Organic Complex Systems

**Chance, Order and Evolutionary Transformation
In
Living and Lifelike Organisms**

Revision 19

**Grant Holland
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What is Evolutionary Transformation?

> Let it be borne in mind how infinitely complex and close-fitting are the mutual relations of all organic beings to each other and to their physical conditions of life. Can it, then, be thought improbable, seeing that variations useful to man have undoubtedly occurred, that other variations useful in some way to each being in the great and complex battle for life, should sometimes occur in the course of thousands of generations? ... Can we doubt…that individuals having any advantage…would have the best chance of surviving and procreating their kind? This preservation…I call Natural Selection…. Natural selection would thus have free scope for the work of improvement. [Darwin 1859]

Evolutionary transformation is the kind of change in which "things can get better." Variations can be "useful." "Improvement" can occur. "Progress" can be made. *Evolutionary transformation* is the name we shall give the kind of improvement that Darwin means when he says, "…natural selection can only act through and for the good of each being…." [Darwin 1859]. On the other hand, thermodynamics suggests powerful reasons to doubt the long-run viability of this concept. This article presents a theory that explores the tension implied by these two established domains of science.

Organic Complex Systems (OCS) presents a formal theory of and a modeling paradigm for a class of systems that exhibits evolutionary transformation. Biological systems provide one instance of this class. OCS asks whether there are others.

In order to present such a formal theory, of course, we must be more specific about what "improvement" means and what these "things" are that are "improving".

As a theory, OCS addresses the question of origination. How is it that evolutionary transformation can emerge? How can it maintain? OCS provides a formal model in which evolutionary transformation begins in uncertainty and arises from chance alone. In evolutionary transformation, chance breeds order from chaos.

Does Disorder Never Decrease in Physical Systems?

Modern physics, voiced by the discipline of statistical mechanics, has already weighed in on these issues – at least for specific kinds of "things", being dynamical molecular systems. And statistical mechanics has articulated unchallenged formalities, in no less

than a law of physics - the second law of thermodynamics, pertaining to what will inevitably occur to these systems in the long run…. They will unceasingly drive toward a state of maximum *disorder*.

The difficulty with having all of the molecular systems in the universe monotonically and asymptotically moving toward a state of maximum disorder is that it leaves no room for any other properties of these molecular systems to "improve" in any way. According to the second law, "things" are most definitely not going to "improve" – not any "things" and most definitely not with respect to the property called *disorder*.

Worse still, if *disorder* is not going to "improve" (reverse and start becoming *order)* then it is difficult to see how anything else (other properties) can either. This cold condition would seem to leave little room for a discipline such as OCS that intends to commit to an investigation of "systems that can improve".

Evolutionary Transformation

Since the second law seems to say that the entire universe is not going to "improve" as it changes, then lets begin our attempt at providing more precision to our meaning of the phrase *evolutionary transformation* by setting our sights somewhat lower and applying the term only to certain systems within the universe – rather than to the whole universe, and to those "improvements" lasting for only limited periods of time.

Lets next address the question of "What can improve?" The second law says that the *degree of uncertainty* cannot improve. (That is, *entropy* cannot decrease.) Therefore, our first attempt at lending precision to this notion of evolutionary transformation will be to declare that, in fact, there may be certain systems (smaller than the universe, of course) that just might be able to *improve for a limited time period with respect to the idea of certainty/uncertainty*.

Thus, we shall begin our quest by defining

> *Evolutionary transformation*: The decrease for a bounded time in the degree of uncertainty (entropy) of a system.

Of course, the next question is whether or not any such systems exist. We shall address that question next. But before we do, let's ponder what we will accomplish if we were to find such systems.

It may not seem that "merely" an increase in the *degree of certainty* of a system is much of an "improvement". However it actually is. In the first place, such a system (if any exist) would have apparently dodged a law of physics! More consequential, though, is what such a "dodge" could lead to. For instance, suppose that a number of other properties have a dependency relationship with *degree of uncertainty*. It could be that such a dependency could result in these other properties improving also. For example, such improvements might apply to the *degree of organization* or the *degree of persistence*. Such eventualities might lead to all manner of other interesting "improvements" beyond that of uncertainty. Such an ensemble of improvements may, in fact, be consequential.

First, though, we must establish the existence of a class of systems that can exhibit an increase in *certainty* over time. Then we shall have evidence of evolutionary transformation and a reason to erect a theory that supports it.

Can Disorder Decrease in Biological Systems?

We already have an apparent example of a class of systems that exhibits *evolutionary transformation*. This class is that of *biological systems*, where evolvement, "improvement", is demonstrated, established and expected.

Consider these words from a popular cell biology textbook:

> One property above all makes living things seem almost miraculously different from nonliving matter: they create and maintain order, in a universe that is tending always toward greater disorder [ECD 2004].

After all, many biologists identify the necessary conditions for life to be replication, growth and *evolution* [Hazen 2005]. It is not in dispute that biological systems demonstrate the capacity to - from time to time and even possibly over a long run period - decrease their *disorderedness*. And, therefore exhibit evolutionary transformation.

Does Evolutionary Transformation Run Afoul of the Second Law?

It is not in dispute that Neo-Darwinism is as broadly accepted in the biological sciences as is the second law of thermodynamics is in the physical sciences [de Duve 1995]. Is science at an impasse? Can these two paragons of contemporary science coexist?

Evidently they can. But their apparent conflict raises a number of questions:

- Is the second law broadly misinterpreted?
- Do biological systems ever "improve" by actually decreasing their *degree of disorder*?
- Are the assumed conditions for statistical mechanics different from those of biological systems?

OCS has investigated these issues, and has concluded that the answers to the above questions are: Yes, Yes and Yes.

OCS, then, can be reasonably described as a formal articulation of how a certain class of systems – including the biological – can increase its degree of ordered-ness over some period of time. We hereby name this class *organic complex systems* and abbreviate it to *organic systems*.

Conditions for Evolutionary Transformation

So, OCS takes the position that evolutionary transformation occurs, at least over finite time periods, and that there is a class of systems in which it does.

Two questions then arise:

1. What are the operating conditions under which evolutionary transformation can arise?
2. What other properties are exhibited by systems in which evolutionary transformation arises?

OCS proposes that the *organic complex systems* in this class exhibit a collection of other properties that collectively give rise to *evolutionary transformation* under certain conditions. Clearly, OCS must identify these properties and those conditions.

Moreover, these properties also distinguish these *organic complex systems* from the systems postulated by statistical mechanics in significant ways. This distinction pertains to the relative complexities of the two types of systems and the dynamics of certainty/uncertainty within the two types.

Disorder, Disorganization and Uncertainty

We have established that if there are any differences in the operating assumptions of statistical mechanics and OCS, those differences pertain to the idea of *uncertainty*. Statistical mechanics says that, as time increases, the *degree of uncertainty* in the universe cannot decrease.

On the other hand, under evolutionary transformation as defined in OCS, the degree of uncertainty can and does decrease in a certain class of systems, at least for some finite time period. And, as we have said, this *decrease in* uncertainty represents the kind of "improvement" that we are calling *evolutionary transformation*. OCS means to make a theory of this class of systems - *organic complex systems*.

Until now, we have used the terms *uncertainty* and *disorder* interchangeably – as well as the terms *certainty* and *order*. In this section we shall de-conflate them. This is because OCS has the need to make a distinction that statistical mechanics may not.

This distinction pertains to a particular ambiguity (double meaning) inherent within the term *disorder*. Especially the practitioners of statistical mechanics use *disorder* to imply two distinct meanings. In statistical mechanics these two meanings are conflated; whereas in OCS they must be distinguished.

One meaning of *disorder* is that of *disorganization*. This semantics pertains to *interrelationships* among or between a system's components – or between systems themselves (in which case they can be considered as nested components of a larger composite system). *Disorganization* pertains to structure and arrangement. Any *measure of disorganization* must use these interrelationships as its input parameters.

A second meaning of *disorder* is that of *uncertainty* or *unpredictability* – the inability to predict from one moment to the next what the outcome of an event will be. We shall call upon information theory to assist in this regard. Information theory defines the notion of *uncertainty* in terms of probabilities. Thus, any measure of *uncertainty* must use probabilities as its input parameters.

In statistical mechanics, the function *entropy* is defined as a measure of *uncertainty*. And, entropy is *not* defined as a measure of disorganization according to the semantics of measuring interrelationships discussed above. This is made clear by inspecting its formula. There are two formulas that are often presented in texts on statistical mechanics. We shall use the one attributed to Gibbs, owing to its generality. (The other is attributed to Boltzmann.) Gibbs' formula is:

$$\text{Entropy} = -K * \sum Pr(E) * \log(Pr(E))$$

Here, the "K" value is a constant and can be considered as a scaling factor [Shannon 1963]. "K" is not an input variable and we can ignore it for the purpose of understanding the semantics of this expression. The only variables (inputs) to the formula are the "Pr(E)" which are the probabilities of all of the sample points [Jaynes 1957]. Each of these represents a possible microstate configuration.

The expression inside the summation is the product of the probability of a sample point with the log of that probability: $Pr(E) * \log(Pr(E))$. And, this expression is summed over the entire probability distribution that considers all possible microstates.

Thus, the entire formula is a function whose only input value is a set of probabilities. As such, it measures *uncertainty*. But the Gibbs formula expresses nothing whatsoever regarding interrelationships among components or among systems. Therefore, it cannot possibly be a measure of *organization* or of *disorganization* – regardless of popular usage to the contrary! The formula ignores any disorganization that may or may not be.

According to OCS, then, whenever physicists use the term "disorder" to describe what *entropy* measures, they are correct insofar as "disorder" means *uncertainty*. But when they use the term "disorder" to mean *disorganization*, they are not supported by the Gibbs formula (or the Boltzmann formula).

For the organic complex systems that are of interest to OCS, these two attributes of *uncertainty* and *disorganization* can vary interdependently. Therefore, in OCS there must be distinct measuring functions for each.

A challenge of Organic Complex Systems is to describe more specifically the interdependent evolution of these two variables, and others, within this class of systems as they transform themselves over time - and how these variables interplay to initiate and maintain *evolutionary transformation* – at least for limited periods of time.

What are Organic Complex Systems?

As stated, this article identifies a special class of complex systems, called *organic complex systems*, which exhibit the capacity for evolutionary transformation.

The subtitle of this article declares that OCS is interested in evolutionary transformation in living and lifelike organisms. One online dictionary [dictionary.com 2011] defines *organism* as "any organized body or system conceived of as analogous to a living being". Clearly *organic complex systems* are "analogous to living beings". Thus, they can be reasonably described as "organisms", or at least as "living or lifelike". Essentially, OCS proposes a general theory of living and lifelike systems.

