SCIENCE OF A LIVING UNIVERSE
(REFLECTIONS ON THE GAIA WORLDVIEW)

Dr. John J. Kineman, Ph.D.
Cooperative Institute for Research in the Environmental Sciences
University of Colorado, Boulder, USA
Kineman@colorado.edu

ABSTRACT

According to R-theory, a new meta-theory of whole systems based on the work of mathematical biologist Robert Rosen, the "Gaia hypothesis" may be better understood as a holistic worldview than a mechanistic hypothesis. The new perspective on nature provides a framework for studying closed systems, which has already yielded a definition of life itself, four organizational types of life, and sustainability as a systemic property of causal closure typical of organisms. These results raise the possibility of "Systemic Gaia", the possibility of ecosystem sustainability and autevolution (influence of a system on its own evolution). This paper asks if the Earth as a whole can be modeled as a self-sustaining and self-evolving system. R-theory's concept of causal closure in modeling relations ('holons'), as a meta-model of natural organization, may be the key to answering such questions. Extension of this model to the global level addresses many of the criticisms on both sides of the Gaia debate. Rather than challenging the dominant mechanistic understanding of nature, it preserves that established territory and gives it a relational foundation capable of adding new factors of organization. With such new factors, the theory addresses many concerns that led to spiritual or theological speculations such as "intelligent design" and pre-destination, instead placing creative process inside natural systems rather than forcing external origins. Consequently, the theory supports causal explanations for stasis and punctuated novelty (punctuated evolution), apparent gaps and emergence in the evolutionary record that would be of concern from a gradualist perspective, and the impression of end-directed evolutionary processes (teleology) as implied by Gaia. Modeling relations are claimed to be a fundamental law of nature involving cyclical causality that had been known since Vedic times, but re-interpreted, for example by Aristotle, as a hierarchy of causes. A cycle of these four causes naturally requires that form and function co-evolve, as do mind and body, as unified dual aspects of holistic self-defining systems. The theory supports convergence of Western and Eastern science within a Vedic ontology of "cosmic order" (*Rta*).

FOREWORD

30 years ago, James Lovelock's Gaia hypothesis was the subject of an AGU Chapman Conference in San Diego, California, in which I presented a paper ("Gaia: Hypothesis or Worldview?") claiming that Gaia should be treated as a new worldview, not a hypothesis subject to mechanistic criteria. Since then, I have developed "R-theory" as a comprehensive view of "whole" systems in Robert Rosen's relational complexity. We can now address the question if the global Earth system, Gaia, shows signs of such wholeness that is typical of organisms. Despite legitimate skepticism, this does not land us in exclusively psychological territory. The *debate should not be if nature is completely mindful or completely mindless, like two political parties vying for power: Nature operates, as we do, somewhere in the middle. This question is important because the "machine metaphor" of nature continues to threaten the wellbeing of complex life that cannot be characterized as a mechanism, and thus is undervalued and largely misunderstood in science, with dire consequences for society and life on Earth. We have no definition in science for a system, thus nothing that demarcates the boundary between mentality and machinery. For the same reason we have no definition in science for life, which involves both in whole relation. Accordingly we have no definition in science for 'sustainability' as an ability of systems to sustain themselves: sustainability has instead been defined as a policy with narrow objectives. Traditional scientists dismissed systemic sustainability and autevolutionary feedback (as I propose to re-label "strong Gaia", defined in the conference) because mechansitic epistemology does not have the formal capacity to evaluate it. This is a worldview problem. The conventional view of existence was framed so narrowly as to preclude systemic research. That is, system science was imagined as a summing of material feedback mechanisms, not properly as a question about systemic principles of organization of those mechanisms. Therefore, I saw the more valid approach to be a discussion of systemic foundations of life and its reflective influence on evolution; that leading to natural causes of ecosystem sustainability. From that perspective it may be possible to evaluate ideas of global or even universal organization, whereas otherwise we are left to squabble between narrow scientific views and equally narrow religious views, with no resolution in sight.*

Dr. John J. Kineman

INTRODUCTION

Ideas of interconnectedness and harmony in nature, implicating a "top-down" causal order (from system to component), have existed since early recorded times (Visvader 1991). Such ideas were represented in the concept of Gaia, metaphorically treating the Earth system as an organism, orchestrating balancing feedbacks in the ecology and evolution of the biosphere (Abram 1987, 1991, 1996). Even modern notions of Gaia are only metaphorically defined, and are therefore difficult to analyse scientifically (Kirchner 1991). Yet the major difficulty stems from a narrow interpretation of science as a study of mechanical processes, a tradition established in the 17th Century by Descartes' "machine metaphor", now applied inappropriately to biological systems (Goldsmith 1990; Rosen 1993a; Marques 2014).

The first Chapman conference on the "Gaia hypothesis" (Schneider & Boston 1992) segregated discussion into *'weak Gaia'* and *'strong Gaia'*, referring to the degree of supposed influence of biota on the environment at microscopic to global levels. The degree of influence that has been variously proposed has included, on the one hand, the "influential", "stabilizing", and "co-evolutionary" taxonomies proposed by Kirchner; and on the other hand, various super-organism and self-generation concepts.

In the 30 years since that conference, various theories have been proposed for systemic control on the part of the biosphere as a whole (Hsu 2001), as well as theories such as "autopoiesis" (Maturana & Varela 1980), "niche construction" (Odling-Smee 1988; Day, Laland & Odling-

Smee 2003; Odling-Smee, Laland & Feldman 2003), and niche 'affordances' (Withagen & Wermeskerken 2010) that establish the idea of ecological and evolutionary potentials in nature. All of these proposals represent some degree of reflexive system control, although without a clear ontology. The modernist science community continues to look for unity in mechanistic foundations, whereas that foundation is inadequate for issues involving life because it expunges causalities directly representing information and existence itself, aspects that are incontrovertibly entailed in life (Kineman & Poli 2014).

"Niche construction" is a process whereby life may alter the physical environment in ways that meet its needs, as for example; beavers build dams that provide food and shelter. It has also led to the idea of "ecological inheritance" when organisms construct developmental environments for their offspring, or modify environmental states that will be experienced by other descendants. Such modifications alter natural selection in ways to sustain a particular life form (Laland, Matthews & Feldman 2016). The idea is not new. 37 years after Darwin published "On the Origin of Species" James Mark Baldwin, working in developmental psychology, proposed that learning should be considered a "new factor" in Darwinian evolution (Baldwin 1896). Baldwin noted the potential contribution of learning to evolutionary process by means of delaying negative effects of natural selection ("*the creature is kept alive*"). He called this process "*organic selection*" involving "*the functions which an organism performs in the course of his life history*" (ontogeny), including "physico-genetic", "neuro-genetic", and "psycho-genetic" modifications (Baldwin 1896). Regarding physical heredity (phylogeny) Baldwin wrote:

> *"Weismann admits the inadequacy of the principle of natural selection, as operative on rival organisms, to explain variations when they are wanted or, as he puts it, 'the right variations in the right place' (Mionist, Jan.,1896) ... the assumption of determinate variations of function in ontogenesis, under the principle of neurogenetic and psychogenetic adaptation, does away with the need of appealing to the Lamarkian factor. In the case, e.g., of instincts, if we do not assume consciousness, then natural selection is inadequate; but if we do assume consciousness, then the inheritance of' acquired characters is unnecessary."* (Baldwin 1896)

The implications of niche construction are similar, although in modern times we are strangely less willing to admit to consciousness or choice as a factor. The picture is quite different if choice is included than if it is eliminated. Niche construction has been defined thus (emphasis added):

> *"Niche construction is the process whereby organisms, through their activities and <u>choices</u>, modify their own and each other's niches."* (Laland, Matthews & Feldman 2016)

These ideas argue strongly for the evolutionary significance of "ecological memory", in which case it would be difficult to argue against organismic memory and learning as Baldwin proposed.

Accordingly, the 'weak/strong' taxonomy originally proposed by Kirchner can be replaced by a more appropriate distinction between "*Mechanistic Gaia*" and "*Systemic*" or even "*Anticipatory*"

Gaia", reflecting more closely the terms "mechanical and organic" introduced by David Abram (Abram 1996). As Abram described rather eloquently, this division is essentially that between the modernist 'clockwork' universe of simple systems, and a view of reality comprising complex systems with system-level causes. Kirchner's three-part taxonomy, which characterizes the mainstream view of Gaia, remains within the clockwork universe and machine metaphor, even considering its co-evolutionary mechanisms. This paper will summarize work since the original Chapman Conference developing R-theory as a more comprehensive theory of nature. Because of its clearly revolutionary nature it is also necessary to include a discussion about the epistemology of science, by way of helping the reader to accept that such an expanded view of natural causality can indeed replace our current view and count as legitimate science. That is done in the Appendix to this paper.

