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The Embracing Flows:
Process and Structure in the Movements of Information and Energy

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Abstract

Broadly speaking, information has something to do with order or organization within a system of elements. The thermodynamic concept of entropy is also associated with such systems, although in an inverse relationship. When we attempt to put these two apparently coordinated schemas of order and disorder together, all kinds of difficulties arise. I will briefly examine contemporary efforts to unify these two ways of conceiving order and show that they are substantially incompatible. In this process I will draw some distinctions that will lead to a broader reconciliation of the concepts of order and information. I will then attempt to re-evaluate the fundamental models behind these dissonant traditions for formulating order in an attempt to reframe a synthesis of conceptual structures that are mutually reconcilable. I will try to show that such a synthesis can finally make sense of the stubborn inconsistencies that persist in the ways Newtonian dynamics, thermodynamics and biology utilize the implicitly conflicting arrows of time.

Introduction

Life is a species of information. This intuition has been increasingly inspiring bio-scientists to formulate new ways to investigate the apparently self-ordering biocosm in an attempt to understand the emergence and evolution of life's diverse forms as a lawful, necessary progression of nature.
But what do we even mean to say that life is information? Aren't we just replacing a loose scientific metaphor with a highly equivocal concept? A survey of the way scientists from various disciplines utilize the term information, would do little to help us clarify just what we mean by the term.

Broadly speaking, information has something to do with order or organization within a system of elements. In communication theory it is the measure of the number of free states to which a system can "move". A system with one degree of freedom has the possibility of communicating one "bit" of information – on or off.

The thermodynamic concept of entropy is also associated with such systems, although in a somewhat inverse relationship. Entropy is a measure of the *unpredictability* of the micro-state of a system, with respect to its general parameters, such as temperature, pressure and volume. When we attempt to put these two apparently coordinated schemas of order and disorder together, all kinds of difficulties arise.

The most serious problem in trying to synthesize talk about entropy and information is to develop a coherent, conceptual model. There have been two approaches which have predominated in this effort, each with limited success. The one, following a thermodynamic approach, has just accepted the original hypothesis by Shannon that entropy simply is negative information or *negentropy*. Since the equations determining the probability of are formally similar, it is intuitively attractive to understand one quantity in terms of the other.

This approach has some distinct advantages for the task of understanding the nature of biological systems. Thermodynamic relations can better model the energy flows that are increasingly being utilized to understand the self-ordering complexity of evolutionary dynamics, as well as the developmental progress of individual maturation. As the life sciences grow towards conceiving biological systems as unified, holistic orders, channeling and conserving energy from the sun, thermodynamic concepts of order and entropy will become increasingly ascendant.
But biological macromolecules are equally banks of *structural* information. The crystalline configurations of proteins and genetic molecules readily model the ordered arrangements typical of informational systems. The informational content of a DNA molecule can be reasonably approximated using the standard approach of communication theory with respect to the degrees of freedom within a given network of elements [$S = k \log W$].
But there are serious difficulties with such easy agreement.

Some have attributed the underlying problems to a difference in 'dimensionality' between information and thermodynamic order. From a functional perspective, entropy has the dimension of energy divided by temperature. Information, on the other hand has no such dimensional residue. It is a merely abstract measure with no relationship to a 'minimum energy flow' or any principle of conservation. In many ways information can be considered energy, and therefore entropy neutral.

There may also be an equivocation nested within the definition of information itself. There is an information of a 'sender' and one of a 'receiver', and then there is the added complication of an 'interpretive system'. Entropy on the other hand is well defined and measureable within the contexts of thermo-dynamical systems.

A second approach is more conservative. Scientists from the fields of cybernetics and information theory are confident that they are developing the tools to mimic life in all its self organizing complexity. They are more cautious about a importing conceptual framework from the less determinate model of thermodynamics. They trouble more deeply about the paradoxes encumbered by the equivocal use of words like order and information and believe that there is little to gain for the quickly expanding and well founded field of information theory.

But such an approach lacks much promise for biology. Information theory is oriented towards the microstate causal model of mechanical determinism. It is intrinsically linear.

Biology most effectively studies systems as functional and holistic. If biology is to construct a model that bridges mechanical and systemic models or organization, it must allow for an alternate causal pattern than that offered by microstate physics.

