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# ARISTOTLE, COMPLEXITY, AND ECOSYSTEMS: A SPECULATIVE JOURNEY

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## ABSTRACT

Aristotle provided a means for understanding natural systems in terms of four kinds of causes. Modern science has focused on the first two of these, material and efficient, roughly corresponding to the Newtonian view of objects in space (material) and processes (efficient). The laws governing transformations in this view are not themselves considered to be part of realized nature, but part of a Platonic realm analysis. Complexity can be understood in a deep sense with regard to Aristotle's original causal structure, re-admitting the second two causes, formal and final, which were eliminated from mechanistic science to make it computationally simple (Rosen, 1991). While scientists hoped in vein for several Centuries that nature itself would turn out to be computationally simple, that now appears to not be the case. Life, psychological choice, quantum phenomena, and the origin of the universe each raises questions of causal origins, which cannot logically be addressed from the mechanistic viewpoint. An understanding of formal and final cause is therefore needed to understand what is life and living. This is most apparent in regard to emerging interests in ecosystem complexity, necessitated by issues of ecosystem management that have been intractable from purely mechanistic frameworks. Ideas of deep complexity may be extended to understand ecosystem complexity in terms of natural information, including feedback of scientific information through management.

Keywords: complexity, complex systems, mechanistic science, philosophy, epistemology

## LIFE AND ARISTOTLE'S FOUR CAUSES

Imagine for a moment that we are in ancient Greece thinking of the meaning of life for the first time in terms of Aristotle's four kinds of natural causation: material, efficient, formal, and final cause. These causes can be easily understood by the example of a meal. The material cause for example breakfast, would be the ingredients (things). The efficient cause would be the cooking (process). The formal cause would be the recipe (design). And the final cause would be one's hunger and desire to eat (purpose).

From a personal standpoint, we can hardly suggest that any of these causes don't exist. What has been suggested is that the last two causes are reducible to the first two. That is what constitutes the mechanistic worldview. For the purposes of this journey, let's suspend that assumption. Instead, let's assume that all four of Aristotle's causes can affect natural systems in their own unique way, and that all four are required for a complete description of a natural system.

It appears to us that the designs and purposes we are aware of as experiential beings exist within the system (i.e., our own system, where we experience them), not external to it. However, it also seems that these designs and purposes can (or must) be related to larger designs and purposes for them to have meaning. For example, survival strategies of organisms are meaningful and therefore derived only in relation to the larger environment and its functional regime. Furthermore, it appears to us that our designs and purposes, however developed, exist in a way that can have causal effects on our actions and thus our surroundings. Finally, we must recognize that according causal effect to thoughts, purposes, and decisions is the basic criteria for according them reality, alongside the reality traditionally accorded to material states and processes.

Formal and final causes (design and purpose) add something to our understanding of a living system. To an external observer these qualities produce behavioral uncertainty. Such uncertainty is becoming well-known in ecosystem science and management, although there is little theory about the cause. Yet we know of this kind of uncertainty from trying to predict other people's (or other species') behavior. To the one producing these causes, they are experienced as plans and goals, involving some kind of self-model. Applying this principle to other organisms may seem unwarranted, but recall that most recent scientists judge this question with a strong bias and training in the physical/mechanical world-view. Considering functional causation is just a different starting assumption that is more appropriate for living systems and allows us to consider them as a continuous phenomena, from man to microbe. The better argument can actually be made for assuming the higher Aristotelian causes in living systems, than not (Ulanowicz, 1990). Living systems share the physically-unlikely characteristic that they are self-generative, recording their own definition and using it to produce subsequent generations. They need only be endowed with the ability to perceive that record as information – i.e., to construct a formal encoding of what self and environment mean – to then have the raw ingredients for purposeful behavior. It is clear that many animals have this ability, because they employ it in ways we can understand, the more obvious examples (to us) being those with a close phylogenetic association with man (e.g. in decreasing order: apes, mammals, and some birds). How many more taxa exhibit this ability in ways we cannot understand do to our greater genetic distance? At the very least, the skeptic would have to propose a taxonomic boundary for experience, or perceptual awareness, whereas it appears more likely to be on a continuum.

Hence, certainly if humans are an integral part of ecosystems, and to an even greater extent as we admit other organisms to the endowment of designs and purposes (i.e., both adaptive and innovative life strategies), we necessarily arrive at a situation in ecology where we must consider all four of Aristotle's causes.

In essence, this can be understood as building and responding to internal organismic models. Part of that model might be experienced reflexively, as we know man is capable of, or perhaps in many cases not, to any significant degree. Yet, the modeling relation itself, whether extended to the level of conscious thought or not, introduces complex goal-setting behavior in any case, through an information processing function that is semi-independent of physical structure and oriented toward defining the organism's function. In this way, a "causally effective end result," which is the traditional definition of final cause, is approximated by a model of anticipated ends.