A NEW FRAMEWORK

Mechanistic Gaia is a class of theories that attempt to explain living phenomena – at any level – in terms of physical dynamics and even uncertainties in physical dynamics. For this reason it is not really about a living planet, but about the physical correlates of a living planet and mysteries where such correlates cannot be found. These are described in terms of two kinds of causality (using terms attributed to Aristotle's philosophy) – 'material' and 'efficient' (which are perhaps better known as state and dynamics). Within those boundaries we cannot discuss life itself as a systemic essence; we can only discuss the particular operation of a system, whereas the argument here is that complex systems entail both particular *operation* and contextual *origin*. Both are required to discuss systemic organization. The same problem was encountered in quantum theory suggesting a common systemic cause that has been overlooked in simplifying science to mechanisms. We will see that the problem may be addressed by restoring the systemic (contextual) causalities of (a) origin of function, which is 'final cause' and (b) functional (or parametric) boundaries on mechanisms, which is 'formal cause'; these 'higher' systemic causes being related to the world of efficient and material causes by information processes that are not strictly speaking causal; they are category relations ("*functors*") that map complete processes as formal images rather than causally entailing specific elements within a category. Archetypically, causality then falls into four kinds establishing two formally inverse categories, one representing physical events and the other representing implicate models of events, perhaps as in Bohm's "*Implicate Order*". These categories can be taken to represent observational and experiential worlds – traditionally the mind-body problem. This core understanding of nature has recurred throughout the ages but was unfortunately (or perhaps necessarily) forgotten in Western developments as we focused on the workings of the material world. Aristotle discussed these four '*aitions*' (Greek word for 'happening' as in our English word ending '*-tion*') which had been known in the Far East several millennia earlier (Kineman 2017); but he interpreted them as existing in a hierarchy from divine to mundane; whereas in ancient Vedic times, and as re-discovered in R-theory, they were understood as a causal cycle.[1]

[1] The Rig Veda refers to this as "Rta" or "Rtam", commonly translated as "cosmic order".

Here we apply "R-theory" (Kineman 2011a; b) based on a synthesis of causal models of life proposed by the mathematical biologist Robert Rosen (Rosen 1985, 1991b, 1999). R-theory restores an understanding of whole systems in natural science in terms of closed causal cycles; that is, four cause cycles that constitute a whole (with transcendent system identity or perhaps 'self'). The theory gives us a causal definition of life and sustainability (Kineman 2018) that can be applied to many questions of our time, including Gaia. This theory allows us to consider how the internal systemic organization of systems can reduce to mechanisms, or complexify as living systems, thus implying a new ontology that places causally complex systems rather than mechanisms at the foundation of nature (Figure 1). We thus have a mathematically sound way to expand the scope of natural science to evaluate living and self-governing systems.

In contrast, the kinds of feedback controls in Kirchner's taxonomy, which came to characterize the critique of Gaia, do not cross the boundary to a new worldview. Thus, even "co-evolutionary" Gaia is already too limited a framework (causally 'impoverished' in a mathematical sense) to evaluate Gaia. This is not to say that important questions do not exist or should not be addressed in terms of mechanisms. The kinds of propositions that can be made at that level include, for example, the hypothesis that land or cloud cover tends to have a regulating effect on global climate (e.g. Lovelock's "Daisyworld" model), or that atmospheric compositions have been governed by the co-evolution of life with feedbacks in both directions, as the paleobiological evidence shows. Global change research has revealed many mechanisms that explain highly interconnected and teleconnected global phenomena. These phenomena come in two varieties: 'positive' and 'negative' feedbacks. For stability, the negative 'control' feedbacks need to dominate, but positive 'runaway' feedbacks also exist. For example, melting of the arctic tundra may release more greenhouse gases leading to more heat trapping – a positive feedback to melting. However, positive feedbacks tend to be limited in how far they can run before exhausting their resources, so the system reaches a 'new normal' from where it may return or it may stabilize in that condition. Thus considerable concern is expressed these days about "tipping points" where a positive feedback will irreversibly lead to a new dynamic system attractor. These kinds of phenomena were well described by James Kay and David Waltner-Toes regarding complex behavior of ecosystems, a prime example being the hysteresis of Lake Erie under changing levels of organic pollution. The Lake Erie ecosystem flipped from a benthic system (where clear water allows light to reach bottom dwelling organisms) to a pelagic system (where species concentrate in the water column due to less light penetration). The polluting industries thought they could simply make a minor adjustment to return it to normal, but it actually required massive reduction in pollutants to flip it back (Kay 1997; Waltner-Toews, Kay & Lister 2008). Such behaviors are obviously physical, but also co-evolutionary because ecosystems comprise many species that are needed to functionally support each other, and the aggregate *contextual cause* provided by the lake ecosystem is a strong selective pressure. Such contextual feedback is characteristic of life, and primarily responsible for sustainability.

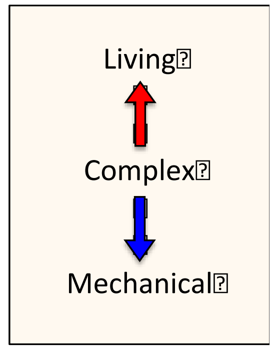

Figure 1: The New Ontology

Systemic Gaia may thus be understood as sustainability; however science has yet to define it. The question of self-directed evolution also arises from that principle of sustainability, to the extent that choices are made affecting contextual (selective) feedback. R-theory proposes a fundamental organization of cyclical causality formalized in category theory as ‘holons’.

GAIA: THE NATURE OF THE GODDESS

There is a pervasive concept implied (or stated) in the Gaia views that have emerged, that is not part of the way traditional science has been formalized, or the way traditional biology has been formalized; one in which life itself involves causes that are more than its mechanisms – what is really meant by the slogan “more than the sum of its parts”. We have only begun to define what that “more” might be. True as our current epistemology may be for ideal mechanisms, it is possible that nothing in nature is an ideal mechanism; or rather that no ideal mechanism exists alone, without important contextual conditions that produce and organize mechanisms. This is precisely the issue regarding the stronger version of Gaia – Systemic Gaia. It is not a hypothesis within mechanism. If we get this point, then it is clear that before any discussion of systemic Gaia can take place we have to propose a logic that goes beyond mechanism, and within which proposals about systemic sustainability and evolution can be tested. This has proven to be a difficult stumbling block. We must allow ourselves to ‘suspend disbelief’ (as we do in watching a play) long enough to entertain the possibility of formalizing something ‘more’.

It was suggested during the 1988 Chapman conference on Gaia, that the “Gaia hypothesis” could only be taken seriously as a metaphor. Lovelock stated metaphorically that:

> *"The entire range of living matter on Earth, from whales to viruses, from oaks to algae, could be regarded as constituting a single living entity, capable of manipulating the Earth's atmosphere to suit its overall needs and endowed with faculties and powers far beyond those of its constituent parts"* (Lovelock 2000).

But a metaphor cannot be used to construct theory, only to hint at theory. Lovelock's statement of Gaia was a metaphor, just as Darwin also said of the idea of ‘struggle for survival’ (Todes 1989; Richards 2014). Present assumptions such as “dark energy” and the big bang theory itself are primarily metaphorical. They are projections (or attractors) in present dynamical theory, which is formalized in such a way as to conform to the assumed ontology, but not in a way that is capable of describing them as a real event. From the perspective of a mechanistic worldview the big bang and dark energy are as mysterious as Gaia, and will remain so until we have a new worldview that goes beyond mechanism. It should also be clear that saying the global ecosystem somehow orchestrates its own conditions for survival has already entered us into the world of evolutionary and anticipatory systems (Rosen 1978a; b, 1985; Poli 2010, 2017); for otherwise the effects of modification, self-induced or otherwise, would be merely reactive; whereas future benefit is clearly anticipatory. It is a highly relevant question if evolutionary feedbacks in “Systemic Gaia” are anticipatory.

Evolution is now as fundamental to the way we see the universe as are space and time. According to the philosopher Peter Medawar: "*for a biologist, the alternative to thinking in evolutionary terms is not to think at all"* (Little 1980). In other words, Darwin’s “descent with modification" is well-known; it is only how that happens that is being studied. This is not the case for effects of self-organization on evolution (*autevolution*). Current models of evolution incorporate many confirmed causal processes (such as genetic variation and expression, heritability, differential survival, gene expression, etc.), but are also composed of 'null' assumptions such as genetic mutation and natural selection that define an obvious physical process without which more subtle proposals of reflexive causal influences on evolution would be meaningless. Thus in explaining the geologic record of species, evolution is assumed; but the precise ways by which species have changed are a manner of empirical study. By expanding beyond the mechanistic worldview we do not abandon it, but introduce more subtle causes that may explain some major anomalies in what might otherwise be restricted to very lengthy gradual change without directive systemic influences. Certainly when we arrive at the human case we are no longer talking about purely mechanistic and statistical processes as we consciously plan for the future. Thus we are faced with either developing a self-consistent theory across all life, or having two theories, one for humans and another for everything else.

Classical reality was shattered in the past Century and nothing has yet been successful in replacing it, although we now formalize models to account for uncertainty. Science has intensively explored the idea that nature might incorporate fundamental randomness, while minority voices including Einstein and Schrodinger, insisted that it could not; that we simply have not yet discovered the larger theory that would explain the appearance of uncertainty. While many are eager to claim that the battle for realism has been lost, it may only be that we continue to view nature through a very special lens, and also fashion science according to that same lens. But we should not continue unnecessary epistemological debates at the expanse of exploring the causes of sustainability in a scientific context. We know that definitions of sustainability to date are inadequate. They were in any case policy statements, not scientific statements, and at that they only described a parasitic goal for humans. Arguably even a bacterium, in establishing the mitochondria of Eukaryotic cells, has already done better simply in the course of natural order (Kineman & Poli 2014).

"*Systemic Gaia*" can be broken down into three levels: *ecosystemic sustainability*, defined as the ability of a system to sustain itself; *autogenic sustainability*, as the ability of a living system to create or enhance its own sustainability; and *autevolution*, defined as the ability of a sustainable system to affect its own evolution. Probably the later are implied by the former but it is best for now to treat them as a matter of degree. Autevolution would have two aspects: evolution of the "self" (whether that is experiential, perceptual, or implicit) and the role of this "self" in affecting the course of evolution; both being implicit aspects of systemic sustainability, and thus logical extensions of R-theory's model for life and sustainable systems that anticipate their own selection (as humans do). Thus R-theory deals with life as a creative causal process, both in ecology and evolution. We may assume that there is a difference between expression of these qualities in ecosystems versus organisms; and whereas sustainability in organismic life has been described (Kineman 2018), the goal here is to consider the theoretical possibility of such qualities at the ecosystems level. The critical missing piece at this point is a framework in which such questions can be asked.