Life is a hybrid with two distinct species of parent.

At one extreme, life is a process, more akin to a fire than a physical object. A controlled, metabolic burn, life is not its physically structured mass, but rather continuously consumes it. The fact that the flame of life is locally contained and thermodynamically stable within a couple of degrees, does not contravene its nature as a continuous transformation of matter into energy.

But life can equally be described as offspring of crystalline matter. DNA, the structural heart and essence of the living cell, has effectively been described as an organic, aperiodic crystal. Like a crystalline formation, each discrete DNA molecule has its own, electromagnetic resonant frequency by which it 'informs' its immediately environment. Igor Svent-Gyorgui hypothesized that it was this field, stimulated by the pi-meson molecular flow on the perimeter of the structure, that 'guided' the appropriate nucleic acids to 'conform' in the process of molecular replication.

In both models there are processes and structures, but each has its causal priorities inverted. The crystalline model identifies the electrodynamic field of the macromolecule as a property determined specifically *from* the discrete structure of the molecule. It is a property and function *of* that structure.

The thermodynamic model envisions the structure as an evolutionary product of and a developmental phase in the energetic and informational flows through the environment, temporarily stored and stabilized within discrete colonies of discrete molecular formations.

Less finicky scientists might complain that such quibbling is vain. These are merely two equivalent ways of describing the same activity. But such distinctions have significant differences with respect to how we attribute causal, and consequently, quantitative degrees in the way these two organizational frameworks *compete* for hierarchical influence.

In order to capture both of these perspectives on the nature of life we will need to synthesize the vocabulary of order and information in a way that does not prejudice the further formulation of these models.

This task begins with the problem of what we mean when we use the term information. Clearly there has developed a technical meaning for the term, following the use since Shannon in the fields of communication and computer science.

Any communication of 'order' or 'form' is in some sense in-form-ative. In this respect we can separate a 'technical' use of the term information from a more general or intuitive use. It is then incumbent on us to develop a coherent and clear vocabulary around the concepts of order and disorder that, if not easily conformable to, at least do not contradict those usages in thermodynamics and information theory. If we are to understand the structure and process of life under a single coherent model, it will be necessary to bring into sync the ways we talk about information and order.

Critical Clarifications

There are three sets of distinctions that need to be drawn before we can begin to hold a clear and coherent conversation about the various kinds of order and their relationship to information.

The first involves differentiating between an 'ideal' model of order and that of an 'applied' or real model. The serious confusion that has arisen about the conflict in the 'dimensions' between information and order is in truth this confusion about which manifestation of order is being referred to.

As in physics we can talk about 'ideal' dynamics, where we ignore friction and gravity and utilize geometrically ideal models. We can draw the same distinctions within our models of information and order, without inviting category fallacies. In addition we must also consider the possibilities of a purely ‘mathematical’ type of order, one level more abstracted from ideal spatial or temporal order, for often information theory is addressing this more completely idealized realm. As long as we make the appropriate distinctions and keep our frame of references clarified, these distinct realms should help sort out the problems of the kinds of order, rather than confute them.

Second there is a critical distinction to be made between models of order that are ‘natural’ versus ‘artificial’. This set of distinctions is necessarily going to have substantial overlap with the previous set, since natural order has its idealized referent in the world of natural laws, where artificial order has no such requirement. Much of information theory is based on a completely ‘artificial’ or arbitrary model of order.

This set of distinctions is meant to help clarify the complications involved with the necessity of ‘interpretants’ for artificial information. Natural systems are genetically embedded in their interpretive systems. They have no need for a separate and abstract system of ‘decoding’. There is a symbiotic relationship between transmitting (DNA) and receiving (RNA) systems. And to the degree and respect that natural systems can be idealized in mathematical models, so can natural information or order. We will from here after refer to what is normally thought of as Shannon information as Artificial Information (AI).

Our final set of critical distinctions is that between microstate and macro-state information or order. This distinction again has residue with the other sets. Artificial Information is defined with respect to microscopic relationships. There is also a kind of natural, microscopic order, as exemplified in the structure of crystals. Information theory has opened new perspectives in the study of natural microstate order, but the equivocation about the previous two distinctions has lead to unnecessary paradoxes. The crystal has more natural order because of its redundancies, although the same repetitive patterns represent a decrease in informational capacity (AI).