We have identified biological life on earth as being a member of this class of lifelike systems; but are there others? It is expected that members could also include certain:

- Artificially engineered lifelike systems
- Non-carbon-based extra-terrestrial organisms

As stated, OCS assumes that organic complex systems are able to exhibit evolutionary transformation due the collective interplay of their systemic properties. Thus, an immediate task of OCS is to identify a set of systemic properties of organic system. This article presents these properties in the form of a set of seven organizing principles.

A second task of OCS is to put forth a formal argument that this specific set of systemic properties can be expected to promote the capacity for evolutionary transformation. This argument will be presented in the form of a formal theory of these seven organizing principles that will imply the capability of evolutionary transformation for systems of this class. This formal model is named *Organodynamics.*

An Alternative Complexity Theory

It is reasonable to categorize OCS under the moniker *Complex Adaptive Systems*, since the systems defined by OCS are dynamic, complex and adaptive. But OCS distinguishes itself from possibly the most established of these theories, *nonlinear dynamics*, often called *chaos theory*, in a number of ways.

In particular, nonlinear dynamics is interested in relatively ordered systems moving to disordered ones in unpredictable ways. This phenomenon is often captured by the phrase "sensitivity to initial conditions". Chaos theory is primarily interested in systems whose input conditions are well ordered, but whose output conditions are unpredictable.

In many ways, OCS is interested in the opposite: conditions that are "highly disordered" but that move in time toward increased order. Such is the nature of *evolutionary transformation*. Specifically, biological systems have emerged from a "primordial soup"

of organic chemicals some four billion years ago to what they are today. They now often exhibit extraordinary degrees of organization, as well as predictability. Yet these two principles vary interdependently in complex ways.

The proposition that organic complex systems can exhibit evolutionary transformation – and the identification of the conditions under which they do - can be developed from the synergy of two sub-disciplines of probability theory: *information theory* and the *theory of stochastic processes*. OCS is interested in the conditions under which regularity emerges from uncertainty. Explains Richard Kleeman of the Courant Institute of Mathematical Sciences at NYU, "The central idea of information theory is to measure the uncertainty associated with random variables" [Kleeman 2009].

On the other hand, the mathematics of nonlinear dynamics is *strictly deterministic*. Chaos theorist Steven Strogatz [Strogatz1994] describes *chaos* as "aperiodic long-term behavior in a deterministic system that exhibits sensitive dependence on initial conditions". He goes on to explain that what is meant by "deterministic" is that "...the system has no noisy or random inputs or parameters. The irregular behavior arises from the system's non-linearity, rather than from noisy driving forces." Thus, nonlinear dynamics is a mathematical systems theory that achieves "surprisingness" through nonlinear determinism.

Thus, nonlinear dynamics achieves its "surprisingness" from the "sensitivity to initial conditions" of non-intuitive nonlinear mathematics. But OCS achieves its "surprisingness" through the uncertainty inherent in probability spaces, the inevitable consequences of information theory and the asymptotic behavior of certain classes of stochastic processes.

OCS also distinguishes itself from an emerging theory named *Evolutionary Dynamics*, which is a mathematical articulation of biological evolution. Like chaos theory, evolutionary dynamics is deeply deterministic. It also draws on a number of structures from nonlinear dynamics, including fitness landscapes, fractals and spatial chaos [Nowak 2006]. And Evolutionary Dynamics depends heavily on mathematical game theory. [Nowak 2006] introduces the dynamics of evolution using such games as the *prisoner's dilemma* and *tit-for-tat*, and goes on to demonstrate increasingly sophisticated cooperative interactions by exploiting the language of game theory.

As concluded by William H. Sandholm,

> Evolutionary dynamics capture the behavior of large numbers of myopic, imperfectly informed decision makers. Using evolutionary models to predict behavior in interactions between, say, two well informed players is daring at best [Sandholm 2005].

Thus, evolutionary dynamics concerns organisms that are capable of "decision making" and even rationality. These entities also exhibit other high levels of systemic organization including teleological aspects such as intention and purposefulness. OCS, on the other hand, is less demanding of its subjects – that they exhibit the seven organizing principles.

OCS does not assume this level of sophistication on the part of its participants (organic complex systems). The following citation from Christian de Duve, Nobel laureate in Physiology 1974, is consistent with the OCS position on the teleology of its subjects:

> The important point is that this result is achieved without design or foresight. The mutations are caused by replication accidents, fortuitous events that bear no relationship to the production of better replicators. This is the essence of Darwin's theory. Natural selection operates blindly on material offered by chance [de Duve 1995].

Thus, OCS differentiates itself from both *nonlinear dynamics* and *evolutionary dynamics* by its focus on stochasticism and random processes – as opposed to determinism. OCS develops its formalities from the mathematics of *probability theory* and *information theory*.

Principles of Organization of Organic Complex Systems

In developing OCS as a conceptual theory, then, the goal has been to identify systemic properties that, collectively, give rise to the quality of *evolutionary transformation*. The approach taken to address this challenge has been to study biological life on earth in order to identify such a set of systemic properties.

In addition, it has been a useful thought experiment to contemplate what would be required as a test to admit certain specimens from the following two categories of systems:

- Non-carbon-based extra-terrestrial organisms
- Artificially engineered lifelike systems.

NASA, for example, is already asking how to discern whether non-carbon-based extra-terrestrial lifelike "organisms" are "alive". After all, space scientists must be prepared for the eventuality of encountering questionable systems in this regard in its interplanetary exploits [Hazen 2005]. What does it take to conclude that a being is *lifelike*? And, consideration of what it takes to artificially engineer lifelike systems has become a scientifically respectable enterprise. Conferences are held on the issue where bona fide scientists entertain serious submissions [Langton 1989; Bagley, Farmer and Fontana 1992; Rasmussen, Knudsen and Feldberg 1992].

These two inspiring system categories are, in many ways, similar to life on earth. What we are seeking, then, is a general theory of *the lifelike* that will encompass all of them. But this theory cannot be a theory of life on earth only. If it were, then the other two system categories would not comply with it. So, it must be less specific than a theory of biology. Thus, OCS can be said to be a *generalization* of biology, a generalization of life, and thus a theory of the *lifelike*.

From this study, such a set of organizing principles has been identified. This set forms the basis of *Organic Complex Systems*. Any system that implements all seven of these principles of organization is considered to qualify as an *organic system*.

We shall develop each of these seven organizing principles in the course of the body of this article. Lets preview them now by listing the names given to their associated systemic properties:

Organized
Emergent
Nested
Reorganizational
Autocogenerative
Uncertain
Persistent

Like a basis for a vector space, this set of seven organizing principles may not be unique in its ability to "span the space" of all dynamical systems that exhibit evolutionary transformation. However, they do span this space, and have been selected as the basis for OCS.

The OCS Initiatives

OCS is articulated as a conceptual theory, but it goes beyond this and takes on a number of other forms as well. In so doing it ranges from theory to practice. This section describes these various OCS initiatives and how they support each other.

The Conceptual Theory: Principles of Organization

OCS is a conceptualization that is articulated as a set of seven *organizing principles* that are believed by this author to characterize the essential nature of "lifelike" systems.

These seven principles were abstracted from an investigation of published research from a number of disciplines related to biological life on earth, its origins, its chemistry and its static and dynamic systemic properties.

The selection criteria for these principles pertained to their evident contribution to the principle interest of OCS – evolutionary transformation.

The next section presents each of these seven organization principles along with citations to scientific sources that support the view of each principle presented.

The Formal Theory: Organodynamics

In order to promote precision and utility, it is essential that the OCS seven organizing principles be manifested as a formal theory. This formalization is a mathematical framework named *Organodynamics*. Complementary paradigms such as nonlinear dynamics and chaos have developed mature formal theories. We should expect the same from OCS.

Organodynamics is an elaborate formal apparatus through which can be implemented comprehensive dynamic models of systems that are as complex as any known to science: "lifelike" or *organic* systems. Obviously, developing such a formal theory is challenging. However, this is the task set forth for Organodynamics.

The latter part of this article introduces the Organodynamics framework. The mathematics presented is essentially the foundations of this framework. Certainty, there is much work to be done in order to develop it to maturity. Thus a call to further research is also issued.

A Modeling and Simulation Paradigm

In order to support practical applications, the OCS conceptual and formal theories must be orchestrated into a general structure that makes it applicable to several classes of science and engineering problems.

As such OCS presents a modeling and simulation paradigm that is immediately derived from the formalism of Organodynamics. The elements of this modeling paradigm are briefly described in a section below.

A Modeling and Simulation Methodology

The organic systems that are modeled with the Organodynamics framework usually exhibit staggering complexity – and so must an Organodynamic model of those systems. This methodology encourages the modeler to start small and build incremental models of organic components. Thus, in an incremental and cumulative fashion, a model of the target system can be built up over a sequence of approximations.

This modeling methodology is not further described in this paper.

Modeling and Simulation Software

In order to assist modelers, it is highly desirable to provide application software to support the Organodynamics theoretical framework, modeling and simulation paradigm and methodology. Such software is not presently available, but is planned by this author. Of course, independent software developers can develop such packages as well.

Principles of Organization

The first initiative of OCS identifies and articulates some systemic properties of organic complex systems that enable them to exhibit the property of evolutionary transformation. OCS has identified seven such properties. Since each of theses pertains to how organic systems are organized, each also constitutes *organizing principles* of organic complex systems. This section introduces and describes these seven principles of organization.

Introducing the Principles of Organization

Before introducing the seven organizing principles of OCS, lets provide some context that motivates their selection. Obviously, they come from a particular bias, a particular point of view about what it means to be lifelike that is held by this author. I arrived at these seven principles independently of any one school or author after considerable research and deliberation. Thus, it was quite a delight when I encountered a single quotation that appears to allude to almost all seven of the OCS organizing principles.

As an introduction to OCS, I would like to present this quotation to you now. It is interesting that the cited quotation is over a half-century old, and that Morgulis penned it slightly before the publication of the structure of DNA by Watson and Crick.

The biologist who offered this insightful quotation is Sergius Morgulis, who was the translator of the English edition of Oparin's historically significant *Origin of Life* [Oparin 1938]. Here are Morgulis' particularly poignant words from the introduction of his Oparin translation:

> Thermodynamically directed chemical evolution could conceivably proceed indefinitely without changing from a non-living to a living state. Only when organic matter had achieved a high degree of organization, and had acquired diverse propensities through the concatenation of such substances (with chance as the only arbiter) did primordial life emerge as a new dimension in nature: matter perpetuating its own organization. Natural selection, operating on chance variations, set the evolutionary direction along numerous pathways which living things have followed irresistibly [Morgulis 1952].

This motivating context is amplified further by the following quotation taken from a more recent source. Their reference to an evolution "from random chemistry to self-replicating entities" indicates sympathy with OCS' interest in evolutionary transformation.

