instance, experts in mathematical complexity and ancient philosophy. In this paper, I have suggested a further explanation, namely that the chaotic systems have usually been studied and even named from a perspective conditioned by Newtonian thinking: the trajectories of point-masses in an absolute space. From this perspective, their dominant characteristic is a rapid erosion of reliable prediction, the behavior with which the term ‘chaos’ was originally associated. If, however, the study of these systems is considered in terms of changes to extended objects, with aspects that can be mapped to notions of matter and form, then an Aristotelian reading of these systems becomes apparent, and the need to acknowledge an irreducible final cause becomes clear. From this perspective, the remarkable property of the evolution of these systems towards a final state is not that they destroy order, but that they bring order out of chaos, or change one kind of order into another.

The implications of this reading are not the ones that might be anticipated. The final cause, or at least a representation of the final cause sufficient to delineate its general shape, is generated consistently from the numerical integration of a particular set of equations in a phase space. Since the delineation of the attractor is generated from the operation of other causes, there is nothing in this reading of chaos that lends support to the influential but erroneous interpretation of Aristotelianism as advocating a ‘mysterious pull’ from the future. Unlike in the idealized Newtonian case of the trajectory of a point mass in a two-body system, however, the chaotic system has a genuine ‘end,’ a final cause that is actualized by the operation of the system as an Aristotelian engine, but is not reducible mathematically to its initial state.²⁵ As has often been remarked, chaotic systems do

25. The ‘three-body problem’ in mechanics is another manifestation of the inability to express a future state as a mathematical function of a present state in chaotic systems. Apart from a few special cases or solutions expressed as convergent series of infinite terms, there are no integrals that are algebraic with respect to time, position and velocity for a system of N mutually interacting bodies where $N > 2$. An accessible summary of the challenge of the N -body problem is F. DIACU, *The Solution of the N -body Problem*, “The Mathematical Intelligencer” 18/3 (1996) 66-70; see also J. BARROW-GREEN, *Poincaré and the Three Body Problem*, illustrated ed. (American Mathematical Society, Providence (RI), 1997). From this perspective, Newtonian systems capable of algebraic solution are seen as a small subset of physical systems generally, and wider metaphysical conclusions drawn from their behavior should be treated with caution.

not, therefore, undermine determinism directly, although the fact that the whole is not the sum of the parts in these models raises the possibility that natural systems may also exhibit causal behaviour that is more than the sum of their parts. Such systems, however, do break the Newtonian symmetry of past and future, re-introducing an arrow of time corralled previously within such esoteric domains of human reason such as the study of entropy, exotic particle physics and common sense.²⁶ More subtly, chaotic systems can also be said to “unfreeze time,” insofar as a future state is not merely a mathematical function of a present state, a characteristic of Newtonian physics that has a tendency to turn time into space.²⁷ Such behavior does require, however, a principle of continuity between initial and final states, a principle that is not formal but corresponds to the Aristotelian notion of matter. Hence matter matters.

Over the longer term, this account of what is largely known but not widely understood about chaos may help to challenge the persistent belief that teleological descriptions of nature are merely convenient metaphors or that much of what is labelled as teleology is in fact reducible to teleonomy. Much of what has given this narrative cultural power, not only in philosophy but also in theology, in the humanities generally and the broader culture, is the belief expressed by the litany that biology is reducible to chemistry and chemistry is reducible to physics. Since physics has long been assumed to be Newtonian or some non-teleological variant, processes of nature have therefore also been assumed to be non-teleological, whatever their complex manifestations. The value of chaotic systems in mechanics is that they have been simple enough to study exhaustively and challenge this assumption. Although these mathematical models are idealizations of nature, they show that the Newtonian idealizations are no longer the only story. Even if the unimaginable

26. The idea that chaotic systems break the temporal symmetry of Newtonian physics has been explored in P. COVENEY and R. HIGHFIELD, *The Arrow of Time: A Voyage through Science to Solve Time's Greatest Mystery* (Allen, London, 1990).

27. The need to find a way to “unfreeze time,” to represent time without turning it into space, is one of the problems of contemporary physics highlighted by L. SMOLIN, *The Trouble with Physics: The Rise of String Theory, The Fall of a Science and What Comes Next* (Penguin, London/New York, 2008) 257.

complexity of the world is reducible to simple mechanics in principle, that mechanics no longer excludes teleology.²⁸

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