The mechanical causal model for the molecular patterns of crystalline structure is well developed. In order to begin to construct a conceptual framework for biological order and information, we need to develop one for its absent parent, macroscopic or systemic order. Although the entropy model from thermodynamics is helpful here, it is both incomplete and poorly formulated for coordinating with the standard models of information. In order to accomplish this I will need to review some of the tragic anthropomorphisms that have haunted the various formulations of the Second Law since its earliest conception.

There are grounds for optimism for such a reconciliation. With information theory we can define order with respect to the limitations of an elements freedom of motion. An element may be constrained through a field or system as effectively as through a direct connection to another element. In this regard the problem of reconciliation reduces to one of part-to-part constraints in relationship to whole-to-part constraints.

An Unsteady Truce

It is widely believed that the modern dilemma concerning the conflicting arrows of time, the thermodynamic and the evolutionary, have been adequately reconciled through the contemporary models of nonlinear dynamics and the energetics of evolution. Such an easy truce belies persistent problems within the synthesis that remain substantially unsettled.

Most generally the reconciliation between the Second Law of Thermodynamics and the possibility of evolutionary progress is explained via models of open and closed systems. Closed systems, such as the universe as a whole, are absolutely constrained to follow the parameters of the Second Law. The universe as a whole is moving to a state of maximum randomness or disorder. Of course this simple generalization does not begin to explain from what kind of "original order" the universe could be descending.

Evolution can take place within the localities of isolated systems, because such neighborhoods are inherently "open" with respect to the flow of energy. The order of the evolutionary progress on our planet is "paid" for by the expenditure of solar energy from the sun.

This overly general story of reconciliation has been gradually supplemented by more sophisticated models. Illya Prigogine in his *Order Out of Chaos* updates the narrative of how order can be spawned from out of entropy's bowels. He leaves to the tyranny of the Second Law those processes which take place in the inanimate world in closed systems. He claims a second arrow of time working within the first, for those processes within the biosphere which demand an open flow of energy to maintain order. Living organisms can locally decrease environmental entropy because they have an unlimited supply of energy, the sun, and an open sink for waste heat, space. These far from equilibrium systems he labels "dissipative structures" in a self fulfilling prediction of what function they must inevitably serve: "to emphasize the close association, at first paradoxical, in such situations between structure and order on the one side, and dissipation and waste on the other."[1]

There are numerous problems with this model of reconciliation, in both its simple and more intricate forms. Intelligent Design theorists garner increasing support, not so much for their compelling alternative models, as for

[1] Ilya Prigogine, *Order Out of Chaos* (New York, 1984), p. 143.

their negative critique that the Modern Synthesis remains deficient of some fundamental axiom. I will briefly present an analysis of the most serious difficulties and then move on to Plato's more adequate resolution.

1) The Autonomy of Order from Energy

Maxwell, with the creation of his hypothetical demon, intrinsically tied energy flow to an ordering of system. This was a logical, though ambitious extension of Clausius' expression of entropy as the limiting usage of heat energy. If a system could spontaneously organize itself to separate out differentially energized particles, then it would be able to create extreme temperatures from an initial state of equilibrium. This implies a heat flow from cold to hot, which is thermodynamically taboo: i.e. the Second Law evolves to a statement of systems which necessarily move to states of greater disorder.

The logical flaw in this development is that even if the flow of energy is order-dependent, *order is not energy-flow dependent*. Scientists posit with a kind of moral certainty that life, as a self-organizing structure, can only exist in nature because it pays for its order by utilizing energy it takes from its environment. *Energy causes order*. The same scientists will immediately reverse their logic to assert, with equal confidence, that the spontaneous crystallization of a winter's snow fall is only possible because the order it creates is paid for by the released energy of crystallization which contributes to increased environmental chaos. *Energy causes chaos*. The scientific view clearly equivocates between whether energy causes order or destroys it.

Clearly the right type of energy, received into just the precise kind of structure can be utilized to increase order. But this is the thermodynamic exception. We cannot utilize photosynthesis *as* an explanation for the thermodynamic basis of life: It is the thermodynamic origin of photosynthesis we have to explain.