> A statistical chemistry approach would view the random emergence of diverse organic molecules, and their assemblies, as natural consequences of undirected prebiotic organosynthesis. It would then ask how life-like processes could emerge with such primordial random assortments, rather than study their specific molecular content. …[T]he transition from random chemistry to self-replicating entities would occur because of intrinsic statistical factors, e.g. the probability for mutual catalysis among randomly selected counterparts within a mixture [Segre' and Lancet 1999].

Having presented these motivating - even corroborating - citations, let me now provide the following table, wherein, each of the seven systemic properties of OCS is listed and associated with an embellishment as an *organizing principle*.

Principles of Organization of Organic Complex Systems

Systemic Property	Organizing Principle
Organized	Any organic entity is comprised of 1) a population of two or more components, as well as 2) a set of relationships among those components. This set of relationships specifies the organization of the entity. Thus, an organic entity constitutes a system; and shall be referred to as an organic system.
Emergent	Any organic system exhibits one or more properties that none of its components exhibits.
Nested	Any organic system has at least one component that is another system.
Reorganizational	Organic systems are dynamic – constantly undergoing change. This change involves some manner of reorganization of its components, or their components. The result is, generally, some form of buildup or breakdown – composition, decomposition, de-nesting, re-nesting, or any combination thereof.
Autocogenerative	The generative agent that initiates the reorganization of an organic system is the system itself. This reorganization is accomplished by virtue of the components of the system co-generating and co-organizing each other. Since the components co-generate and co-organize the other components, then the result is that they co-generate and co-organize the system. An organic system is co-generated by its components-in-relationship, and thus by itself. This phenomenology obviates the philosophical problem of a thing generating itself prior to its own existence. Consequently, the nature of this systemic reorganization, or dynamism, is that it is autonomous. All organic systems decay, or decompose, autonomously. But they also autonomously recompose in varieties of ways. These autonomous regenerations ramify into many flows that branch and loop. Some changes promote the propensity of the system to remain the same with respect to certain properties (regulation); while other changes cease such promotion (deregulation). Some changes promote the continued persistence of the system (adaptation), while some retard it (extinction).
Uncertain	All living processes depend upon both chance events as well as deterministic ones. Living processes operate along a spectrum between complete randomness and complete determinism, uncertainty and certainty. Where along that spectrum an organic system lies at any time is uncertain. Thus, the degree of predictability or uncertainty of an organic system is itself uncertain. ("Life is unpredictably unpredictable.")
Persistent	The nature of the autocogeneration and uncertainty of an organic system is that it engenders the ongoing existence of these systems. Taken together, all of these static and dynamic elements have resulted in, at the least, a limited persistence of life itself. While no organic system persists, the existence of organic systems has.

Let us now develop in further detail each of the seven organizing principles of OCS that were presented in the table above.

Organic Systems are Highly Organized

[Any organic entity is comprised of 1) a population of two or more *components*, as well as 2) a set of relationships among those components. This set of relationships specifies the *organization* of the entity. Thus, an organic entity constitutes a *system*; and shall be referred to as an *organic system*.]

Citations from Scientists concerning Organization

The biological stage concerns itself with the appearance of biological organization, with the building of a coordinated population of large molecules with catalytic function out of a random assortment of building blocks. [Dyson 1999]

…[I]n biology, as in other complex systems, these origins are not to be found in the matter itself, but in its interactions. [Strohman 1997]

"Organization" signifies those relations that must be present in order for something to exist. [Maturana and Varela 1998]

…[T]he structure of every organic being is related, in the most essential yet often hidden manner, to that of all other organic beings, with which it comes into competition for food or residence, or from which it has to escape, or on which it preys. [Darwin 1859]

Biological information is structural. [Morowitz 1992]

…definition of systems as 'sets of elements standing in interrelation….' [Von Bertalanffy1968]

The current realization that the structure of DNA already allows us to understand practically all of its fundamental features at the molecular level is thus most significant. [Watson 1970]

There exists a universal network of intermediate reactions such that the metabolic chart of any extant species is a subset of the universal chart. [Morowitz 1992]

Is there a sharp distinction between living and nonliving systems? Or can there exist levels of organization that are between those of the present living and nonliving systems? [Kauffman 1994]

Objects and events are not primitive experiences. Objects and events are representations of relations. [von Foerster 2002]

The problem of the origin of life is for me the biological stage, the problem of the appearance of biological organization out of molecular chaos. [Dyson 1999]

[Regarding *order*] we may wish to account for apparent relationships between elements of a set…[von Foerster 2002]

The OCS Idea of Organization

Organization is the hallmark of living systems. All of life is an organized population of some kinds of entities.

The essence of organization is *relationships* – relationships between and among a set of components in such a way that the entire apparatus forms an integrated whole. And, the essence of *system* is organization – the organization of a population of *components*.

OCS defines *system* as:

> *System*: A collection of entities, and a collection of relationships among those entities.
>
> The collection of entities is called the *population* of the system. The collection of *relationships* among the entities is called a *system organization*, abbreviated to *organization*.

So, we have preserved von Bertalanffy's two ideas about systems: 1) set of elements, and 2) interrelation among those elements [Von Bertalanffy1968].

Note that any given population can have multiple *system organizations*.

OCS defines the term *system* to mean a population together with all if its possible *organizations.* The term *system state* is defined as a population together with exactly one of its *organizations*. Thus, *system state* in OCS is essentially defined by a system organization.

It is interesting to contrast OCS with classical dynamics with regard to *system state*. In classical dynamics, system state is defined by the position and momentum of a particle at a single moment in time. But, in OCS, the *state* of an organic system is defined by its *organization* at a single moment in time.

Of course, a *population* and its *organization* are quite more complex to describe than *position and momentum*. Thus, as a dynamical system, OCS is in this way more complex than classical dynamics.

Organic Systems are Emergent

[Any organic system exhibits one or more properties that none of its components exhibits.]

Citations from Scientists Concerning Emergence

The chemical combination of two substances produces, as is well known, a third substance with properties entirely different from those of either of the two substances separately, or of both of them taken together. Not a trace of the properties of hydrogen or of oxygen is observable in those of their compound, water….There, most of the uniformities to which the causes conformed when separate, cease altogether when they are conjoined; and we are not, at least in the present state of our knowledge, able to foresee what result will follow from any new combination, until we have tried the specific experiment. [Mill 1859]

The laws of organic chemistry cannot account for those phenomena of a higher order which are encountered in the study of the living cell. The study of the protein molecule, its amino and carboxyl radicals, polypeptide or other linkages, etc., determine only the ability of this material to evolve and change into a higher grade of organization, which depends not only on the arrangements of atoms in the molecule but also on the mutual relationships of molecules toward one another. (p. 137) [Oparin 1938]

But the collective system does posses a stunning property not possessed by any of its parts. It is able to reproduce itself and evolve. The collective system is alive. Its parts are just chemicals. [Kauffman 1994]

The concepts of emergence trace back to the statistical mechanics of Ludwig Boltzmann, James Clerk Maxwell, and Josiah Gibbs….Thus while Perrin and others were pursuing the development of the reductionists view of atoms and molecules as the operative agents, the statistical mechanicians were showing that the microscopic particle view led to the macroscopic laws of thermodynamics in terms of emergent properties. [Morowitz 2002]

In short, we will not understand life and living organisms until we understand emergence. [HollandJH 1998]

Chemical systems create new properties through recombination of molecules via chemical bonds. New combinations between existing molecules and combinations of new molecules with other molecules, then define new functional properties in a system at large. [Rasmussen, Knudsen and Feldberg 1992]

[L]ife began as an integrated emergent property of complex systems of polymer catalysts. [Corning 2005]

The OCS Idea of Emergence

Complexity scientists are often quoted as saying that they don't know how to define *emergence*. For example, John H. Holland, arguably the contemporary father of emergence in complex systems, dared not tread into this dangerous territory. In [HollandJH 1998] he says (famously) "It is unlikely that a topic as complicated as emergence shall submit meekly to a concise definition, and I have no such definition."

However, I shall attempt here a simple and consistent working definition of the concept that I believe conserves most of the richness implied. In fact, I shall provide two, which I shall label *process emergence* and *systemic emergence*.

Process Emergence

Likely the most frequent use of the term *emergence* pertains to a phenomenon that occurs within a system process. The usage refers to the occurrence of something during the process that had not occurred earlier.

> Process emergence: the exhibition of a systemic property at some stage of a system process, wherein such property is not exhibited before such stage in the same process. Such systemic property is referred to as a *process emergent* property.

Systemic Emergence

However, there is a second manner in which the notion of *emergence* within complex systems could also be defined - an approach to emergence that is essential to OCS.

This second notion of emergence pertains to a phenomenon that can occur in systems due to their multiple levels of organization – that is, their *part-whole* relationships. For that reason, we shall name it *systemic emergence*.

Occasionally, it happens that a *whole* system, the system itself, can exhibit a property that is not exhibited by any of its parts, or *components*. This phenomenon is what we shall call *systemic emergence*.

A fruitful place to find examples of *systemic emergence* is physical chemistry. Macromolecules generally exhibit properties that none of their component molecules do. Many have put this idea forth. John Stuart Mill noted "The chemical combination of two substances produces, as is well known, a third substance with properties entirely different from those of either of the two substances separately, or of both of them taken together." [Mill 1859]

An example from biochemistry will be helpful. Consider the enzyme RNA-polymerase, which exhibits the systemic property "x can synthesize messenger RNA". But none of its amino acid components, individually, can synthesize RNA. Thus, RNA-polymerase exhibits this property, but none of its components do. Thus, "x can synthesize messenger RNA" is a *systemically emergent property* of RNA-polymerase.

This idea of *systemic emergence* can be seen in the work of Stuart Kauffman of the Santa Fe Institute in his description of autocatalytic sets, a notion that we shall see again in the development of OCS below. (The italics are mine.)

> A set of molecules either does or does not have the property that it is able to catalyze its own formation from some simple food molecules. No vital force of extra substance is present in the *emergent*, self-reproducing whole. *But the collective system does posses a stunning property not possessed by any of its parts*. It is able to reproduce itself and evolve. The collective system is alive. Its parts are just chemicals. [Kauffman 1994]

The idea that we shall adapt from Kauffman is the "not possessed by any of its parts" portion of the above quote.

With this introduction, we shall define *systemic emergence*.

Systemic emergence: The exhibition of a property by a system, when at the same time none of its components exhibits that property. Such a property is called a *systemic emergent property*. Such property is also said to be *emergent systemically*.

There is an essential difference between *process* emergence and *systemic* emergence. *Process* emergence requires at least two time steps to detect. On the other hand, *systemic emergence* can be detected by the inspection of a single time step. No dynamics are required.

But the distinction between these two forms of emergence is important to OCS, because it is systemic emergence that is responsible for the popular notion within systemics that "the whole is greater than the sum of its parts".