Regarding that framework, relational holon theory, R-theory in particular, may provide a mathematical foundation. Like Gaia, the concept of autopoiesis is very similar in that it looks at nature in terms of self-generating systems and closed loops of causation (Maturana & Varela 1980; Mingers 1994; Margulis & Sagan 2000; Luisi 2003; Schatten & Bača 2010; Luhmann & Baecker 2018). Reportedly, the Gaia hypothesis and autopoiesis were introduced at the same time, in 1974 (Clarke 2012). Rosen's causal closure in M-R Systems was introduced 16 years earlier (Rosen 1958a; b; c) and yet these three ideas continued to develop independently(Rosen 1958b)(43). R-theory tries to show the mathematics that may underlie, and thus prove, the legitimacy of all such concepts; also prevalent in 2nd-order Cybernetics. We must remember of course, as Rosen also emphasized, more than mathematical possibility is required to realize such closed causalities as actual life forms or ecosystems in nature. The empirical details do matter, but one must first have a theoretical framework where those details can be brought into a logical schema, otherwise they are simply impossible to consider. Recursive causation appears to be that framework, but it is very hard for scientists trained to think in terms of mechanisms to make the necessary shift to this view. Gregory Bateson apparently remarked, in a conversation with Stewart Brand about the millennial implications of cybernetics:

> *"We didn't realize then (at least I didn't realize it, though McCulloch may have) that the whole of logic would have to be reconstructed for recursiveness".*
> (Bateson quoted by Brand 1976, pg. 33, cited in Clarke 2012)

It is clear that such a change is needed. Clarke, speaking of modern times, goes on to say:

> *"All of our systems are in turmoil, and so are the theoretical bases by which we try to understand how these systems operate. Taken together, the systems concepts of autopoiesis and Gaia epitomize a shift in the aims of scientific rationality, from instrumental control without due regard for environmental ramifications, to the observation and integrated coordination of system/environment relations...The autopoiesis of the planet links life, mind, society, and biosphere, even in their systemic differentiations, in a way that treats the world with a common mode of operation-in-context. Second-order systems theory thus creates a conceptual framework large enough to contain, and sufficiently complex to guide, the requisite thinking of ecosystematic interconnectedness thrust upon us by the literal climate crisis."* (Clarke 2012)

MODELING RELATIONS

R-theory provides the foundational notion that systemic sustainability is the result of complex but entirely natural relations responsible for building models of self and the environment; perhaps the biological answer to Hawking's "model dependent reality" (Hawking & Mlodinow 2012). 'Choice' is less escapable in biology than in physics (although difficult there as well), appearing here as a selection between such models, limited to their content and to the sophistication of the organism's interpretative ability. If we consider such a process in some way conscious, the question is still "what is it conscious of". Are we, even as humans, able to make choices we, as yet, have no model for? Clearly we cannot do so intentionally; we must somehow 'envision' the intended result. This, as argued here, is a natural instance of *final cause* and it is the key to closing the causal loop. The assertion here is that such causally closed modeling relations are embedded throughout the biological world, with material behavior as one aspect and subjective memory as another.[2] It is the relation between these that may account for experience.

In our exclusively mechanistic view of nature we have overlooked the question of what organizes dynamical systems. To dig a bit deeper into our habits of thought, let's take a commonplace thought problem. It goes unnoticed that there might be a question as to why wind blows in different ways across a landscape. Clearly it is organized, whether as a result of its own action or the environment containing mountains, valleys, heat, etc. But we take the concept of organization for granted, reducing it to forces. In a strictly material system, that works. Taking now a biological example, the physical laws governing motion apply everywhere, but we walk only along intended pathways not 'predicated' strictly on environmental causes. Our movements may look as variable as the wind, but in this case they do not reduce to external physical forces. We accept that conscious movements are constrained by intention, just as a knife cuts only what we want it to cut, if our organizational context is working normally. What justification is there for saying these two forms of organization are fundamentally different versus saying that the 'impredicative' causes in the physical case have been reduced to a mechanism? Thus mechanism is simply general predication within uniform *formal* causation, or the classical idea of "natural law". Are they different kinds of systems, or different degrees of organizational control? Thus it is possible to have a consistent theory for both if we think of the external forces also as natural models. In both cases mechanisms are organized within formal contexts, but now we allow for internal contexts that are causally isolated from the general ambiance. We see such isolation in the quantum world, certain molecular processes, catalysts, regulators, and even universal systemic parameters in the relativity of space-time. We may continue to believe that physical mechanisms are organized indirectly by other physical mechanisms, but their organization via informational contexts (models) is not reducible, either practically or in theory. Therefore it must be represented as its own causality.

To get a mathematically sound definition of life Rosen found that it was necessary to go to Category Theory, where such causality could be introduced and generalized into precise "entailments" within categories and "impredicative" relations between categories. He presented these ideas in the form of "modeling relations". Figure 2 shows Rosen's modeling relation combined with Category Theory mappings, which he also discussed. In this synthesis (Kineman 2011a; b, 2018) we can see the modeling relation's implicit and necessary self-referential nesting. In essence it is a holarchy of modeling relations that logically include each other. The diagram describes material system **X** and its complementary contextual system **X'**. The modeling relation couples these two logical categories that form a holistic system. **X**' comprises all natural models of **X** summarized at a given level of analysis. One complement is the '*efficient entailment*' on the left given by ***f*:(X, *s*)**, where ***f*** is a function that abstracts condition ***s*** from material system **X**. The other complement is the '*final entailment*' on the right given by ***s*:(X', *f*)**, where ***s*** is a state of the material system input recursively into the contextual system **X'** inducing function ***f***. **X'** may be the context **X** that generates and sustains system **X** (and as we will see later establishes its identity), or it may be another context **X'** in which the complementary system (**X, X**) has some function. For example, if (**X, X'**) identifies a human heart, **X** is the model that

[2] Perhaps a version of "dual aspect monism" (Benovsky 2015), expressed here as holon theory.

sustains the heart, whereas **X'** would be other systems in or outside the human that affect the heart or in which the heart has a function, such as pumping blood. It is owing to its extended contexts that the system will change, but owing to its self-model that it will retain its original identity. The result, therefore, of having a complex model is specific adaptation.

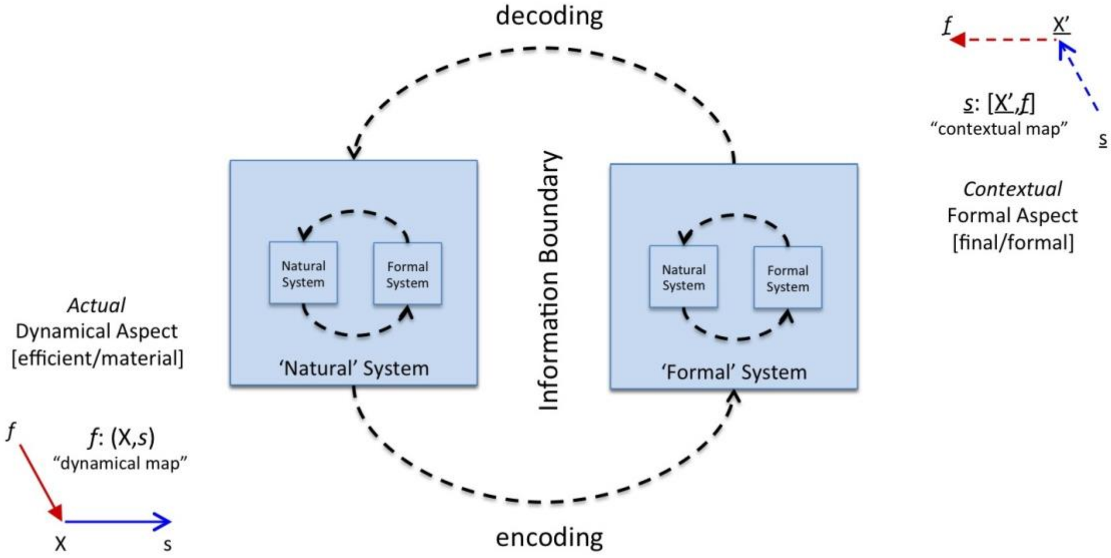

Figure 2: R-theory contextualized modeling relation

It is important to note that neither dual aspect of the system (**X, X**) explains the "information boundary" in the diagram; it is not a part of either system being related, as we would traditionally think of these systems. For example, in the mind-body relation it is what relates mind and body – a third aspect which is the impredicative relation itself (Rosen 1993b). It exists as a transcendent implication of the relation, logically within either aspect of larger systems. Information thus crosses the boundary between local ('Natural') and non-local (Formal) systems, because of context. This view of nature is one of cyclical causation as found in ancient philosophy. It is clear that the left and right entailment arrows assemble as a causally closed whole that resolves Schrodinger's question as to how states produce functions (i.e., inverse entailment) (Rosen 1999; Louie 2013).