Considering the third possible ordering state, that of a protein re-raveling itself into its fourth degree confirmation, there is no energy absorbed or released. It is apparent from the consideration of these three energy states of self-ordering systems that the process of order growth can be substantially *disassociated* from any strict energy determination. This leaves us where I assume Maxwell intended with his hypothetical demon. While energy flow can never determine the direction of order, microscopic ordering might well affect the level and direction of energy fluctuations.

2) The Misidentification of Equilibrium with Disorder

A closely related fallacy of the received models of order and thermodynamics is that the inevitable flow of systems towards a state of energy equilibrium is just a move to maximal disorder. This conclusion is drawn from the misleading condition that the state of maximum disorder would in fact be one of equilibrium. Although the state of maximal disorder is one of equilibrium, the *converse* is by no means necessarily true. There are an unlimited number of states configured at equilibrium that are less than maximally disordered, and some particular subset could reasonably be adjudicated as maximally ordered: ie. Hegel's or Aristotle's fully evolved, universal deity in self-conscious contemplation.

3) A Fundamental Inconsistency between the Second Law and Its Macroscopic Predictions

There are yet more direct problems with the modern synthesis. There is an inherent inconsistency between the Second and Third Laws which may be proved with no more than a consistent application of the classic principles of thermodynamics. Given the prevailing model of the Big Bang cosmology, the universe is a finite, expanding continuum of matter and energy. By definition no heat may enter from "outside" the universe, therefore the expansion is adiabatic. In all adiabatic expansions, the temperature uniformly decreases as the (square) of the rate of radial growth. In any closed system, and this is the only case we may safely so signify, with a decrease in temperature the entropy must either decrease or remain the same. Universal entropy cannot increase.

David Layzer of Harvard University has recognized the insufficiency of contemporary accounts, and he makes an interesting attempt reconstruct our understanding of the problem. Layzer, in his *Cosmogenesis,* attempts to reconcile the growth of order within evolution with the increasing entropy of the Second Law by hypothesizing the concept of R_{Max}, the maximum possible entropy in the universe.[2] He then speculates that as the universe expands both the potential maximum and the actual measures of entropy increase, but the second quantity less than the first. Information, or order, can be calculated as:

$I = R_{Max} - R$

The growth of information and entropy have been reconciled.

There would appear to be two problems with this reasoning. First it based on the misconception that with the expansion of the universe, actual entropy must increase. We have shown that such a supposition is both inconsistent with the Second Law, and an unnecessary consequence of the relationship between energy and order.

But perhaps just as problematic is his creating a concept, the maximum potential entropy, that is preponderantly explanatory, therefore ad hoc, to account for an ontological or causal phenomenon. If there is some quantity that grows with universal expansion, it should be formulated as an actual, causally effective phenomenon.

The approach of J. S. Nicolis in his treatise the *Dynamics of Hierarchical Systems*, is somewhat closer to

[2] David Layzer *Cosmogenesis* (Oxford, 1990), p. 138.

recognizing the hurdles to be overcome, but still hits short. Nicloas recognizes the problem that we have put forward that in an expanding, adiabatic system, the temperature necessarily falls and the entropy must remain at least invariant.

His approach to explaining the increase in entropy that he feels he must justify is to speculate that since the expansion of the primordial mass is *asymmetric*, entropy is enabled to increase. This approach seems doubly flawed. First, the parameters of the Second Law, as applied to an expanding adiabatic system are blind to any particular configuration of sub-systems. Entropy must decrease or remain the same.

Just as importantly, there is something counter-intuitive about his supposition. Surely an ideal gas, expanding with perfect symmetry would represent a maximally random configuration for the given conditions. Any asymmetric fracturing would open the possibility for aggregation and self-ordering. It is the precisely the asymmetric distribution of mass that allows for a decreasing of universal entropy.

In point of fact, there are no perfectly open or closed systems in the universe. To the degree that the solar system is a unity encompassed by its own gravitational field, it remains partially closed. And to the degree that the universe is expanding, it needs to be considered as a partially open system.