Organic Systems are Nested

[Any organic system has at least one component that is another system.]

Citations from Scientists Concerning Nested Systems

The physiologists…associate the term hierarchy with organelles, cells, tissues, organs, etc., and so on, a scheme which implies a nested set of functional parts-wholes relationships. [Corning 2005]

Complex structures which carry out living processes I believe can be identified at seven hierarchical levels – cell, organ, organism, group, organization, society, and supranational system. My central thesis is that systems at all of these levels are open systems composed of subsystems which process inputs, throughputs, and outputs of various forms of matter, energy, and information. [Miller 1978, p. 1]

Each higher level of organization has its own rules, and there is no continuous gradual transition from one level or hierarchy to the other. [Strohman 1997]

At each level of observation the persistent combinations of the previous level constrain what emerges at the next level. This kind of interlocking hierarchy is one of the central features of the scientific endeavor. [HollandJH 1998]

The appearance of novelty occurs at many scales ranging from societies, to individuals, to cells, to genes, to molecules…. [Fontana 1992]

All the biologists and molecular biologists today are 'mechanical materialists'. But the machines they study differ from the ones imagined by Descartes. As the philosopher and mathematician Gottfried Leibniz was the first to point out, natural (or 'divine') machines are infinitely divisible. If we analyze a living organism, we find that it is composed of micro-machines (metabolic cycles, enzymes). [Smith and Szathmary 1999]

The contemporary position of most neurobiologists is to try to go up the hierarchy from atoms to minds to understand the emergence of mind in terms of the underlying members of the hierarchy….This of course presents an epistemic circle. [Morowitz 2002]

The OCS Idea of Nested Systems

A component of a system may itself be a system. This organizing principle requires that an *organic system* must have at least one component that is another system.

Certainly, all biological systems are nested systems. A population of carbon-based macromolecules constitutes the smallest cell, a prokaryotic cell with no nucleus or other organelles. These are large molecules that are themselves constituted by an assemblage of smaller – yet still complex - molecules. Plant and animal cells are

eukaryotes. Their components are organelles that, in turn, contain macromolecules as components, which is an added level of nesting as compared with prokaryotic cells. In OCS, we refer to these levels of nesting as "levels of organization", or as "levels of abstraction".

And complex plant and animal orders, classes and genera - composed as they are of eukaryotic cells - exhibit many levels of nesting, or levels of organization. Primate organisms consist of organs that consist of tissues that consist of cells that consist of organelles that consist of macro (polymer) molecules that consist of basic organic molecules that consist of atoms. The requirement above translates into the organizing principle that an organic system must exhibit at least two levels of organization.

Therefore, there are really two aspects, or dimensions, of system organization that must be considered. We have already discussed one aspect in the section above on the *organized* organizing principle, which considered the *amount of organizational relationships* of the population's components with each other. We can call this the "horizontal" aspect of system organization.

But we must also factor in the *nestedness* aspect of system organization. This aspect must measure the degree to which there is nesting occurring within a particular system: how often it occurs within each population, and how deeply the nesting occurs whenever it does occur. We can call nesting the "vertical" aspect of system organization.

An important side effect of nestedness is that it provides increased opportunities for systemic emergence. For each level of organization nested within an organic system's structure, emergent properties can arise. Thus, in deeply nested organizations, uncertain and sophisticated systemic properties often emerge.

This complexity may offer an explanation for some of the seemingly inexplicable properties of higher life forms, including various ill-defined notions as intelligence, altruism, intension, purpose and other teleological concepts. John Holland asks "Can we explain consciousness as an emergent property of certain kinds of physical systems?" [HollandJH 1998].

Of course, investigators such as Peter Corning [Corning 2005] are convinced that some of these properties, such as purposefulness, are foundational to living entities. But OCS offers a model in which they are the result of emergence through many levels of organization.

Organic Systems are Reorganizational

[Organic systems are dynamic – constantly undergoing change. This change involves some manner of reorganization of its components, or their components. The result is, generally, some form of buildup or breakdown – composition, decomposition, de-nesting, re-nesting, or any combination thereof.]

Citations from Scientists Concerning Reorganization

Chemistry is mostly about reactions – processes in which groups of atoms are reorganized. [Zumdahl 2006]

…[I]n biology, as in other complex systems, these origins are not to be found in the matter itself, but in its interactions. [Strohman 1997]

To engage in the Darwinian saga, a living system must first be able to strike an *internal* compromise between malleability and stability. To survive in a variable environment, it must be stable, to be sure, but not so stable that it remains forever static. Nor can it be so unstable that the slightest internal fluctuation causes the whole teetering structure to collapse. [Kauffman 1994]

Most importantly, on all levels the interactions are constructive, in the sense that they enable, either directly or indirectly, the formation of new objects. [Fontana 1992]

The link between biosynthesis and biodegradation is the primordial link in the web of life. Most likely, it existed already in the first common ancestor of all life. [de Duve 1995]

…[C]omplexity alone is an insufficient measure for characterizing the transition from nonliving to living. This point has often been missed by theoreticians studying living systems. [Morowitz 1992]

The decisive events in a theory of the origin of metabolism are the rare statistical jumps when a molecular population in one quasi-stationary state happens to undergo a succession of chemical reactions that push it up, against a gradient of probability, over a barrier and down into another quasi-stationary state. If the initial state is disorganized and the final state is organized, the jump may be considered to be a model for the origin of metabolism. In a complete theory of the origin of life it is likely there would be several such jumps, each jump taking a population of molecules to a new quasi-stationary state. [Dyson 1999]

We are interested in reversible polymerization reactions, in which either two polymers *condense* to form a single long polymer, or a single polymer *cleaves* into two shorter polymers. Cleavage and condensation can be considered together as a single reversible reaction. [Bagley and Farmer 1992]

The OCS Idea of Reorganization

The first three organizing principles that we have discussed (*organized*, *emergent* and *nested*) define the *state* of an organic system. The remaining four systemic, beginning with the present one, describe its *dynamics* – or how the state of an organic system changes over time.

In OCS we use the term *dynamics* in the same sense as is used in mathematical modeling and simulation: *a change in state over time*. In the physical sciences, the term *dynamics* often denotes an interest in force, work and energy. But in mathematical modeling these physical issues may not be directly addressed. They are not denied, but neither are they detailed. Only their consequences in terms of any resultant change of state over time may be represented in the mathematics.

This usage is consistent with the way the term *dynamic* is used in simulation modeling. According to [Law and Kelton 1982], the terms the terms *dynamic* and *static* are viewed as antonyms. "A *static* simulation model is a representation of a system at a particular time, or one that may be used to represent a system in which time simply plays no role….On the other hand, a *dynamic* simulation model represents a system as it evolves over time…."

Since OCS identifies the essence of *state* of organic system as its *organization* - defined as a set of interrelationships among its components, then the dynamical aspects of OCS are defined in terms of changes in that organization over time.

As indicated above, in classical dynamics changes to a system's state are tracked over time by tracing its path, or trajectory, through a six-dimensional phase space. This phase space is an ordinary Cartesian space, named R^6, which provides three dimensions for the position of the system, and three more dimensions for its momentum. These six dimensions completely specify all that physicists want to know about the "state" of a system at any moment in time.

But these six dimensions of classical dynamics do not satisfy the interests of OCS regarding the "state" of an organic system. OCS is not terribly interested in where, within a Cartesian space, an organic system currently is, or in its current momentum. Indeed, OCS contemplates the possibility of the existence of *organic complex systems* existing

in abstract spaces (information spaces) that have no concept of momentum – or, indeed, certain other assumed concepts of physics.

OCS is interested in describing system change-of-state in a rich and complex manner: as a change in the system's *organization*. OCS calls this change *reorganization*. Thus, to OCS a change in system state is a change in the organization of the system – a change in the system's population or in the relationships its components. In any event, such a change takes place between two moments in time, or *time steps*.

Be aware that this new approach to dynamics by OCS, which defines *state* as an *organization* (essentially a configuration of arrangements), and *trajectory* as *reorganization* is profound. It recognizes *system state* as considerably more complex than in classical physics. And it is forced, then, to understand *change of system state* in a much more complex way. No longer can a picture easily represent a "trajectory" as a simple path through a Cartesian Space.

This new "phase space" contemplated by OCS consists of all possible "organizations" (structural arrangements) of a system's components and their relationships, no matter how deeply nested. Such a phase space is quite complex, and is difficult to image. Moreover, this space does not reduce to real or complex numbers, or vectors, and therefore does not lend itself easily to quantification.

In biological systems, this *reorganization* is represented at the molecular level as chemical reactions – most of which take place within cells. According to [Watson 1970], "The sum total of all the various chemical reactions occurring in a cell is frequently referred to as the *metabolism* of the cell." Thus, for the specific case of biological systems, this *reorganization,* at the cellular level of organization, is primarily represented by metabolism.

Organic Systems are Autocogenerative

[The generative agent that initiates the reorganization of an organic system is the system itself. This reorganization is accomplished by virtue of the components of the system co-generating and co-organizing each other. Since the components co-generate and co-organize the other components, then the result is that they co-generate and co-organize the system. An organic system is co-generated by its components-in-relationship, and thus by itself. This phenomenology obviates the philosophical problem of a thing generating itself prior to its own existence. Consequently, the nature of this systemic reorganization, or dynamism, is that it is autonomous. All organic systems decay, or decompose, autonomously. But they also autonomously recompose in varieties of ways. These autonomous regenerations ramify into many flows that branch and loop. Some changes promote the propensity of the system to remain the same with respect to certain properties (regulation); while other changes cease such promotion (deregulation). Some changes promote the continued persistence of the system (adaptation), while some retard it (extinction).]