## NEWTON'S WORLD

The classical physical worldview deals only with material and efficient causes (things and law-bound processes). In Newton's physical concept (generally regarded as the foundation of mechanistic science), there was no actual recipe for nature, other than the passive aggregation of repeatable processes involving materials. A recipe would imply a design, and so perhaps a designer, so the world we inherited from Newton (apparently against some of his own preferences – see Ulanowicz, 1997) was constructed from the bottom up – from matter and the laws of dynamics. It is a meal where the ingredients are cooked automatically. This is the traditional physical reductionism that, despite earlier challenges in thermodynamics, was the main belief about reality in modern science until quantum uncertainty became generally accepted. These kinds of systems do not exhibit uncertainty, except in our ability to measure or reproduce them; that is, experimental error. Aristotle's reason for that would be clear: they do not contain any independently operating formal or final causes.

In these efforts at reduction, the one thing science became most certain about was that it must dispense with final cause (purpose), to avoid dealing with any god-like powers. This was done by reducing everything to materials and their dynamics; but the cost of this trick was to create a bottom-up explanation of everything, where parts can produce (or explain) larger systems, but those systems of themselves can have no causal (or explanatory) effect on the parts. As a consequence, however, this allowed science to focus almost exclusively on the study of mechanisms, thus launching a technological revolution. Believing this to be the foundation of reality, scientists applied mechanistic interpretations to everything, including ecosystems and people.

Biological discoveries, particularly DNA, reintroduced the problem of a recipe, that is, formal cause. However, that was dismissed on the basis that DNA evolved by passive selection of more primitive material. By allowing only error to affect replication and selection, one could imagine that evolution might still be accounted for by material and efficient causes. But in any case, with less concern about religious separation, it was eventually shown in mathematics (in Goedel's incompleteness theorem) and in quantum-physical science that explanations reduced in this way are incomplete pictures of reality, which otherwise involves the powers of observation (information processing) as a necessity in determining physical states. This fundamental result, if applied across disciplines, should finally eliminate the bad habit of physical reduction in explanations of life (Ulanowicz, 1999; Kineman and Kineman, 1999). Carl Popper, to whom much of the philosophy of science owes rent, identified the mechanical as a degenerate limit of a more general contingent nature (Ulanowicz, 2003, personal communication).

## UNCERTAINTY AND CERTAINTY

A classical (i.e., physically mechanical) explanation can always be applied to systems when viewing them from the outside, if one labels the formal and final causes as law and uncertainty, respectively, and if one also excludes considerations where either may itself be affected by natural processes. Regardless of how law and uncertainty arise, as long as uncertainty does not exceed experimental error and laws are considered absolute, a classical explanation will seem valid. Only if we are very precise, or the uncertainties are large, will we see non-classical behavior, as with quantum particles. We should also see it when we consider the origin of laws, as we do in the Anthropic Principle, origin of the Universe, organismic life strategies, ecosystem functions, politics, and economics. But externalizing true origins from science prevents one from studying them. This fact explains why ecology and evolution are not well integrated: In faithful Newtonian tradition, Darwin took pains to place natural selection external to his dynamics, thus excluding it from direct study. Those who tried to consider the boundary problem, such as Baldwin (a staunch Darwinist), were largely ignored for 100 years. On the other hand ecology traditionally internalizes original processes by recognizing the role of organismic behavior and life strategies; thus improving understanding but causing all but the bravest ecologists to apologize for using non-mechanistic language.

Yet we must apply non-classical thinking to living organisms, because regardless of how we might explain it, or however the phenomenon may scale, living organisms seem to have the ability to preserve and use uncertainty (and, consequently, information): Humans are the obvious case. The principle for recognition is simple: when uncertainty cannot be attributed to observational error, one is not dealing with an entirely classical system. Explanations then become progressively worse approximations of reality as one attempts to explain or predict longer sequences of events from deterministic causes. Further knowledge then requires one to study the constraining or defining contexts (the larger system, life history, behavioral goals, ontological processes, etc.). In ecosystems, that context is provided by the patterns and processes established over time by the system itself. In this sense, each living system establishes its own operational reality. Knowing the trajectory of specific states of a system therefore requires knowledge of that system reality. Disturbance, for example, can not only change the trajectories, it can also increase uncertainty by destroying the laws that constitute the system reality, which is what normally constrains its behavior to known modes. The result is a system transition to different and perhaps new behavioral laws: Life is famous for its ability to change the rules.[1]