Furthermore, because information relations (functors) are needed to link them, the 'whole' is actually self-transcendent ('holistic' rather than locally whole) in the sense that other systems participate in the causal wholeness via self-similar relations. This is a fractal reality. In fact, logically, mathematically, since those information links always transcend what they relate, it is implicit that every system in nature must be related to every other system in a universal holarchy. That clarifies many things and of course raises concerns that stymied even Einstein as he tried to wrestle with Mach's idea of universal relation (Mach 1919). It gives mathematical meaning to the often stated mantra in Ecology that "everything is connected to everything else". We now know how. Similarly it says how and why "the whole is greater than the sum of its parts", most clearly in the sense that it must involve information relations, but also in the sense that any locally whole system of this kind will involve all systems, even if weakly.

While this interpretation may seem unacceptable to many traditional thinking scientists the implications are not so bad. It is equally implied that proximal relations will be stronger because their nature is to be both self-defining and self-sustaining. In this way, even the famous 'butterfly effect' would be limited because such closed systems maintain their identity and accordingly minimize external disruptions such as a butterfly effect. Causal closure thus allows us to understand how information relations exist in nature intangibly but nevertheless would be subject to evolutionary forces within and among species as systems, as they differentially succeed to be sustainable.

LIFE ITSELF AS CAUSAL CLOSURE

In mechanistic philosophy we assume the natural models (formal cause) for dynamical behavior are already established in the classical idea of fixed natural law. But if we relax the assumption that all models are given generally, we may consider 'higher causes' associated with building system-dependent models, which is what complex and living systems characteristically do. Surely such ability would co-evolve as each organism establishes and improves modeling relations with the other. Even the measurement problem in physics (a.k.a 'observership') can be seen as complexity of modeling relations at the Planck scale. These considerations imply that nature is in part governed by control information (Corning 2001), and that life has managed to capture and enhance that ability through evolution to produce self defining models (including but not limited to genetic code). In this sense life itself is a definition of sustainability (Kineman 2018).

Rosen reasoned that life manages to enclose its own causality, and that is why it can behave in novel ways according to its own models, in variance with the dictates of general law that governs a general environment. In exploring that idea he found what he believed to be the minimum statement of causal closure required for organisms. But there was an obvious problem in communicating this finding to traditional scientists because the answer goes beyond the current mechanistic tradition. He therefore first presented this result as a paradox in the same language as traditional science (as Einstein had done in establishing his theory of relativity), mentioning only accepted efficient and material causality. He presented the diagram as a "*Metabolism-Repair*" (M-R) system, showing "closure to efficient causation", and he argued convincingly that cellular and organismic life must accomplish this closure in order to exist. But the diagram is like an Escher drawing – it is a paradox in the mechanistic world: it can't exist if the universe is mechanistic. His hope as expressed several times in his writings, was that scientists would understand and rescue science from its mechanistic prison, but he also knew from painful experience that would not happen easily or soon. We can see Rosen's diagram (Rosen 1991b) in Figure 3 with the addition of implicit evolutionary entailments with the environment that are necessary for any realization of the diagram, but not part of the internal definition of life. Arguably it is this more complete diagram that explains how the internal closure comes about, and also how it can continue to sustain itself and evolve more sophisticated internal models of self and environment.

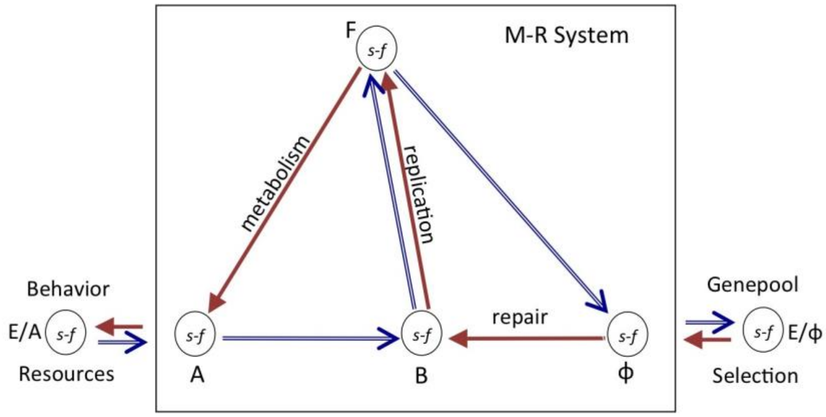

Figure 3: Rosen's M-R life extended to show evolutionary life

The way organisms accomplish this is represented in Figure 4, which applies the category mappings in Figure 2 to the efficient entailments in Figure 3 to thus include all four causes (i.e, both efficient and formal entailments of a system, brought together as a whole). It turns out there are minimally four logical possibilities for complete causal closure realizing Rosen's M-R diagram in Figure 3. These four types correspond to (and predict) the four most fundamental taxonomic domains of life, including three organism types and a component (hosted) type. The organization of these types is clearly evolutionary as phenotype and genotype, which correspond more generally to function and structure respectively, and are necessary for completion. Notice also that these types are 5th-order causal closures: in other words, the four Aristotelian causes are in cyclical order and the cycle thus forms a 5th order identity – arguably the beginnings of 'self'. As abstract diagrams they include the environment, thus summarizing all relations with other systems in nature and internal relations that may develop with more sophisticated forms. The implicit relational holarchy also makes them co-evolutionary, at least in principle.

We are now armed with a clear technical definition of sustainability, at least at the level of organisms, but implicitly any causally closed whole system. The next question is if that principle can scale up to ecosystems and global Gaia. Can a co-evolving system of organisms realize a diagram as in Figure 4? There is no logical barrier to the kind of system these generic or archetypal life types can describe. They may describe ecosystems as well as socio-economic or political systems. Thus we can use this logic to analyse if or when sustainability of a system actually occurs, be that an ecosystem, a civilization, a business enterprise, or Gaia.

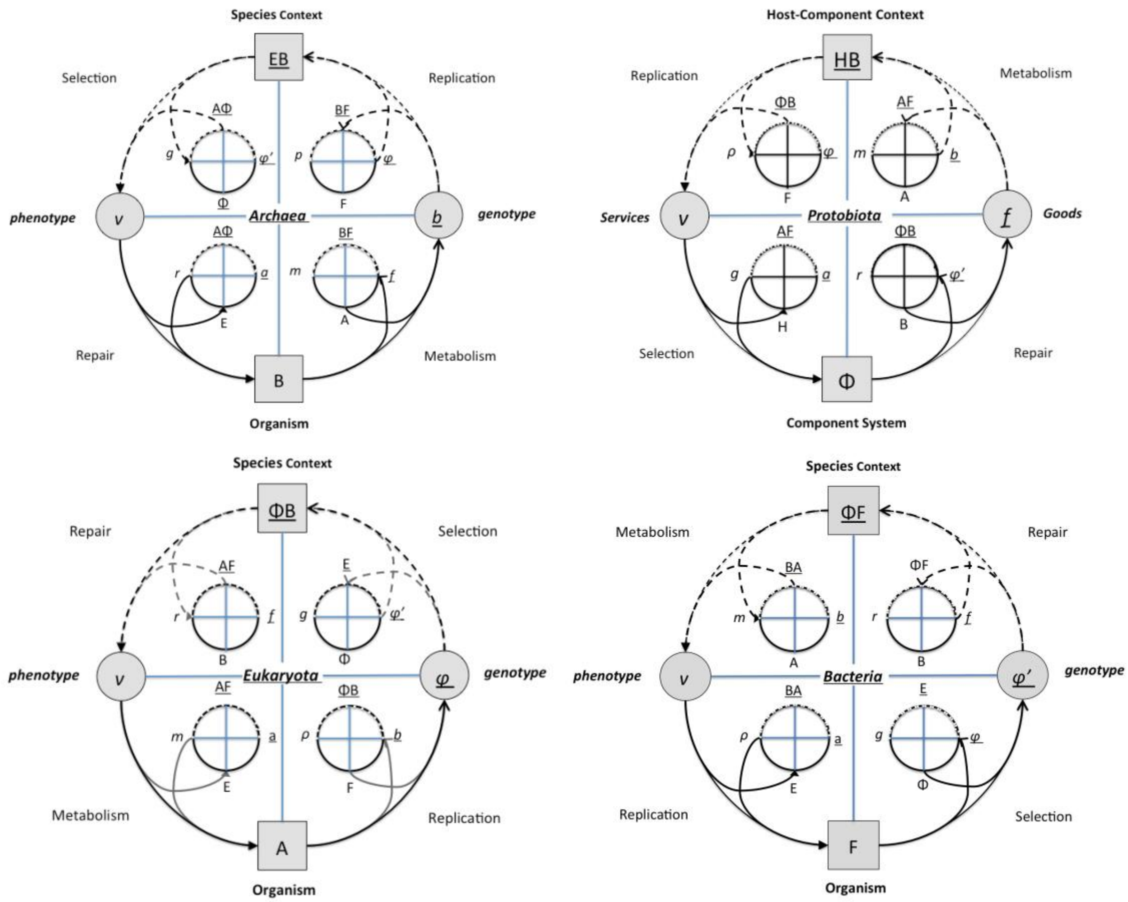

Figure 4: Causal closure defining four kinds of life

We have not specified how these types might exist in specific forms, if they require boundaries (or just lucky proximity) for the necessary functions to interact, how they can compartmentalize (easiest for the Eukaryote), or what advanced structures might be evolved by such relations to realize ever more sophisticated life. Indeed, Rosen said there are additional requirements for the "realization problem". When we specify only the functions that need to be performed we do not say how they will be performed by specific physical structures. The diagrams are logical requirements only that dos not say what would be needed if the model is to be realized. For example, it is clear that proximity of specific chemical constituents, catalysts, enzymes, etc. is necessary for the specified functions to entail each other. It is another discussion, the subject of biology and ecology, as to how that happens, but the organization diagrams can tell us certain characteristics and necessary relations that *must* be realized. For example we can infer the behavioral strategies of each type by the context from which its behavior function is generated. In this way the four types match the empirical taxonomy for metabolic strategists (*Eukaryota*), repair strategist (*Archaia*), replication strategists (*Bacteria*), and quasi-organismic types requiring a host as selective strategists, including perhaps the origin of life (*Protobiota*).