Citations from Scientists Concerning Autocogeneration

The laws of nature are written by man. The laws of biology must write themselves. [von Foerster 2002]

…[T]he spontaneous emergence of self-sustaining webs is so natural and robust that it is even deeper than that specific chemistry that happens to exist on earth; it is rooted in mathematics itself. [Kauffman 1994]

…[T]he potential diversification and plasticity in the family of organic molecules has made possible the formation of networks of molecular reactions that produce the same type of molecules that they embody, while at the same time they set the boundaries of the space in which they are formed. These molecular networks and interactions that produce themselves and specify their own limits are…living beings. [Maturana and Varela 1998]

…[A] fundamental challenge for autocatalytic, self-ordering theories of evolution is this: Can hierarchical, cybernetic controls evolve spontaneously…? [Corning 2005]

…[T]he very gratuitousness of these systems, giving molecular evolution a practically limitless field for exploration and experiment, enabled it to elaborate the huge network of cybernetic interconnections which make each organism an autonomous functional unit, whose performances appear to transcend the laws of chemistry if not to ignore them altogether. [Monod 1972]

No preformed and complete structure preexisted anywhere; but the architectural plan for it was present in its very constituents. It can therefore come into being spontaneously and autonomously, without outside help and without the injection of additional information. [Monod 1972]

Autonomy in living systems is a feature of self-production (autopoiesis), and…a living system is characterized only as a network of processes of production of components that is, continuously and recursively, generated and realized as a concrete entity (unity) in a physical space, by the interactions of the same components that it produces as such a network. [Maturana 1974]

It is as if the cell has interposed between its genome and its behavior a second informational system able to integrate environmental and genetic information into its dynamical process, and able to generate from this integration responses that are functional – adaptive. [Strohman 1997]

The emergence of autocatalytic sets is almost inevitable. [Kauffman 1994]

…*[A]utonomy* becomes synonymous with *regulation of regulation*. [von Foerster 2002]

The meaning of the signals of the sensorium are determined by the signals of the motorium; and the meaning of the signals of the motorium are determined by the signals of the sensorium. [von Foerster 2002]

What is distinctive about [living beings], however, is that their organization is such that their only product is themselves, with no separation between producer and product. [Maturana and Varela 1998]

…*[S]elf-programmable matter* is a dynamical system of interacting elements, with associated functional properties, which through their autonomous dynamics, develop new compositions of elements with new associated functional properties. Such systems are characterized by an *ability to construct novel elements within themselves*. [Rasmussen, Knudsen and Feldberg 1992]

This balance requires that the final flows of materials generated by the electronic transitions return to points in the network where they originated. Thus, the steady state is necessarily characterized by cyclic flows of material around loops in the reaction network. [Morowitz 1992]

Life is universally understood to require a source of free energy and mechanisms with which to harness it. Remarkably, the converse may also be true: the continuous generation of sources of free energy by abiotic processes may have forced life into existence as a means to alleviate the buildup of free energy stresses. [Morowitz and Smith 2006]

In my version the history of life is counterpoint music, a two-part invention with two voices, the voice of replicators attempting to impose their selfish purpose upon the whole network and the voice of homeostasis tending to maximized diversity of structure and flexibility of function. The tyranny of the replicators was always mitigated by the more ancient cooperative structure of homeostasis that was inherent in every organism [Dyson 1999]

Contemporary organisms achieve specificity through a codependent relationship between templates and enzymes. Proteins and nucleic acids synthesize each other through a replication mechanism in which none of the components synthesizes itself. [Bagley and Farmer 1992]

Unquestionably, a factory could not originate through some natural phenomenon and independently of man, simply because every factory is constructed in accordance with some set, previously worked out plan. Everything in the factory, beginning with the erection of the building and machinery down to the arrangement of different sections, has been calculated by the engineer with a view to fulfill definite and foreseen aims. The natural elements could not accomplish such human objectives or fulfill a previously laid-down plan. (p.61) [Oparin 1938]

The OCS Idea of Autocogeneration

What generates this change, this "reorganization"? OCS proposes that an organic system mostly generates its own change. As observed by Monod: "…[A] living being's structure results from a totally different process, in that it owes almost nothing to the action of outside forces, but everything from its overall shape down to its tiniest detail, to 'morphogenetic' interactions within the object itself." [Monod 1972].

Essentially, the term *autocogeneration* has been coined by this author to mean: the self-generation of a system by virtue of its components generating each other as well as generating relationships among those components.

Paradox Raised and Resolved

But this raises a philosophical difficulty – the bootstrap problem. How does a thing generate – originate, grow, replicate, manage – itself? How can a thing bring itself into existence if it does not already exist? It seems a paradox.

OCS resolves this paradox by leveraging the fact that organic systems, *being systems*, have components. Originally there is no system. There are only components. The components then coalesce and form relationships. And the system itself *is* those components and their relationships.

Interdependent Co-origination

Once some components that have the ability to create more components exists, they may also be able to organize (form relationships with) each other and generate more of each other. But, since the organic system is constituted by its components and their relationships, then the organic system *is* generating itself as a result of its components generating each other through their relationships. This is autocogeneration.

In living systems, a consequence of all of these dynamics – this buildup and breakdown – is the maintenance of *organization*. Consider these words from a popular cell biology textbook:

> One property above all makes living things seem almost miraculously different from nonliving matter: they create and maintain order, in a universe that is tending always toward greater disorder. To create this order, the cells in a living organism must carry out a never-ending stream of chemical reactions. In some of these reactions, small organic molecules – amino acids, sugars, nucleotides and lipids – are taken apart or modified to supply the many other small molecules that the cell requires. In other reactions, these small molecules are used to construct an enormously diverse range of proteins, nucleic acids, and other macromolecules that endow living systems with all of their most distinctive properties….[ECD 2004].

Autocogeneration can be seen as a generalization of the concept of cellular metabolism – a generalization that can be taken to other spaces beyond the biological. But buildup and breakdown are not enough machinery to describe all that transpires here. Both metabolism and genetics exhibit still more complex reorganizational feats.

These processes also produce complex network behaviors including branching of processes, cyclic behavior and regulatory management [Kauffman 1994]. For example, a widely discussed example from genetics is how proteins regulate gene expression, which controls the creation of RNA that determines the creation of proteins. As emphasized by Wilkinson, "Note that auto-regulation by its very nature implies a 'loop' in the reaction network." [Wilkinson 2006].

Autocogeneration is not a new idea, but an integration of others. We shall cite two specific theories as predecessors. First, we are obliged Humberto Maturana [Maturana 1974] with the theory of *Autopoiesis*. The essentials of the theory are that living systems are both closed and open systems. At the risk of oversimplifying…they are open networks pertaining to their intake and outgo of food and energy. But they are closed with respect to their functions: they are networks of components whose function is to generate each other. [Maturana 1974]

Then there are the cross-catalytic theories of Santa Fe Institute biologist Stuart Kauffman [Kauffman 1993]. This is a somewhat abstract theory that demonstrates the possibility of complex molecule type A, consisting of components a1 and a2, behaving as a catalyst to construct complex molecule type B from components b1 and b2; while at the same time molecule type B behaves as a catalyst to construct complex molecule A from components a1 and a2.

This example immediately ramifies into the more complex idea of a directed network of a large number of such molecules that contrive to catalyze each other in a set of cross-catalytic relationships. This network is called an *autocatalytic set* [Kauffman 1993].

The OCS organizing principle named *autocogenerative*, then, embodies many of the implications of such theories as *autopoiesis* and *auto-catalysis*, as well as seminal ideas of autonomy that have been expressed by many others. The statement of the organizing principle reveals the manner in which autonomy operates within organic systems in order to encourage both continuation as well as adaptation in response to environmental conditions.

Regularity and Regulation

A consequence of autocogeneration, however, is that it can enable the continuation of operations that are "working" while enabling a change ("correction") in operations that that are no longer "working". In short, autocogeneration can result in system *regulation*.

One kind of system regulation is named *homeostasis*. Homeostasis, associated in Cybernetics by "negative feedback", is a self-correcting mechanism [Wiener 1961].

The importance of homeostasis in organic systems cannot be overstated. Kauffman makes this case. "For a dynamical system…to be orderly, it must exhibit homeostasis: that is, it must be resistant to small perturbations." [Kauffman 1994]. And, again Dyson offers: "The essential characteristic of living cells is homeostasis, the ability to maintain a steady and more-or-less constant chemical balance in a changing environment…. Without homeostasis there can be no ordered metabolism and no quasi-stationary equilibrium deserving the name of life." [Dyson 1999]

A second kind of system regulation that is embodied by autocogeneration is the opposite mechanism to homeostasis, described in Cybernetics as "positive feedback". Since it functions in the opposite manner as homeostasis, we shall name it *heterostasis*. (Whereas, homeostasis acts to keep the system organization "the same"; heterostasis acts to make the system organization in some state other than what it was.) By itself, heterostasis can result in instability – such as a runaway train. ("The rich get richer and the poor get poorer.")

However, in autocogeneration, both homeostasis and heterostasis cooperate and interoperate to result in a dynamic and adaptive regulation mechanism. The interplay between homeostasis and heterostasis is a relatively sophisticated expression of autocogeneration. Homeostasis serves to continue a process whenever it is "working"; while heterostasis serves to change a process when conditions change in such a way that it ceases to function well (adaptation). Both of these, and their interplay and coordination, are expressions of autocogeneration.

This combined cooperation mechanism is identified by OCS and named *regularity selection*. Regularity selection is any mechanism that selects between homeostasis and heterostasis depending on which promotes persistence under current conditions. *Regularity selection* can be thought of as *the regulation of regulation* mentioned by von Foerster [von Foerster 2002].

In Cybernetics, "regulation" is performed by a system component, named a *regulator*, which is dedicated to the role of regulation. However, in OCS, there is no requirement for a regulator component to exist! It may exist, but it may not. In OCS, regulation often occurs simply as a property of the system process itself. Regularity need not be implemented as a set of "rules". Indeed, it can be a natural consequence of the architectural dynamics of an autocogenerative system.

An example of this endemic regularity that functions without a dedicated regulator component is the well-known predator-prey model, discovered independently by the Italian mathematicians Lotka and Volterra in the early 20th century [Hazen 2002].

In this dynamic, the population size of each species continuously rises and falls, one lagging slightly behind the other. Thus, we can see that "regular behavior", or regulation, occurs. However, there is no particular component of the system that is "the regulator" and there is no apparent set of rules that are enforced by any such regulator. Rather, the regulation is a result of the nature of the system's own organization and dynamics.

Organic Systems are Uncertain

[All living processes depend upon both chance events as well as deterministic ones. Living processes operate along a spectrum between complete randomness and complete determinism, uncertainty and predictability. Where along that spectrum an organic system lies at any time is uncertain. Thus, the degree of predictability or uncertainty of an organic system is itself uncertain. ("Life is unpredictably uncertain.")]