4) An Equivocation of Orders

All of the prior problems with the Second Law can finally be included within a more fundamental misunderstanding within the foundation of thermodynamics - an anthropocentric bias on the simplification of our concepts. An experimenter creates an ordered structure in her lab, modeled after some regular mathematical pattern. After the structure is exposed to an unprotected environment, it is eventually reduced to a state of disorder. Whether it is separated ideal gases which are allowed to mix, or an ordered deck of cards which is shuffled, there always are more probable states of chaos than order. The difficulty is in comprehending that such manufactured orders are totally artificial and therefore have no validity as orders of the "real" world. They were not designed to be physically competitive, and therefore can stake no claim to any durable stability. That civilization has to continually struggle to fight back the encroaching jungle, even in this day of high tech miracles, is no sign of impending chaos. It is rather a competing branch of nature's order letting us know the race may not yet be over. The infinitely adaptable virus and the communal bee waste not their time commiserating over laws of doom.

It is perhaps significant that we have established entropy rather than its converse, order or information, as the measure of thermodynamics. Certainly it is easier to gauge the relative disordering of a structure than it is to formulate some absolute standard of hierarchical conformation. To posit the fragility of order from witnessing the deterioration of our artifice is a silly form of vanity. Science must search for a norm outside of some relative perspective.

The Triple Goddess of Macroscopic Order

In order to understand how the disassociation of order and energy contributes to the interaction of kinds of order within biological evolution, we need to better clarify they ways in which macrocosmic or systemic order flows within an expanding universe. There are three organizational conditions that determine the extent and direction of such transmission.

1) The Absolute Growth of Systemic Order

Given the prevailing model of the Big Bang cosmology, the universe is a finite, expanding continuum of matter and energy. By definition no heat may enter from "outside" the universe, therefore the expansion is adiabatic. In all adiabatic expansions, the temperature uniformly decreases as the (square) of the rate of radial growth. In any closed system, and this is the only case we may safely so signify, with a decrease in temperature the entropy must either decrease or remain the same. Universal entropy cannot increase.

2) Gravity as Anti-Entropic

If we understand the Second Law fundamentally as the principle determining the *destruction* of gradients,[3] gravity, in its tendency to attract mass, and therefore *construct* differential gradients is the paradigmatic *anti-entropy*. The formulation of the Second Law within chemistry labs, dealing with small amounts of ideal gases has predictably ignored such an influence. But at the cosmic level, gravity is the single greatest source of energy, and potentially order and information, in the universe.

Gravity also performs two further functions in the service of universal order. By attracting masses into local centers, it avails the possibility of local informational growth. Aggregated matter localized within a cooling environment provides the perfect petry dish of organizational emergence.

At another scale, when a greater amount of mass is brought together the energy of a star is born, supplying that heat source that is equally necessary for the possibility of organic evolution.

3) Harmonic Order in the Interaction Between Gravity and Entropy

In the dynamic interaction between the contractive forces of gravity and the expansive forces of thermodynamics, the universe has experienced a symmetry breakdown that has nurtured the isomorphic, harmonic

[3] Eric Schneider and Dorion Sagan, *Into the Cool* (Chicago, 2006).

transmission of cyclical order. This order *processes* down through galaxies, star systems and planetary motion and is *ingressed* finally into the tides, seasons and rhythms of planetary evolution. The dynamic and energetic patterns of life have been systematically programmed over eons of cycles to reflect this harmonic inheritance.

A Proposal for Further Work

I have suggested in this paper a preliminary program to advance the integration of the distinct ways in which we talk about order and *natural* information. The explicit purpose of this discussion is to make more transparent the distinct provinces of this field, as well as those areas of equivocal conceptual reference.

If we are to develop a robust field of bio-informational development we need to begin to which we presently refer to informational structures.

The part of the field that is most in need of quantitative formulation is that of the macrocosmic fields of thermodynamic and gravitational interaction. The last principle that I began to develop in this regard, that of the harmonic transmission of cyclical order, may provide some glimpse into a future system that has ironically already been developed in the distant past.

Plato, in his cosmological thesis, the *Timaeus*, presents an harmonic mathematical sketch by which the cyclical heavens orchestrate or *persuade* the chaotic microcosmic necessity to cooperate. If we could follow through on the development of such an harmonic, non-linear system of quantifying order, we could lay the foundations for a fully integrated program to measure and better formulate the conservation and evolution of informational flows.

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