CONCLUSION

> *"The trouble with you, Rosen, is that you keep answering questions nobody wants to ask."* [3]

There is no longer doubt that a feedback loop exists between apparently purposeful behavior and selective conditions in the environment. Clearly, consciousness to the extent it is expressed by an organism factors in, but in ways we may not be able to distinguish from systemic (model dependent) feedback. An impredicative system acts in complex ways that may be interpreted as willful and self-interested; at least in ways that anticipate adaptation. If all systems in some sense posses latent consciousness and experience, we still cannot know what that experience is aside from human analogies. Still, only a process similar to mental process, i.e., involving information relations, can build anticipatory models (Poli 2017, 2018). As suggested by the holon model above, these inferred factors of learning, memory, and apparent choice are explainable in terms of cyclical causality as a form of natural intelligence pervading nature; one that always has an implicit identity; perhaps a theoretical basis for our human sense of 'self'.

Odling-Smee, citing B.C. Patten, claims that the Modern Synthesis *"leads us directly to the separation of organisms from their environments."* (Odling-Smee 1988). He further states that:

> *[the modern synthesis] "cannot model environmental changes in terms of anything at all... the synthetic theory lacks any medium of inheritance that could allow it to describe environmental changes as an integral part of the evolutionary process. Instead it is forced to assume that the environment is autonomous and that environmental change is a separate matter from changing organisms. The result is two disciplines: ecology, which handles environmental change, and evolutionary biology, which deals with changing organisms. ...Hence the Modern Synthesis has to rule out the possibility that the outputs of active organisms are capable of modifying their own subsequent inputs in evolutionarily significant ways."*

It is thus critical to Gaia and similar worldviews to formally de-couple behavior from genetic determinism by formalizing greater causality. Theories within the Gaia framework, like other macroevolution theories, may describe processes than are not dealt with adequately in current biology and geoscience traditions. Because they attempt to be holistic in their consideration of ecological and evolutionary time, and because of the critical, causal role that concepts like 'observer-participancy' may have in anticipatory evolution and thus in forming a systemic Gaia theory, greater importance should be placed on theories of perception and psychology applied to all living forms (Abram 1991), the role of behavior in directing evolution (Plotkin 1988), and epistemology that allows theory to formally include certain kinds of teleology (George & Johnson 1985; Gare 2008; Ulanowicz 2013; Holm & Powell 2013; Lane 2018).

It is fitting to end with a few salient quotes, the first from a recent Special Issue of the journal "Ecological Complexity", perhaps marking a greater entrance of these ideas into mainstream ecology. Dr. Patricia Lane, Editor of that issue, wrote:

[3] Comment to Robert Rosen by a frustrated colleague (Judith Rosen, personal communication).

> *"Traditional science has had difficulties with the notions of teleology and purpose. Rosen did not; he concluded: "Complex systems are also unlike simple ones [in that they] admit a category of final causation or anticipation, in a perfectly rigorous and non- mystical way."* (Lane 2018)

Rosen himself wrote:

> *"It should be stressed that, by advocating the 'objectivity' of complex systems, systems with non-formalizable models and hence closed loops of entailment (impredicativities), I am advocating the objectivity of at least a limited kind of final causation. This is precisely what closes the causal loops"*. (Rosen 1993b)

APPENDIX: EPISTEMOLOGY OF WORLDVIEWS

Given the controversies that have been raised and that persist in this field, it is necessary to go into epistemological matters in order to cultivate the reader's openness and to "suspend disbelief" long enough to consider another worldview without the feeling that something is being lost or violated. A different worldview is a different look at the same facts – the facts do not change; it is their interpretation and explanation that changes; hopefully in ways that lead us to new insights into nature. Assumed elements and inferences change according to the new ontological referents. But a major part of the message in this paper is that 'origin' is as important in nature as 'operation'; both as assumed of nature and as constructed in theory. New hypotheses about the relation between these essential aspects of existence are then possible.

Thus first, we have to recognize that all theories are based on founding assumptions (technically metaphysical) that are not themselves subject to experimental confirmation. Such foundations often involve circular (i.e. tautological) definitions or arbitrary views of nature that provide the starting point for formalizing theory. For example, the Euclidean geometry assumed by Newton was consistent with all tests at the time and was therefore accepted as an accurate model. The fact that it was eventually found to be inaccurate on relativistic scales does not damage Newtonian theory itself, but rather establishes the limits of its worldview – the assumed boundaries on explanation. The same was true of the Ptolemeian view that it replaced. Such definitions and underlying assumptions represent the way we choose to perceive reality, i.e. from what perspective (paradigm or worldview) we will develop theories, all of which are limited and many of which have taken dramatic turns historically. The value of theory thus cannot be judged on the testability of its foundations (assumptions and definitions), but rather on its performance as a structure for productive scientific thought (fruitfulness, or utility). It is, in contrast, individual processes or mechanisms proposed within theory (constructed within a worldview and according to its assumptions) that can be tested empirically. The empirical experience may cross-cut all worldviews, but how we perceive and describe that experience is dependent on them. For example, we can measure the strength of gravity and that will be consistent across worldviews, but what is gravity? That interpretation of what we are measuring will be different across worldviews and between theories. This distinction between assumptions and causal processes of theory is critical to evaluating new concepts such as implied by strong forms of Gaia. Mechanism does not consider origin (or rather assumes origin is not entailed in the system being studied). So, in the new view described in this paper we put origin back into science so that we could model complex phenomena such as life and self-entailed evolution, which are characterized by relations between origin and operation of a system. It is that simple, if we accept that worldviews underlie science; but of course the worldview has to make sense on many dimensions, and for that we need good criteria.