Citations from Scientists Concerning Uncertainty

Pure chance, absolutely free but blind, at the very root of the stupendous edifice of evolution: this central concept of modern biology is no longer one among other possible or even conceivable hypotheses. It is today the *sole* conceivable hypothesis, the only one that squares with the observed and tested fact. And nothing warrants the supposition – or the hope – that on this score our position is likely to ever to be revised. [Monod 1972]

The important point is that this result is achieved without design or foresight. The mutations are caused by replication accidents, fortuitous events that bear no relationship to the production of better replicators. This is the essence of Darwin's theory. Natural selection operates blindly on material offered by chance. [de Duve 1995]

With the globular protein we already have, at the molecular level, a veritable machine – a machine in its functional properties, but not, we now see, in its fundamental structure, where nothing but the play of blind combinations can be discerned. Randomness caught on the wing, preserved, reproduced by the machinery of invariance and thus converted into order, rule,

necessity. A *totally* blind process can by definition lead to anything; it can even lead to vision itself. [Monod 1972]

Physicists have abandoned determinism as a fundamental description of reality. The most precise physical laws we have are quantum mechanical, and the principle of quantum uncertainty limits our ability to predict, with arbitrary precision, the future state of even the simplest imaginable system. [Lemons 2002]

$\Delta x \Delta p_x \geq h$. This uncertainty relation specifies the limits within which the particle picture can be applied. Any use of the words "position" or "velocity" with an accuracy exceeding that given by [this] equation is just as meaningless as the use of the words whose sense in not defined. [Heisenberg 1930]

$\sigma_p \Delta_x \geq \pi \hbar$, and this bound cannot be further improved. [Schürmann and Hoffmann 2009]

One would think such a haphazard concoction of thousands of molecular species would most likely behave in a manner that was disorderly and unstable. In fact, the opposite is true: order arises spontaneously, order for free. [Kauffman 1994]

The temporal dynamics of a biomolecular reaction system is the evolution of the system state in time, which can be modeled as a Markov process that is generally described by the Chapman-Kolmogorov equation…. [Hlavacek and Yang 2010]

Consider a bi-molecular reaction….What this reaction really means is that a molecule of X is able to react with a molecule of Y if the pair happens to collide with one another (with sufficient energy), while moving around randomly, driven by Brownian motion. [Wilkinson 2006]

In general, there is no set of observations conceivable which can give us enough information about the past of a system to give us complete information as to its future. [Wiener 1961]

*The creation of energy channels by means of phase transitions provides a way to understand how the core biochemistry of life can have been stable throughout the age of the earth: a state of the geosphere which includes life becomes *more likely* than a purely abiotic process. The non-living earth would have become *metastable* under conditions of continuous geochemical free energy production. "Its collapse" to greater stability was the emergence of life. [Morowitz and Smith 2006]

…[M]eaningful information necessarily emerges only as an interplay between random events and deterministic selection. Each on its own are insufficient. [Vedral 2010].

Once instability is included…the meaning of the laws of nature changes radically, for they now express possibilities or probabilities. Here we go against one of the basic traditions of western thought – the belief in certainty. [Prigogine 1996].

What is now emerging is an "intermediate" description that lies somewhere between the two alienating images of a deterministic world and an arbitrary world of pure chance. [Prigogine 1996].

The development of neuronal arborizations is a remarkable mixture of deterministic and stochastic events. [de Duve 1995]

Evolution involves both deterministic and random processes, both of which are known to contribute to directional evolutionary change. [Rice 2008]

This perpetual novelty renders it difficult to make predictions…[HollandJH 1998]

The thesis I shall present in this book is that the biosphere does not contain a predictable class of objects or of events but constitutes a particular occurrence, compatible indeed with first principles, but not deducible from those principles and therefore essentially unpredictable. [Monod 1972]

We call these [mutation] events accidental; we say that they are random occurrences. And since they constitute the *only* possible source of modifications in the genetic text, itself the *sole*

repository of the organism's hereditary structure, it necessarily follows that chance *alone* is at the source of every innovation, of all creation in the biosphere. [Monod 1972]

…[H]ighly improbable "self-organized" assemblies may be shown to arise by a combination of random composition seeding and gradual mutation-like small compositional changes. [Segre' and Lancet 1999]

The OCS Idea of Uncertainty

OCS postulates that life persistently exhibits a spectrum of behavior that ranges along an entire continuum between *complete determinism* (*certainty*) and *complete randomness* (*uncertainty*) - with much of its time being spent between these two poles. But this sixth organizing principle, the uncertainty of organic systems, goes beyond the epistemological and into the operational by characterizing how life inter-mingles determinism and randomness at every level.

This postulation puts OCS squarely within the realm of *information theory* – whose mathematical foundation also postulates that *information* can be measured on a scale that ranges from complete certainty (total determinism) to complete uncertainty (total randomness).

It is generally held that "situations" are either *deterministic* or they are *random* – that these are mutually exclusive concepts. Yet in OCS, rather than arguing about which of the two is "the nature of the universe", we are postulating (as does information theory) that *determinism and randomness* are mere poles of a continuum. And the entire continuum characterizes living system, not merely one of its poles.

OCS's *uncertainty* organizing principle can be almost entirely reduced to propositions from *information theory*. As explained by Richard Kleeman of the Courant Institute of Mathematical Sciences at New York University,

> The central idea of information theory is to measure the uncertainty associated with random variables. [Kleeman 2009].

A telling example is that of the process of DNA replication. When the enzyme DNA polymerase copies a DNA strand, the result is nearly always perfect - but not always. The random copy errors occur on the order of once in a billion copy attempts. The situation is "near-deterministic", but not completely deterministic. Its *degree of determinism* is "on the continuum", but very near the deterministic pole.

But, it is a very good thing that DNA replication is nearly deterministic, rather than perfectly so, because otherwise life would perish and cease to exist on earth! This is because these DNA copy errors provide an important mechanism (and it is a *chance* mechanism) for species adaptation, and therefore for Darwinian evolution [Monod 1972]. On the other hand, if, DNA replication were any more random than it is, then perhaps not enough of the "working parts" of parents would be preserved in their offspring.

On the other hand, the introduction of highly random phenomena into biological systems has been essential. A striking example of the introduction of increased randomness into the evolutionary process - resulting in an explosion of complexity, variety, adaptability, robustness and richness of life on earth – was the conspicuous emergence of sexual reproduction. This form of reproduction, through a process known as *meiosis*, functions by introducing a step which "shuffles the genetic deck" into the replication process [Watson 1970]. From a probability perspective, this step can be described as "interjecting a probability distribution whose degree of uncertainty is large into the dynamical process of gene selection."

Understanding Stochastic Dependence

When the outcome of one event affects the calculation of the probability of a second event, then we say that the second event depends on the first. This is called *stochastic dependence*. This happens, for example, when we know what cards have already been dealt from the deck ("card counting").

On the other hand, sometimes the knowledge of the outcome of one event does not help us calculate the probability of another. For example, the rolling of a die in succession is like this. Knowing that the first outcome is a "2" does not alter our calculation of the second outcome. This is called *stochastic independence.*

Probability theory (and mathematics in general) does not contain notions of "cause and effect". This is unfortunate for scientists, because they are very concerned about cause and effect and would often like to use probability theory to model it. However, probability theory does provide the notion of *dependent events* as an analog. The notion of *stochastically dependent events* is a reasonable model for phenomena in science that are either loosely or completely causal.

Thus, the notion of dependent events in probability theory is used to model causation to some degree. However, such modeling must be done very carefully, because the dependent events are not the same as causation. The most that can be said is that events in science that have either a strictly or loosely causal relationship can be modeled as dependent events. However, just because two events are stochastically dependent does not mean that they enjoy a causal relationship. Further, causation in science has a directional nature. But the stochastic dependence of two phenomena tells you nothing about such directionality.

Scientists often make the mistake of assuming that two or more events are stochastically independent when they are, in fact, statistically dependent. This misappropriation often causes problems because it can lead to wildly incorrect calculations of the probability that certain events occur jointly.

In my estimation, this mistake likely occurred in an often-quoted finding by Fred Hoyle and his collaborator Chandra Wickramasinghe [Hoyle and Wickramasinghe 2001]. They calculated the probability of a protein molecule coalescing "randomly" in the history of the universe as a value so small that it effectively ruled such occurrence out of admissibility.

OCS makes the case that biology is, from a probability and information theory perspective, a case study in stochastically dependent events. Virtually any "causal" event in biochemistry can be modeled in the language of probability as stochastically dependent events. Here are some examples: mutually polar molecules, the relationship between catalysts and substrates, chemical synthesis (e.g. energy and condensation), protein synthesis by RNA, and gene regulation.

It's not that "chance" is nowhere involved. Rather, it is that stochastic independence is the wrong probability model for these so-called "causal" events. The right model is more often one that exhibits *stochastic dependence*.

Can Chaos give rise to Order?

In the parlance of OCS (and information theory), the joint occurrence of stochastically dependent events often exhibits an intermediate degree of uncertainty as measured by Shannon entropy. [de Duve 1995] points out that this "constraint of chance" is due to any number of "sensitivities", "influences" and "significance". In other words, "true

randomness" is "constrained" by these "influences". But this is precisely the meaning of *stochastic dependence*.

We shall demonstrate below that *stochastic dependence* is responsible for much of the "surprisingly well behaved" dynamics of organic systems over time – even in the face of initial randomness.

The introduction of stochastic dependence into a process can drastically decrease the degree of uncertainty of the events in the process as it proceeds forward in time. In other words, stochastic dependence can evolve a highly uncertain situation into a predictable one. So, the presence of *stochastic dependence* can move chaos toward order!

Examples of stochastic dependence at work in biochemistry are: catalysis, autocatalysis and the use of information (nucleotides) to synthesize biomolecules. In other words, these biological phenomena can move randomness in the direction of determinism.

As indicated, an overall decreasing trend in uncertainty is often detected in organic systems. Of course, *in real life*, dependent stochastic processes do not generally present a strictly monotonically decreasing sequence of Shannon entropies. Rather, the degree of uncertainty of living systems, itself, changes uncertain in time.

Organic Systems are Persistent

[The nature of the autocogeneration and uncertainty of an organic system is that it engenders the ongoing existence of these systems. Taken together, all of these static and dynamic elements have resulted in, at the least, a limited persistence of life itself. While no organic system persists, the existence of organic systems has.]

Citations from Scientists Concerning Persistence

When is a piece of matter said to be alive? When it goes on 'doing something', exchanging material with its environment, and so forth, for a much longer period than we would expect an inanimate piece of matter to 'keep going' under similar circumstances [Schrödinger 1945].

Persistence of a pattern can occur by replication, as long as the pattern gives rise on average to more than one similar pattern, that pattern will exponentially increase. [Morowitz 1992]

The necessity of persistence in a nonequilibrium domain leads to a Darwinian-like struggle for survival long before there are organisms in a conventional sense. [Morowitz 1992]

…[T]he survival problem is ongoing, relentless and inescapable; it will never be permanently solved…. Life is, at bottom a survival enterprise. [Corning 2005]

The central feature in the organization of the organism lies in its manner of being a unity in an environment wherein it must operate with stable properties that permit it to conserve its adaptation, whatever the properties of its components may be. [Maturana and Varela 1998]

All functional adaptations in living beings, like all the artifacts they produce, fulfill particular projects which may be seen as so many aspects of fragments of a unique primary project, which is the preservation and multiplications of the species. [Monod 1972]

The stochastic chemistry approach is distinct from molecular dynamics in that no spatial details are obtained and only population time evolution of the different molecular species in the system are obtained. [Shenhav and Lancet 2004]

Here in this class of open thermodynamic systems, the spontaneous dynamics drive the system into an infinitesimal corner of its state space and hold it there, quivering for an eternity. Order for free….Nearby states converge in state space. In other words, two similar initial patterns will likely lie in the same basin of attraction, hence driving the system to the same attractor. Thus, such systems do not show sensitivity to initial conditions; they are not chaotic. The consequence is the homeostasis we seek. [Kauffman 1994]

The fact that their underlying deterministic dynamical equations appears to have a unique stable fixed point endows autocatalytic metabolism with a considerable degree of robustness to trauma. A perturbation in the concentration of one of its elements, for example, quickly dies out. Thus, "self-repair" of autocatalytic metabolisms is built into their chemical kinetics. [Bagley and Farmer 1992]

The OCS Idea of Persistence

The end result of the interplay of the other six organizing principles of OCS can lead to the organizing principle that organic systems are *persistent* – that is, that life, by its very nature, has the possibility of being self-sustaining.