[1] For those who are disturbed by this interpretation of the term "law," be assured that it does not preclude the possibility of reduction to less system-specific laws as in the case of well-known physical mechanisms. The discussion of life, however, must for the moment refer to instrumental laws because physical reduction does not work for explanations of living behavior. There is a philosophical question, however, as to

One can also deduce from this explanation that it is possible for a complex system, at times, to behave almost like a classical one. There is no requirement that functionally driven systems that can write their own laws must always diverge from classical behavior just because they have the ability to do so. It is possible, for example, for ecosystems to develop and reinforce deterministic behavior through positive feedbacks. Just as a young child can imitate a robot, or in rare circumstances behave according to a parent's set of rules; an ecosystem can operate in very predictable ways – for awhile. Ultimately, however, change may allow the inherent causes of surprise and innovation to emerge from where they exist fundamentally in living system components.

## GOD-LIKE POWERS OR MACHINES?

We personally experience formal and final causes, and thus accord them reality, albeit a private reality. That is why Aristotle originally included them. Even Descartes, in laying the foundation for experimental science, said that our inner experience is the only thing of which we can be certain, all else being subject to doubt and uncertainty. There is a great deal one can learn about mechanisms, and consequently there was tremendous success in the physical sciences of attributing formal and final causes to material and efficient causes. But that success story did not get rid of the need for these causes elsewhere. There is an important failure, for example, in explaining the existence of blueprints in terms of paper, ink, and uncertainty, rather than ideas and ambitions. Epistemological exclusion merely forces these causes to appear outside one's model of reality – as an external creator, designer, or creation event. The restriction was largely for this purpose; to place the consideration of god-like powers -- which was the exclusive right of the Christian Church -- outside science, so that scientists would be safe from persecution. But what was lost in doing this was the ability to formulate theoretical origins from within the system. This precluded the idea of systems that design or create themselves, as biological systems seem to do, but made it tremendously fruitful to study systems that don't, that is, machines.

To correct that problem, we must put formal and final cause back into science. We can think of formal cause as a model, and final cause as an anticipatory model, or model with a vision of the future and even a goal. This "closes" systems to their own causes, and thus eliminates the need for an external source; something the mechanical view cannot do by itself. Robert Rosen (1985) proposed a "modeling relation," between natural systems and information about them. If this relationship is taken as a natural phenomenon, rather than just a model of perception (or science), it provides a way to close systems to their causes, and suggests that something analogous to a model exists within all living systems. The strange and unpredictable behavior of living systems is primarily explained by the idea that they are driven by their own information model (a formal system), and secondarily that they can correct that model to correspond to a larger functional context (encoding and decoding relations with the environment). It is perhaps easiest to imagine this in the

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whether ultimately all laws are instrumental, the physical ones being rooted in perception itself, and thus always with us.

case of an animal that is responding not to its environment, but to its model of its environment (and self), which it builds from interactions and through development, and then employs to anticipate the future. This, of course, is what scientists and managers try to do, so we know the process exists in natural, living systems (which they are).[2]

## INFORMATION AS FORMAL CAUSE

Since models exist in the realm of information, one can also think of the uncertainty of complex systems as arising from its response to internal information. Certainly this can be visualized in the case of how systems in general respond, through generations, to the information stored in DNA, which itself was produced by the preceding system. In both organisms and ecosystems there are other forms of information storage besides DNA. Learned behaviors constitute ecological information because they have a causal effect on what organisms do. At the ecosystem level, the patterns and processes established by biotic relationships constituting the ecosystem historically, is also a form of ecological information or memory (Peterson, 2002) stored in the ecosystem structure (its organization or pattern). That information is “read” by members of the system, which adapt accordingly, contributing their influence on patterns to those of the whole. This, of course, implies some level of operative capacity for dealing with the abstract reality of information as information. Rosen calls this a capacity for “abstraction.”

We can speculate accordingly that evolutionary pathways would be the result of all three kinds of information – genetic, developmental, and systemic – affecting the natural selection of organisms through their overall functional fit within the ecosystem (Kineman, 2002). In this view, the functional model is not required to be entirely reducible to DNA. It can include information learned through development or memory in each generation, or stored in the ecosystem’s self-created structure, and yet all of these forms of information would have causal effects on evolution. A very similar idea was first proposed by James Mark Baldwin (1902) in terms of the role of developmental abilities in altering selection and thus shaping evolution.