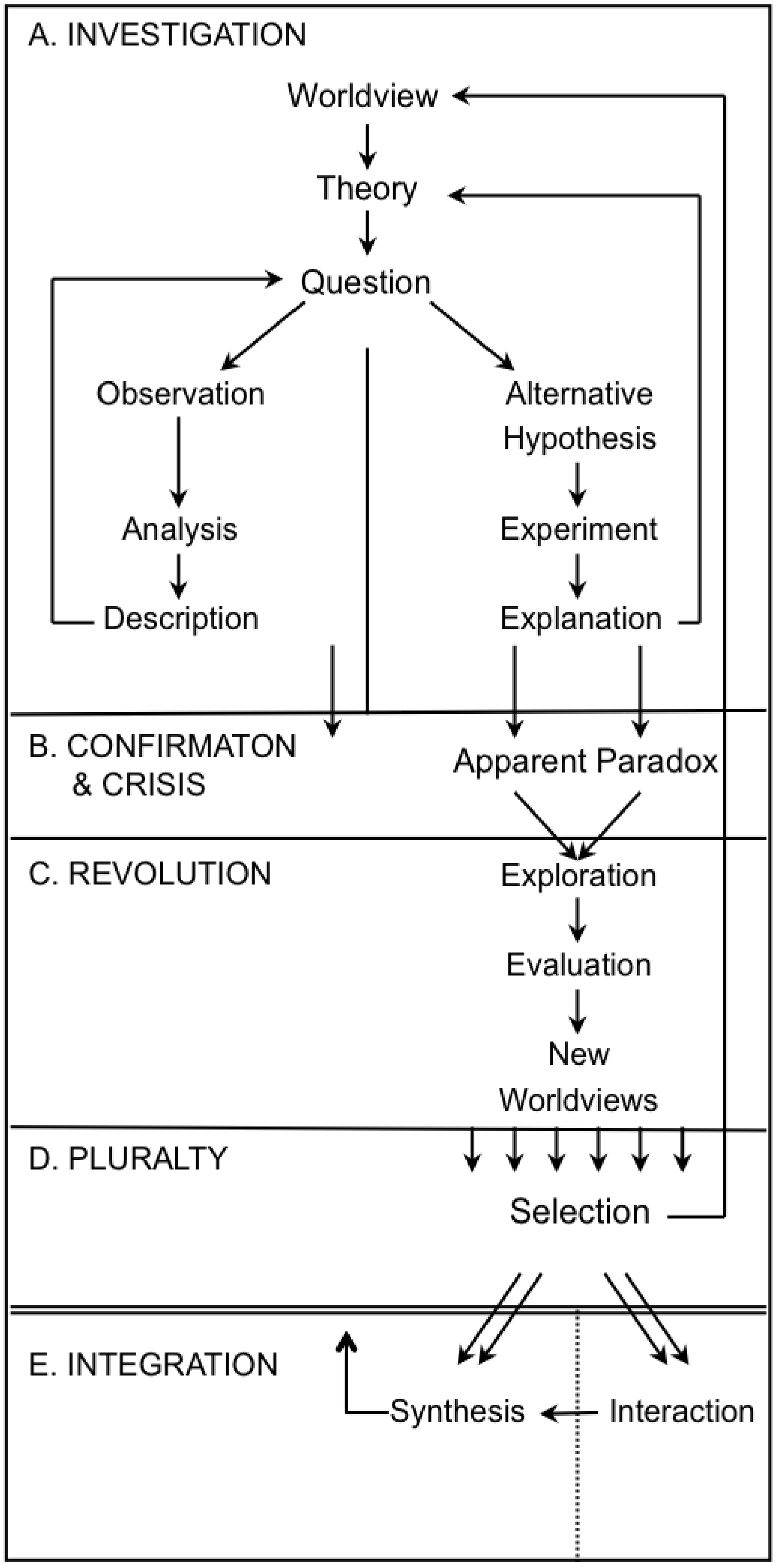

Figure 1: Epistemological Model of Science

Science itself follows closed causal loops as proposed in the paper for nature. Figure 4 shows a model for science as a closed knowledge system based on relations between theory development, transitions to new founding assumptions (in either the gradualist sense of Toulmin or the revolutionary sense of Kuhn as described by (Suppe 1977), and processes of integration. The model attempts to combine the postpositivist tradition represented by logical empiricism, the instrumentalist view of independent theories, the realist view of seeking fundamental laws of nature, and the historicist tradition, which deals with the context for science in terms of paradigms of scientific theory, or worldviews. The dominant philosophy of science has been historical realism, which "recognizes an historically shifting yet relatively theory-neutral empirical basis for theory confirmation" (Goldberg 1989). Traditional realism (i.e., Platonic as opposed to existential) maintains that there is a hidden reality "out there," and is intent on representing it from basic principles. Theory then becomes a parsimonious attempt to represent natural law. Even though it is recognized that theory is never perfect, this philosophy maintains that closer approximations to reality are always possible, and that a unique, ultimate reality exists (Rohrlich 1989). Perhaps the trend in science is now shifting to a relative or qualified realism, in which reality itself is dependent on perspective. A more radical view is pure instrumentalism, e.g., “shut up and calculate” (Montandon & Baars 2011), where reality is not an issue, only what the theory predicts that can be confirmed. Thompson, for example, argues for adopting a formal instrumentalist epistemology that accepts current (separated) ecological and evolutionary theory structures as part of a "family of interacting theories" (Thompson 1989). This "semantic" construction of theory abandons the idea of constructing theory in terms of elements with "real" meaning, and instead constructs abstract models, according reality only to what can be observed or measured. Pluralism that results from the instrumental approach may be balanced by attempts at theory integration or the development of interdisciplinary linkages. Such integration may reveal important contradictions in the foundations of theory, thus opening the way for new ideas, but there is mainly its openness that allows true exploration.

In the epistemology presented here the entire model is considered ‘real’ as an organizational view of systems. Science is a system. Thus we implicitly adopt a qualified realism here. What is most important, however, is how the various epistemic processes interrelate (including their qualified real elements) and the results they produce. The model recognizes the existence and value of instrumental theories, but views the search for ‘real’ elements of theory as a more robust pursuit entailing instrumentalism and synthesis. Realism provides a goal and means for deciding which of competing theories are ‘best’. In practice we tend to accord some reality to instrumental theories and to hold supposed realities in suspicion, so a synthesis such as presented here seems in order.

Figure 4 presents a model[4] of the growth and evolution of knowledge facilitated by the identification of theoretical crises, combining philosophies of science. The phases are: (A) scientific investigation considers theory development within established paradigms as a combination of phenomenal and causal studies. (B) Confirmation leads to crises as facts are accepted but inevitably reveal paradox. (C) Revolution in assumptions, which is expansion to a more encompassing worldview, resolves crises. (D) Multiple worldviews may remain or become

[4] Modifications of the original diagram: (1) The loop back from Phase E has been generalized; (2) The Crisis phase is changed to “Confirmation and Crisis”; (3) An arrow is added from Description to Confirmation & Crisis.

linked, integrated, or unified. (E) The whole of the knowledge enterprise may exist as separate but potentially interacting theories, which may or may not seek unification.

Phase A depicts normal science as a relation between description and the search for explanations based on strong or weak forms of logical empiricism (hypothetico-deductive or strong inference methodology). In practice description and explanation may inform each other through the various loops shown. On the one extreme, the essence of logical empiricism (Popper 1959, 1965) can be described as disproof of reasonable alternatives (hypotheses) in relation to observation and existing knowledge (i.e., which must necessarily be used when designing experiments and interpreting data). Within the established paradigm, new ideas that are contradicted by experiment (or prior knowledge) are rejected, and those that cannot be rejected (or as some philosophers argue, are confirmed) are added to the body of knowledge, which thus grows by accumulating consistent concepts. This quest for theory that is logically self-consistent and consistent with both observation and experiment is shown as the operating procedure of Phase A, or daily routine of science.

Yet philosophers have discovered the impossibility of defining an absolute set of knowledge. Historicism therefore recognizes that a body of knowledge that is built upon previous learning must be relative to a particular set of assumptions. These assumptions form a worldview that is defined by historical scientific development, cultural influences, and current philosophy. Furthermore, as described by (Kuhn 1970) and his followers, there have repeatedly been scientific revolutions. This is also shown in Figure 1, where the emphasis on empirical and theoretical studies in the primary cycle (phase A) leads to paradigm shifts in phase C. In this view, theory growth can become punctuated when contradictions in theory are seen as representing a philosophical and scientific crisis. This assumes, of course, a strong epistemological motivation to resolve apparent paradox, as is most prevalent in the concept of realism described here. Whereas apparent paradoxes are crisis within the old theoretical context (phase A), they are also the fuel for new worldviews (phase C). This combines philosophical traditions into a simple model of "punctuated equilibrium," between stable and transitory phases where opposite criteria are employed in the testing or selection process in these two phases. The epistemology in phase A operates on the assumption that two alternative explanations cannot both be correct. Phase C, however, operates on the assumption that two apparently paradoxical elements of theory that have otherwise been confirmed must both be correct.

Empirical methods of science thus operate within established thought structures (i.e. paradigms and worldviews), testing well-posed hypotheses to build a theory, but not testing the structure itself. As an example, empirical science does not test the idea of force directly: Under appropriate circumstances, it is equally valid to view gravity as a force or as an artifact of curved space, and the merits of each view depends on how they are formalized. Empirical testing is concerned with how forces act (e.g. $f = ma$) or interrelate (e.g. the equivalence of acceleration and gravitational force). The paradigm itself is judged first on its necessity to resolve a paradox, then if it can be formalized, then on its parsimony, consistency, and generality, and finally on its ability to spawn new, testable theory applicable to new phenomena. Therefore, the means for evaluating the foundations of theory (ontology in a realist mode) are different from the means for testing hypotheses about elements and predictions of the theory. The first is synthetic and judged indirectly by its ability to construct good theory; the later is selective and judged on its agreement with observation. Both are essential components of science, but confusion between these two levels of thought is common.

This view of science and knowledge construction suggests analogy with the organism type diagrams in the main paper. If we think of phase E as representing the social environment in which scientific knowledge is used, then Phases A, B, C, and D are analogous to the cyclical causes, Repair, Metabolism, Replication, and Selection, respectively. In this analogy the normal enterprise of science is repairing the main functional unit (confirmed theory, which can also enter crisis), which is replicated and encoded as knowledge and subject to selection through use in society. As there are four ways of realizing the living system closure (aligning the causal cycle with the quadrants), there are four analogous ways of doing science (recalling from the paper that the efficient cause quadrant is what strategic behavior anticipates, and thus the quadrant that characterizes the life type). Labeling the four quadrants according to a Participatory Action Research (PAR) cycle for clarity (Edson, Henning & Sankaran 2016), we can assign the phases as follows to identify four kinds of science:

PAR Cycle	**Exploratory**	**Utilitarian**	**Consensual**	**Traditional**
Plan (formal)	A – repair	B – metabolism	C – replication	D – selection
Act (efficient)	B – metabolism	C – replication	D – selection	A – repair
Observe (material)	C – replication	D – selection	A – repair	B – metabolism
Reflect (final)	D – selection	A – repair	B – metabolism	C – replication

Thus science is seen as a living enterprise that can be pursued for different purposes or with different priorities. Clearly, as labeled, the Exploratory mode is what most scientists aspire to. As with the Eukaryote type of organism it is the most creative and flexible, and in theory it can compartmentalize like *Eukaryota*, with metabolic and genetic components analogous to Scientific institutions or universities, and libraries or other repositories respectively. Such compartmentalization allows for more sharing and creative research. The utilitarian type, like *Bacteria*, can acquire many useful functions and spread widely across society, for example in engineering, construction, education, and other applications: This is "science for society". The Consensual type, being a selective strategist, is analogous to "policy-driven" or culturally motivated science dictated by societal needs and applied to addressing popular questions or policy goals. This type is the least secure in its knowledge and includes proto-science or even pseudoscience. Finally, the traditional type, like its analogous life form *Archaea*, focuses on retaining historical knowledge. Inflexible by design, it serves to preserve history and is most readily prone to dogmatism if dominant among the types. Arguably realism works best for the Traditional and Exploratory types, and pluralism or instrumentalism would work best for Utilitarian and Consensual types. All four types are thus essential components of the scientific enterprise, which is made strongest when the four types operate in their best way and are informing each other in a harmonious manner.

Until recently the realist view worked well in physics (Rohrlich 1989), which is more easily referenced to basic axioms, however other branches of science have not been so blessed and now physics as well is trending toward instrumentalism. Purely phenomenal or descriptive theories, such as Ptolemy's model of a geocentric solar system, might be seen as a hybrid of the two extremes in phase A (i.e., a theory which does not seek basic laws, but yet has predictive value based on the regularity of phenomena). Although logical contradictions can be identified within such theories, it is undetermined whether they will look for paradox in an exploratory mode, or become traditions. As a whole system the ‘identity’ of the scientific enterprise is best characterized by phase E, which comprises all theoretical results of all modes and, like any living entity, may have a unified or confused identity.