Living systems specifically, and organic systems in general, are persistent because their dynamics conserve their "organic-ness", or shall we say their *organicity*. From the OCS perspective, this means that all seven of the organizing principles of OCS have the possibility of being conserved.

The first organizing principle can be conserved. This means that organic systems remain *systems* under the dynamics of OCS. The second organizing principle can also be conserved: organic systems remain emergent – and also deeply nested, as required by the third organizing principle.

The fourth organizing principle states that organic systems are dynamic, can change; and furthermore identifies some classes of transformations by which they can change. These possibilities can also be conserved.

The fifth organizing principle, *autocogeneration*, describes the *mechanisms* behind this conservation. Essentially, this organizing principle says that *homeostasis*, involving negative feedback cybernetics, is the mechanism that promotes the conservation of organization through these dynamics; while the mechanism that we called *heterostasis*, involving positive feedback cybernetics, promotes the alteration of organization, or the *reorganization*, of organic systems. This homeostasis manifests as survival, while heterostasis as adaptation. Through these two mechanisms, organic systems stay the same as long as they can; but can also change, adapt, to conserve their organicity.

The sixth organizing principle, *uncertainty*, says there is enough *stochastic dependence* to drive the *degree of uncertainty*, or entropy, lower. There is also enough stochastic independence to drive it higher. These two propensities give all of the mechanisms of autocogeneration their opportunities to operate – to often favor regularity when it promotes persistence; and to often favor irregularity otherwise. This stochastic interaction does not guarantee persistence, but it promotes its stochastic expectation.

The principle of *persistence* means *the conservation of organicity through the organizing principles of OCS*. Even though the *identities* of organic systems may be lost through their dynamics; nevertheless, their *organicity* can be conserved.

Organodynamics – The Formal Theory

> The whole process of metabolism still bears the marks of being somewhat chaotic, its different parts still lacking quantitative correlation. But gradually out of this chaotic metabolic activity strictly interrelated systems have evolved, which brought definite order and integration into the current chemical reactions. [Oparin 1938, p. 243]

Organodynamics is the formal embodiment of the OCS organizing principles. The task of Organodynamics is to establish a mathematical framework in which the seven organizing principles of OCS can be articulated; and then to subsequently discern the conditions under which, within that context, evolutionary transformation can arise.

This section on Organodynamics sketches an outline of the mathematics involved in the formal theory. Each subsection introduces mathematics that implements one or more of the seven OCS organizing principles, by which the section is titled.

Considerable detail on the development of Organodynamics is described in unpublished manuscripts also authored by this researcher [HollandJG-I 2011; HollandJG-II 2011; HollandJG-III 2011]. However, considerable work is still to be done; and it is hoped that this article will encourage an interest in further research in this area by other investigators.

Organization

Organic complex systems are organized because they are systems. It is their *systemics* that gives them their organization.

Organodynamics uses the language of set theory to define the notion of system. We begin by defining *system state* and then define other systemic ideas. A system's *state* is constituted as:

- A *population*: a set whose elements are called *components*
- An *organization*: a set whose elements are ordered pairs, called *duples*, of the population's components.

A highly organized system state will contain many duples; while a highly disorganized system state will contain few – maybe even none, in which case the organization will be the empty set. An organization is referred to either as an *organization of the population* or as an *organization of an underlying system*. Thus, a *state of a system* is a pair (P, O_i), where P is a population and O_i is an organization of P. A system's state is often abbreviated to it organization: O_i; however its complete state (P, O_i) is implied.

A system's state space is the set of all of its possible organizations. That is, $Q = \{ O_i \mid O_i$ is an organization of the system$\}$.

Having defined the necessary terminology we can now define system:

A system is the pair (P, Q), where P is the system's population and Q is the system's state space.

Reorganization

OCS is interested in the change of system state of a system. Such a change is referred to as *reorganization* because it usually entails a change in *organization*. We shall initially represent this change via a mathematical construct called a *system process*.

A system process is an indexed sequence of *system states*, each of the form (P, O_i), as defined above; but that are often abbreviated merely to O_i. Each consecutive element (state) in this sequence is, without loss of generality, referred to as a *time step.* Within a system process, the smallest instance of change is a transition between two consecutive time steps. This transition is referred to as a *system transform*.

A system transform is a mathematical function that maps the state at one time step (the function's domain element) to the state at the next consecutive time step (the function's codomain element). An optional articulation of a system process is a functional composition of consecutive system transforms, called a composite system transform.

Evolutionary Transformation captures the notion that one of more of the seven OCS organizing principles can improve over time. This is represented in OCS by a composite system transform whose measure of one or more of these principles of organization

increases over time. An example of such improvement would be the *degree of uncertainty* decreasing – as measured by *Shannon's entropy* (discussed next).

Uncertainty

Organodynamics models *uncertainty* with probability spaces, which is the mathematical representation of randomness.

Probability Distributions

A probability space represents randomness via the concept of an experiment. Each observation of the experiment is called a trial. The values of the trials must be members of a set called the sample space of the experiment. The members of the sample space, then, behave as alternative outcomes.

A probability space is defined as a set of three sets: 1) the sample space, 2) a sigma-algebra, called the events, which is generated from the sample space, and 3) a probability measure on the events.

The members of the sample space are also called sample points, "outcomes", or "alternatives". The use of the sigma-algebra is a way to create a larger set to assign probabilities to than only the sample space. This larger space, "the events", includes the sample points as well as their logical combinations.

A probability space can be summarized and abbreviated by only discussing parts 1 and 3 of the probability space: the sample space and the probabilities of its sample points. This abbreviation is called a probability distribution. The events and their probabilities are implied.

Random Variables

In general, the sample points can be anything that represents the outcomes of a trial. Outcomes are not generally numbers, but rather configurations of states, such as Heads and Tails. In the case that the sample points consist of numbers, it is possible to calculate means, medians, standard deviations, and other statistics. However, if the sample points are not numbers, then these statistics cannot be calculated.

But, if the sample points of the probability distribution are not numbers, then we can associate (map or substitute) real numbers to those sample points. For example, we could substitute the number of heads for the configuration of heads and tails in a coin toss. Once we perform this mapping, then we have a related probability distribution whose sample space has numbers. And, we are now able to calculate statistics on this new probability distribution. Such a mapping is called a random variable.

In many cases it is highly desirable to develop a random variable version of a probability distribution in order to be able to calculate statistics. One particular set of statistics is called "moments of a random variable". These include the mean and the variance. In Organodynamics, we often consider the probability distributions using the initial sample space without mapping them to the real numbers. But, we also use random variables as well. Not all probability distributions in Organodynamics require random variables.

Organodynamic Probability Distributions (OPDs)

The sample spaces that we use in Organodynamics are very special – and complex. Their individual sample points are, in fact, system organizations. This means that each sample point (alternative) is a set of ordered pairs (duples) of components of an

underlying system population. We give these probability distributions a special name: organodynamic probability distributions, or OPDs.

The probability of a sample point of an OPD measures the likelihood at the current time that the sample point (a system organization) will be realized at the next time step. Thus, an OPD is a probability distribution whose sample space is the set of all possible system organizations of an underlying population. Organodynamics is the study of OPDs.

Interdependence of the OCS Organizing Principles

Knowing the OPD at a certain time enables one to make many statements about the states of the seven OCS organizing principles at that or future times. For example, since the OPD describes system organizations and their probabilities for an underlying system, then many conclusions can be drawn regarding the first organizing principle: *organization*. And, since the OPD is a probability distribution, then its *degree of uncertainty* can be calculated. We can also determine many aspects regarding the *nested* and *emergent* organizing principles as well as their probabilities. As we develop more machinery around the OPD, we shall see that we can also project information regarding the *persistence* and *autocogenerative* principles and their probabilities.

Thus, from these relationships, we can derive probability distributions pertaining to organizing principles other than the first – which is directly addressed by the OPD. These other probability distributions are functions of the OPD, and some of them are random variables. Since these distributions are derived from each other, then there is mutual stochastic dependence among them. This interdependence is explored more below. It is central to the formal theory and the applications of Organodynamics.

Joint OPDs

Thus, the collective exhibition of the seven organizing principles by an organic complex system over time depends on their collective prior exhibitions at an earlier time. That is, the seven organizing principles are probabilistically interdependent. This interdependence can be represented by a joint probability distribution where each organizing principle is a dimension in the joint sample space. These joint OPDs will play a central role below in the development of *evolutionary transformation* in Organodynamics.

Also, one can form joint distributions of smaller dimensions where a subset of the seven organizing principles is used. These joint distributions will be indispensible to us later when we study the long-range behavior of organic processes.

Random Variables of OPDs

Some of these derived probability distributions are random variables. Specifically, we shall address two of these below.

Related to the first organizing principle is a measure of the degree of organization exhibited by each of the system organizations in the sample space. We shall define the *organizational extent* of a system as the count of the number of ordered pairs of components within the organization being measured. Clearly, organizational extent is a function that assigns a real number to any system organization – and therefore to each sample point in the OPD. Consequently, *organizational extent* is a random variable on the OPD. Organizational extent is an obvious, even simplistic, measure of *degree of organization*. Further research is suggested to identity more consequential measures.

A second random variable on the OPD is the *measure of uncertainty* associated with each sample point. We shall take this measure from information theory. It is the notion of the surprisal of an event E. Information theory declares that the *degree of the uncertainty* of an event should be inversely proportional to its probability. In other words, the more unlikely an event, the more uncertain it is that the event will be realized by a trial.

Moreover, information theory also declares that, should an event be realized, its informational value (*degree of information*) should be the same as its *degree of uncertainty* [Khinchin 1957]. Thus, we shall refer to both of these values as "I(E)", or the "information value inherent in event E". Another way to describe this value is "how surprised" one is whenever the event is actually realized. In information theory, this value is called the surprisal of the event, and is given by the formula:

$I(E) = \log(1/Pr(E))$, which is equal to
$I(E) = - \log(Pr(E))$

Thus we have defined random variables for two of the seven OCS organizing principles: *uncertainty* (principle 6) and *organization* (principle 1).