The self-construction and natural selection of organismic functions and their cumulative interactions that shape ecosystem functions, might be analogous to elements of computer programming, if we include an analogy with programmers (modelers), to represent abstraction and anticipation functions, which operate to ensure that subroutines have a functional fit in the whole. The modeling process itself confers uncertainty to the system, which facilitates evolution and confounds prediction. Each interacting part is able, through modeling, to adapt in ecological time to changes in the other parts, and over evolutionary time to convert cumulative modeling errors into innovation. Remove one

[2] To what extent formal and final causation are restricted to human or similar species, or where the species boundary actually is, or if there is one, is, of course, a legitimate question. However, it is not right to assume the existence of such a boundary as an epistemological requirement as was argued for Centuries. The proper assumption, or null hypothesis, is the fundamental similarity of living systems in regard to their ability to incorporate self-causation, which is a logical basis for introducing formal and final causes. It is that similarity which would require disproof, not the mechanistic assumption, which itself eliminates the possibility of disproof and merely outlines an overly limited field of explanation.

sub-routine and the effect on the overall program is hard to guess: the response of concurrent mutual adaptations is obviously non-linear. The system may not be significantly changed because of compensation by the other components, or it may cause a crisis. Change enough of the sub-routines and a program crashes irretrievably, as when a seriously disturbed ecosystem flips to an entirely different operational mode (Kay et al. 1999; Scheffer et al. 2001). Programmers also know that, after a while, fixing old code can become ineffective. Similarly, ecosystem response to change is dependent on how the system developed, that is, the system history as much as present circumstances. Disturb it slowly, however, and it most likely can rewrite its own code. This is the self-organizing, complex, adaptive nature of living systems.

## HUMAN VALUES AND ECOLOGICAL ECONOMICS

We know that in the human case, motives, values, and intentions are involved in the internal functional model to which the human organism actually responds. By analogy (between self-organizing systems) and the fact of observing non-classical behavior, one may presume the existence of functional models in other organisms, regardless of how different from human models they may be. Because organisms and physical systems are tightly coupled in ecosystems, it follows that they respond to an aggregate set of values and purposes in addition to physical mechanisms. Because humans and natural ecosystems are becoming tightly coupled (the process Ulanowicz quantifies as an increase in "ascendency"), it is possible to know many of these functions through human experience. This is, in fact, the assumption of ecological economics -- that natural ecosystems can be managed in terms of ecological goods and services to mankind (Costanza et al. 1997). This assumption is valid only if it is possible for human values, through intuition and empathy, to reflect ecosystemic ones that are shared by other organisms. Once again we rely on the commonalities of living systems, and the belief that the human organism is in some way more inclusive that most others – but these are grand assumptions. There is no test that can determine if such intuitions are correct, or to ensure that human values reflect natural ones, except by practicing them and experiencing the result. Nevertheless, the existence of natural functions in a causal relationship should not be doubted merely because they cannot be directly observed. They are implicit realities based on observation of non-classical system behaviors that are consistent with a relational model of structure and function that appears to be fundamental to living systems in general. The question is whether we have gotten them right, not whether or not they exist. Hence the ultimate success of goods and services assessment lies in the likelihood that by including a wide enough range of human values and intuitions, the natural set will have been approximated. It thus becomes very important both scientifically and socially in ecosystem management to incorporate the greatest diversity of interested parties – the stakeholders – in the design of management plans.

## EASY AS PHYSICS

This story is actually consistent with the kind of change that has become necessary in modern physics, with the exception that physics is not primarily concerned with the source of uncertainty in nature, except for those who speculate about "quantum realities." It is otherwise only concerned with the patterns and processes that have become universally established, and that consequently constrain the allowable states of new events. These are the physical "laws." Physics, in this sense, studies nature from the perspective of a universal or collective observer, which constitutes the functional model we all create together and share in common because of our reliance on sensory perception of an external world (Kineman and Kineman, 2000). That constitutes the general "frame of reference" of physics, which then appears to us to be universal.

The similarity between the constraints of modern physics and the opportunities for living systems is not broadly admitted because complexity is not well understood in either discipline. But in the one discipline complexity causes the exception, and in the other it forms the rule. Misunderstanding of this relationship is common, and perhaps even popular, but it need not stop science. For example, Richard Feynman was famous for the statement that "nobody understands quantum mechanics," which he said after a lifetime of achievement in the field. Similarly, at the beginning of his quantum discoveries Einstein supposedly said: "For the rest of my life I will reflect on what light is;" and near the end of his life he said, "Anyone who claims to understand light is fooling himself." (Zajonc, 2002). Somehow this sort of naïve wonder and playfulness with one's own theoretical constructs is allowed in the rigorous and "hard" science of physics, but ridiculed in the "soft" sciences that must deal more directly with complex systems. Maybe this is why Ulanowicz (1997) suggested that it is time to ease up on the softer sciences and let them breathe – they are actually tackling a more difficult problem than the nature of light and quantum phenomena, and it is no wonder that some theoretical tools are yet missing. Finding them will require us to return to a more complete picture of nature, regardless of what inconveniences need to be revisited

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