Six Criteria for Evaluating Worldviews

The immediate concern, in regard to systemic, sustainable, evolutionary, and autevolutionary Gaia is to determine by what means the worldview portion of this model (i.e. new founding assumptions) can be evaluated. We might also classify the type of science desired here as Exploratory, in contrast to popular renditions of Gaia theory that are primarily Consensual; that is, selected by popular appeal. Certainly it is too early for agreement on traditional and utilitarian views, although those convinced of a Gaia entity will recommend management of the global system accordingly. But here we are actively asking for a rigorous evaluation to justify such an expanded view of reality. As mentioned earlier, the basis for theory (worldview) cannot be evaluated in the same way as the content of theory (i.e. by logical empiricism and hypothesis testing). There are, however, specific criteria that can be employed to justify worldview assumptions. Six such criteria are discussed below.[5]

Criterion 1: Necessity (crisis resolution)

As history implies, the relentless pursuit of a rigorous body of theoretical knowledge (phase A of Figure 1) can eventually lead to a "crisis" in scientific thought. Such crises can be defined by one or more apparent or specific paradoxes (i.e. paradox that is specific to the given worldview). A worldview paradox consists of at least two inescapable theoretical conclusions that are mutually exclusive, given our original assumptions about nature. Paradoxes in thought or theory, whether consciously identified or not, form the psychological basis for re-evaluating assumptions, both in everyday thought and during major scientific "revolutions" (Kuhn 1970). Wave-particle complementarity at first appeared as a paradox, but it no longer seems paradoxical to some who have accepted this duality as a new view of nature. Still others, including Einstein and Schroedinger, who were realists, sought an integral theory that would give a synthesis of these results (Einstein’s famous quip that ‘God does not play dice’).

If we do not actively challenge the foundations of theory, and seek the more expanded synthesis, the revolutionary aspect of science will cease and progress will be more consensual, perhaps even traditional. For that reason paradoxes should not be accepted as general theory, except provisionally. Paradox was a particular interest of Bohr and was prominent in the many discussions between Bohr and Einstein. And yet Bohr argued for the Copenhagen Convention that accepted uncertainty, largely for expedience; it was as a provisional solution to rescue physics, since they did not have a more general theory at the time. In all other matters the

[5] The original order of these criteria was changed to reflect a more logical sequence

identification and resolution of paradox became an intentional characteristic in the progress of physics beginning with Einstein (e.g. the EPR Paradox, Schrödinger's Cat Paradox, Twin Paradox, etc.). But the present state of physics seems to be falling into traditionalism as we do not seem to be able to transcend dualism (for example, to integrate relativity and quantum mechanics), nor to escape the paradox of the machine metaphor of life. This is perhaps a grand paradox compared to those that preceded it, but in resolving this one, we will enter into a more animate reality capable of seeing life and non-life in one view.

The value of demonstrating paradox is also illustrated by the noticeable lack of such demonstrations in pseudoscientific theories (theories invented without appropriate epistemological criteria). With two opposite processes operating within the scientific method (selection and unification) if there is no clear way of deciding when to apply each, science easily becomes consensual and traditional, because revolutions are not tied to a genuine necessity (i.e. they are solutions without a demonstrated problem). The necessity of crisis resolution establishes both the need for new directions and the likelihood that the line of reasoning to which one is led will be linkable to prior work. The search for genuine theoretical paradoxes, and their resolution, should be relentless.

As indicated in Figure 1, paradox can also appear when previously separate theories, worldviews, or disciplines are combined. The process of disciplinary or worldview integration can identify logical conflicts between interacting theories, which can stimulate unification.

Criterion 2: Formality

A scientific worldview must allow theories to be formalized in a way that affords testable hypotheses about their predictions. In practice, if theory is to be testable it must follow a formal logic. Thus a worldview also needs to have a strong formal, i.e., mathematical, foundation (Rosen 1990, 2003). That said, mathematical foundations are themselves various. Rosen pointed out that mathematics may be under-constrained without natural referents, which is perhaps the important foundation with regard to scientific applications. Of great importance for science, “mathematical” does not necessarily mean numerical. Set theory and category theory are equally foundational in mathematics prior to number theory. Quantitative mathematics and quantitative reasoning rely (in principle) on number theory, which involves both countable and uncountable sets and thus supports both discrete and continuous mathematics (Real numbers). Number theory itself has been shown to be incomplete, implying that a presumption of discrete nature entirely describable by number theory would also not be a complete referent. In practice the continuous or uncountable mathematical objects are only ‘simulable’ by countable objects, and mathematics itself relies heavily on modeling (Rosen 1993c). Without getting into the many arguments regarding completeness, it is probably safe to say that mathematics and natural science are themselves in a modeling relation, and that, at least in Rosen’s view, modeling relations may be the most complete object we can define. That is why modeling relations have been given a foundational role in relational theory.

To deal with complexity Rosen concluded that the meta-theory must adopt the broadest view possible in order to explore more than the mechanistic world. For this he went to Category Theory, perhaps the most general level of mathematics alongside Set Theory. There, it was possible to discuss how models can express natural events in broad enough terms to discuss, for example, life and mind-body relations. The recent R-theory synthesis applied this category theory logic to modeling relations, thus establishing an analytical method that is arguably as general as mathematics allows.

Here we might discuss the status of theistic worldviews in this picture of scientific generality. Can science be general enough to encompass religion? The answer here is a qualified one. Traditional theism usually proposes a top-down (larger system to smaller system, or context to content) causality. Science has traditionally rejected such theistic arguments because they cannot be formalized. First, theism presumes a hierarchy (in which there is a top and bottom) rather than a cycle of influences, which means it must be an infinite hierarchy reaching to an infinite and unknowable deity. If science is a "way of knowing" then such immanent cause cannot be part of its scope because in principle it can't be defined. Secondly, as argued above, it would be a category error to say that a theistic context 'causes' worldly events as such because the relation between context and event is informational, not causal. This does not mean that the larger context (theistic or systemic) cannot be intimately and necessarily involved in bringing about a world of events (as with the big bang singularity); it means that only post-singularity events will have their own analyzable causalities reflecting in some way natural law or cosmic order. That domain is typically were science can operate.

Nevertheless, we must always remember that experience is the unassailable starting point for both science and theism. Even Descartes emphasized that experience is the only thing we must be certain of if we are to make sense of our existence, "all else" (i.e., explanation of that experience) being subject to doubt and thus requiring experimentation (Descartes *et al.* 1994). Hence knowledge has two sources – direct knowledge from conscious existence (the inside story), and experimental knowledge from observational experience (the outside story). Science formalizes the story in logical/mathematical terms that are necessarily separated from personal experience so they can be placed into a logical context and evaluated according to criteria: It is thus the outside story. Theistic or spiritual experience comes to us in personal terms requiring that any formal understanding or intimate explanation must also be expressed in personally relevant terms. These may be intuitive or culturally acquired, but they are drawn from our deepest personal metaphors having no requirement to fit into a sharable logic. If science is to be about a sharable logic of natural explanation, its formalization will necessarily be different from these personal domains and systems of rationale build on them. Still, there is no fundamental incompatibility between the two sources of experience, only between their means of description. This is the beauty of a complex existence.

Accordingly different bases for explanation – pluralistic worldviews – can aim for compatibility if formalized broadly enough so each remains consistent with the other's semantics. In other words, experience itself can be preserved across may different worldviews and even formalisms. Experience may not be describable in terms suitable for scientific testing outside of that direct experience, but the fact that we can experience something, for example thought or consciousness, means that such experiences must somehow be allowed to exist in a general view of nature, including science, even if we do not yet have accepted theories for it. In fact, it is vitally important that a general worldview for science be formalized in a way that allows for the existence of inner experience, otherwise it has foreclosed testing any theories of it. This principle is also true for paranormal research into Psi phenomena, now recognized as a valid subject of science (May, Marwaha & Broughton 2018): If the scientific worldview does not allow for certain phenomena to exist, no theory of that phenomena can be studied or tested in that worldview.

Criterion 2b: Causality

This is listed as a sub-criterion because causality can be taken more or less synonymously with explanation, and is thus part of formality. Also, opinions differ as to the status of causality. The position here is that it is a necessary component of scientific formality. Whereas otherwise rational theories may be said to be a-causal, most likely they are simply rejecting present conventional limits on causality, as this work also does. Aristotle's treatment of "*aitions*" has been translated as a treatment of causes, however the word equally means a way of explaining or knowing, and most importantly and archetypal way; that is a parsimonious set of logical answers the question "why". It has been found throughout the ages, since the most ancient philosophies, that set comprises four essential types. The proposition is made here that if science purports to explain nature, it must formalize all four types, otherwise it is addressing only a limited and abstracted portion of nature (Rosen 1986, 1991a; b).

The four causes in R-theory (taken from Aristotle's philosophy but also recognizable in ancient Vedic texts) are thus four ways of explaining nature, or answering the question "why". In practice, a revolutionary theory will not be taken seriously unless it can state how it works; that is, explaining nature in broadly constructed causal terms. Our traditional idea of causality in modern science was very limited, excluding the "higher" causes (final-formal entailments), and even narrowing the efficient causes (especially recently) to discrete and computable logic suited only for simulation. Thus, leaving the higher causes, or rather implicitly reducing them, has led to claims of a-causality more or less as a rebellious assertion of the left-out territory; behaviors that are not simulable and thus can get around mechanism. That was partly the issue even with the Copenhagen Convention in physics, as no one knew how to introduce the higher causes without creating an unscientific hierarchy. Probability waves came to the rescue as a away of un-constraining the mechanisms. Stronger forms of a-causality have grown more popular in some fields (Ulanowicz 2013) and they can also be part of this model, because there are always aspects of a theory that cannot be precisely entailed, and in any case exact causes do not always need to be specified.

The functor relations between physical and non-physical categories (encoding and decoding in a modeling relation) could be considered a-causal since they are informational, and by their inherent nature open to multiple contextual influences. Such relations do not specify a necessarily unique 1:1 element mapping. Information encodings 'mirror' causalities between different categories and such relations are the essence of relational theory. They are capable of relating dissimilar categories with the help of a transcending contextual system that facilitates the information translation. The difference is that causality is defined as a 1:1 map between elements and a given morphism (a law for the mapping); whereas information relations impart only the structure or pattern of causality, not the specific 1:1 elements (since the elements of one category cannot be present in the other for direct entailment). A-causality, therefore, is *something*, it is information as a process of inducing a pattern of causes in one category into another. Information is not the pattern itself (a common misuse of the term). It is, in a sense, an imprecise (technically "impredicative" – i.e., "not fully predicated") 'fifth cause' or 'fifth essence' ("quintessence") that maps one type of causal mapping (e.g., an efficient-material entailment) to another (e.g., a final-formal entailment) or vice-versa. We could say that a whole system in this view is 'a relational system of inverse entailments'.

We can also compare this idea with the Buddhist concept of "Interdependent Co-Arising", generally attributed to Nargarjuna (Vimal 2009). Often considered a way of dispensing with causality, it actually corresponds with a relational definition of interdependence between dissimilar categories representing objective and subjective existence, or 'text' and 'context' as formalized here in terms of actual and contextual categories. The idea is that foregrounds are undefined except in terms of backgrounds; thus they co-arise. It does not mean they do not inform each other; in fact their very interdependence and co-arising is a statement of co-informing relations that mirror entailment structures in each category. So, for example a "deer running" in one category is a model entailing "running-ness" and "dear-ness" in the other category. The modeling co-arises, but the running-ness could be realized by a different kind of motion and the dear-ness by a different kind of animal. What constitutes a "good" model is then a matter of overall experience. Thus backgrounds provide the general affordances of foregrounds, and vice versa (Chemero 2003). We would not know about forests if we were not informed of trees, and a group of trees would be a very impoverished concept out of context without the characteristics of forests. But such co-arising relations cannot be parsed element-wise without the possibility of multiple interpretive influences (in the final cause direction from content to context – model building), or multiple realization possibilities (in the formal cause direction from context to content – model expression).

Criterion 3: Consistency

An acceptable new worldview must be consistent not only with itself, but with previous knowledge (i.e. previous observations and the principles they confirmed). Consistency is also implied in resolving paradox. To demonstrate that a paradox exists in the first place, we rely on previously established facts. In doing so, we implicitly accept previous forms of evidence and methods of confirmation. Therefore, a new, more explanatory worldview cannot reject results of the old, even though it may provide radically new ways of explaining them. For example, the view of evolution through the lens of cyclical causality (as presented in the main paper) is a much richer view, but it does not reject material evolution, nor does it deny mechanistic evolution according to Darwinian methods. Instead, it adds greater possibilities, some of which can explain inconsistencies in the previous view. The new view thus helps to complete the old, even if the entire method of representing nature is different. The new view should also be consistent with our language.

There is a difference, however, between consistency and correspondence. As Niels Bohr stated: "*We must not forget that, in spite of their limitation, we can by no means dispense with those forms of perception which colour our whole language and in terms of which all experience must ultimately be expressed.*" Bohr thus argued for a classical "correspondence principle" but over time we have come to understand that an exact correspondence between views may not be possible. Correspondence is more properly considered as consistency, or non-contradiction; or perhaps in this case a stronger version of consistency where classical ideas retain a certain metaphorical status with regard to theory elements. As individual organisms with sense perception, the classical view will probably always be important to us as our means of conceptualizing the world. Thus, while non-classical formalisms may be proposed, classical definitions will have to change or be translated for consistency, but the actual phenomena described will be the same.

Criterion 4: Parsimony (Ockham's razor)

Parsimony is an appeal to adopt the most 'elegant' formalism that meets the preceding criteria. William of Occam stated it thus: *"It is futile to do with more things that which can be done with fewer"* (Kneale & Kneale 1962), although the principle is more properly attributed to John Duns Scotus (d. 1308) in two statements: *"Plurality is not to be posited without necessity"* and *"What can be done with fewer would in vain be done with more"* (Thorburn 1918). But the concept also originates with Aristotle in "Posterior Analytics" ca 350BC: *"We may assume the superiority ceteris paribus [other things being equal] of the demonstration which derives from fewer postulates or hypotheses"* (Barnes 1984). Note there are two parts to that statement that must be fulfilled, simplicity and necessity; so it is not strictly a matter of simplicity, nor can it be evaluated by counting assumptions. Quantification of parsimony is impossible because it is a quality that is itself context dependent. For example, by leaving out the higher causes, mechanism was very parsimonious with regard to classical systems. But when applied to living systems mechanistic explanations quickly expand into a non-converging infinite regress –the need for more and more patches as with Ptolemy's divine circles. Parsimony arrives in this case by proposing a certain kind of causality that eliminates the need for endless corrections.

If we find a more parsimonious view of nature, operating from that view will make description and explanation of phenomena easier and more accurate (once the new idea is understood well enough to be used). But it will also allow us to explain more than was explainable before: It is not a "keep it simple" principle as is the common misunderstanding. Relational complexity claims to describe the most causality in nature with the fewest assumptions and least explanatory construction (e.g., propagation of theory 'patches'). That view is that nature is fundamentally complex, not mechanistically simple.

Various forms of parsimony can apply to descriptive models, to theory development (explanations), and to worldview assumptions. In the latter case, the goal is to provide a more useful and accurate thought system, recognizing that a simplifying assumption may not seem simple when first perceived from a different worldview. As Niels Bohr stated:

> *"Only by experience itself do we come to recognize those laws which grant us a comprehensive view of the diversity of phenomena. As our knowledge becomes wider, we must always be prepared, therefore, to expect alterations in the points of view best suited for the ordering of our experience. In this connection we must remember, above all, that, as a matter of course, all new experience makes its appearance within the frame of our customary points of view and forms of perception".* (Bohr 1961)

Parsimony, in evaluating a new worldview, should be established by experience with the new view itself, a process which may involve significant theory development, rewriting previous knowledge into the new terms and then evaluating predictions along those lines; at some point deciding if there is 'more bang for the buck'. Another way to state it is "theoretical elegance, not just eloquence".

Similarly the separation between theories or disciplines (say between psychology and biology), or among Thompson's family of interacting theories in evolution and ecology, is not a requirement driven by nature, although it may have analogies with biological species. In science it has to do with our social compartmentalization of knowledge and to different assumptions or theory elements. The family of theories concept may itself be arrived at from attempts to simplify theory within separate disciplines; but viewed more generally this is a matter of expedience, not parsimony. We can presume that where theoretical unification is possible without loss, that option will be the more parsimonious path.

Criterion 5: Universality

Universality means the extent to which a worldview applies to everything in the universe. A theory may be specific to a given application or discipline, and implicitly there will be assumptions made by that theory that do not generalize and do not need to in an instrumentalist (utilitarian, consensual, or traditional) mode. But the position taken here is that the search for universal principles as the basis for explanation is essential to the advancement of scientific understanding. This is a 'qualified' realist tradition in that it is also necessary to recognize that science is operationally constructive, social, inspired, practical, and many other things – not everyone is seeking general theory nor is it established that entirely universal theory is possible. For the instrumentalist, seeking general theory, as opposed to "useful" theory seems like a waste of time, however universality is important as a goal because it alone provides a test as to which theoretical perspective explains more with fewer problems (parsimony) and thus contributes to greater understanding not just to efficient use. If one seeks universal causal explanations *within* a worldview, there are several possible outcomes as the diagram shows. The result may be a satisfactory disciplinary theory that remains limited to that discipline, or its rigorous development and broader testing may ultimately challenge the universality of the view itself, in terms of paradoxes as described above. The aim of achieving universality is like the carrot in front of the rabbit; it drives the evolution of science through revolutions and to greater knowledge. The implicit assumption that nature is itself a unity can be questioned, but not to any practical end. Plurality cannot reject the possibility of unity, thus it will always remain as an attractor driving science.

Criterion 6: Utility

Having met all other criteria, the final test of a worldview is its ability to spawn meaningful theories that eventually produce useful results. This criterion, sometimes called “fruitfulness” or “usefulness” is crucial, however it cannot be applied in evaluating a worldview in advance of its formalization and use to construct and test theories. Utility can be determined only after painstaking attempts at theory development and application. For example, the principle of relativity was known for a long time before Einstein articulated a theory of relativity. But without the theory the principle would have been lame. Similarly evolution was an established principle before Darwin proposed a theory for how it might work. We could say that Gaia has also spawned theoretical proposals, but without a more solid foundation as attempted here, its theoretical accomplishments remain limited and controversial. Here we also enter the social world. Clearly usefulness cannot be judged without actual use, and for researchers to justify spending time on a new formalism, which could take years to understand and to rewrite previous theories, they must have the assurances sufficient to reach a consensus. A certain amount of serendipity seems to be involved in the first adoption of a new view, if not outright promotional bravado. But many an excellent idea has gone unnoticed in science for even centuries simply because it was not tried. Tradition thus plays an important role as well in the sociology of acceptance. Thus all four modes of science come together in this criterion.

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