Uncertain Reorganization

This section discusses how to introduce organodynamic probability distributions (OPDs) into the *system processes* that we discussed earlier. This integration will provide a probabilistic form of system process, which we shall call an *organodynamic process* and use henceforth to represent the dynamics of organic systems.

Stochastic Processes

A stochastic process represents probabilistic change of system state over time. A stochastic process is implemented as an indexed sequence of probability distributions. Without loss of generality, the elements of the sequence represent consecutive points in time. Thus, each indexed element in the sequence is referred to as a *time step*.

Organodynamic Processes

We shall define a special kind of finite step stochastic process that will form our basic model of organic systems. We shall call these models *organodynamic processes*. For them, the probability distribution for each time step is an OPD. Often, the sample spaces of an *organodynamic process* are all based on the same underlying system population, but each time step may have its own OPD. One can think of an *organodynamic process* as a system process whose single system state time steps have been replaced by a whole sample space of system organizations and their probabilities.

We shall also define *organodynamic cessation*, aka *cessation* as: the final time step of an organodynamic process. This cessation occurs whenever at least one of the seven OCS organizing principles no longer obtains. (Because all seven are necessary conditions for organicity.)

Organodynamic Transforms

When we defined *system process*, we also defined the related idea of *system transform*. The *system transform* is a way to model the transition between consecutive time steps as a mathematical function. Just so, we shall bring the corresponding idea to organodynamic transforms. Thus, within an organodynamic process, an *organodynamic*

transform is a probabilistic function that maps an OPD at one time step to an OPD at the next time step.

So, an organodynamic transform provides a way to change the probabilistic state of an organodynamic process from one time step to the next. Whereas system processes and transforms are deterministic and only provide one possible state for each time step; organodynamic processes and transforms are stochastic and describe a whole range of possible states and probabilities at each time step. Organodynamic transforms generally work by changing probability distributions, and thus alter the entropy as well. They are used to model the occurrence of events that change the current state of an organodynamic process.

Organodynamics defines several categories of *organodynamic transforms* by "stochasticising" the existing system transforms. Generally, every defined system transform has a corresponding organodynamic transform. These include: Reform, Replicate, Catalyze, Consume, Expel and other transforms that mimic the behavior of living systems. Organodynamics emphasizes organodynamic transforms, and only defines system transforms as a foundation to develop organodynamic transform.

Dependent Stochastic Processes and Markov Chains

Probabilities at each time step in a stochastic process can be influenced by the outcomes of previous time steps in the same process. When this occurs, the stochastic process is called a *dependent stochastic process*.

In order to make use of this dependency information, a *collection* of distributions is used at each time step – one for each influencing condition. Depending on the outcome of the current time step, one of the distributions is selected for "predicting" the next time step. Thus, these distributions are called *conditional distributions*. A Markov chain is dependent stochastic process whose influencing conditions pertains only to outcomes of current time step, and is not influenced by outcomes of previous time steps.

In Organodynamics, these conditional distributions are also OPDs (conditional OPDs), because they share the same samples space of system organizations. For a dependent stochastic process these distributions are represented in a matrix - the *transition matrix*.

Stochastic Dependence and the Auto-regulation of Uncertainty

Stochastic dependence among the times steps of a stochastic process reduces the overall uncertainty of the process. Depending on the degree of interdependence, this reduction in uncertainty can be drastic. This fact turns out to be the deciding factor that makes *evolutionary transformation* work.

Let's first set the context for what stochastic interdependence means by entertaining a simple scenario. Suppose we have a finite stochastic process with, say, three time steps: X_1, X_2, X_3. Of course, each of the three time steps has its own probability distribution – each with its own entropy value. We could add these three entropies to get the sum for the entire process.

On the other hand, we could look at this in another way – a way that considers the process-as-a-whole. This way considers the joint occurrence of all three events as the triplet (X_1, X_2, X_3). Each possible configuration of this triplet would be a sample point, e.g. (x_{i1}, x_{i2}, x_{i3}). And of course each such sample point would have its own probability. So, what we have just constructed is the *joint distribution* of the whole process. As a probability distribution, this joint distribution has entropy, which is calculated against all if its sample points. This is called the *joint entropy* of this three-step stochastic process.

So, we now have two different ways to look at the "overall entropy" of this three-step stochastic process: 1) the sum of the entropies of the individual probability distributions of each of the three time steps; or 2) the *joint entropy* of the three-step process (which is the entropy of the *joint distribution*). It is the difference between these two entropy values that is significant to the concept of stochastic dependence.

It turns out, as we shall demonstrate below, that the joint entropy will be less than the sum of the individual entropies whenever the three time steps are mutually dependent – or have influence on each other's outcomes. But they will be the same whenever the three time steps are stochastically independent. Moreover, the more interdependent they are, the less will be the joint entropy.

It also turns out that the *joint distribution* models the process as a whole – not the distributions of the individual time steps. And it is therefore the *joint entropy* that models the *degree of uncertainty of the process as a whole* – not the sum of the entropies of the individual time steps.

Clearly, adding a new time step to a stochastic process adds some amount (possibly zero) of uncertainty to the whole process (the joint distribution). If the new time step is stochastically dependent on some of the previous ones, then the total amount of entropy that it adds will be less than the individual entropy of the new time step. But, if the new one is independent of the previous then the additional joint entropy will be the same as the individual entropy of the new time step [Kleeman3 2009]. In fact, if the new time step is totally determined by the previous ones, then the increase in joint entropy is zero.

Let us now proceed to provide the mathematical background to demonstrate this reduction in overall (joint) entropy due to stochastic interdependence.

Stationary Distributions in Markov Chains

In Organodynamics, we have made the conservative but simplifying assumption that organodynamic processes are Markov chains. For this case, we can make even stronger statements than made in the previous subsection: There are conditions under which the long run behavior of Markov chains asymptotically approach a specific probability distribution. This distribution is called the *stationary distribution* of the Markov chain [Kemeny and Snell 1969, p100].

These conditions are well known [Kemeny and Snell 1969, p100]. They are these: the chain must be homogeneous (transition matrix does not vary), and it must be *irreducible* – which means all states can "reach" all other states in a finite number of time steps.

Moreover, under these conditions, it can be shown that adding a new time step to a Markov chain increases the joint entropy by a quite limited amount - no greater than the conditional entropy of the second step of the segment given the first – that is, no greater than $H(X_2| X_1)$ [Kleeman3 2009].

Thus there is a degree of self-regulation in Markov chains that pervades Organodynamics. This self-regulation pertains to limits on uncertainty of these chains, and is the result of the stationary distribution and its entropy.

Stochastic Dependence and Reductions in Entropy

Lets now drop the special assumption that organodynamic processes exhibit the Markov property, and assume only that they are stochastically dependent. It turns out that the reduction in entropy of the overall process due to stochastic independence still holds. We shall now look at the mathematics behind this phenomenon. This mathematics

properly belongs to the field of *information theory*. We shall cite the pertinent results from information theory here, but refer the reader to various sources for most proofs.

We shall argue that the joint entropy of a stochastic process is reduced whenever the time steps of the process are mutually stochastically dependent, or *stochastically interdependent*.

We have already discussed that by "a stochastic process as a whole" is meant the joint probability distribution of its time steps. Such a state is represented by the ordered tuple $(x_1,\ldots,x_n)$, where X_i are probability distributions (random variables), the x_i are sample points of the X_i, n is the number of time steps, and $(X_1,\ldots,X_n)$ is the joint distribution.

This is measured mathematically by comparing the following two values:

    A) The sum of the entropies of all of the time steps of the process including the new one. This is represented by $\sum_{i=1,n} H(X_i)$.
    B) The *joint entropy* (from the joint distribution) of all of these time steps. This is represented by $H(X_1,\ldots,X_n)$.

There is a theorem in information theory [Kleeman2 2009] that says the following: $H(X_1,\ldots,X_n) \leq \sum_{i=1,n} H(X_i)$, where "H" is the entropy measure of a random variable or probability distribution.

Moreover, $H(X_1,\ldots,X_n) = \sum_{i=1,n} H(X_i)$ if and only if the $X_1,\ldots,X_n$ are stochastically independent. Therefore, $H(X_1,\ldots,X_n) < \sum_{i=1,n} H(X_i)$ if and only if the $X_1,\ldots,X_n$ are stochastically dependent.

The theorem says that equality holds whenever the probability spaces (random variables) are mutually independent; but that the inequality holds if they are mutually dependent. In words, the joint entropy is always less than the sum of individual entropies - unless variables are stochastically independent, where they are equal [Kleeman2 2009]. The "more dependent" are the random variables, the smaller is the $H(X_1,\ldots,X_n)$.

In order to see how much "additional entropy" has been added to a stochastic process by the addition of a single new random variable (time step distribution), then it is reasonable to take the average of the joint entropy. This average, called the *entropy rate* of the stochastic process is:

    Entropy rate = $H(X_1,\ldots,X_n)/n$

Explains Richard Kleeman of the Courant Institute of Mathematics at NYU:

> "The entropy rate is the additional uncertainty added to the whole chain introduced by adding another random variable and in general this will be less than this particular variable by itself since there is dependency between the random variable then and earlier random variables in the chain."

Note that if the outcomes of new time steps are completely determined by previous time steps, then the stochastic dependency is so extreme that we have a completely deterministic situation. In such a case, the entropy rate becomes zero. Thus, in extreme cases of stochastic interdependency, the additional entropy added by additional time steps can be radically reduced.

The point being made here is that stochastic processes whose consecutive outcomes are highly interdependent are kept from "wandering off into chaos", and can instead exhibit very predictable behavior – despite the fact that that can be accurately described as being "random processes". This contradicts the popular notion that any "random process" must necessarily lead to chaos.

Scientists often fail to take the constraining affect of stochastic interdependency into account when surmising probabilities of long run processes. A case in point is that of [Hoyle and Wickramasinghe 2001] fervently deny the possibility of life arising from a random process. To prove their point they calculated the probability of a protein molecule coalescing "randomly". Their calculation produced a value so small that it effectively ruled its occurrence out of admissibility. A look at their calculations reveals that they assumed that all steps in the process of building up the protein molecule were mutually stochastically independent. (They multiplied together the individual probabilities.) However, if they had assumed that these steps were stochastically *dependent*, then their calculation could have produced a radically different result – so much so that the probability that a protein molecule coalesced randomly may not be out of the question.

The interpretation of all of this by Organodynamics is that stochastic interdependence brings a self-regulating result to organodynamic processes that constrain entropy rates.

Interrelationships between Uncertainty and Disorganization in Organodynamics

Early in this article, we presented an idea that is contrary to a popular interpretation of the second law of thermodynamics. The idea is that entropy can increase without a corresponding increase in the degree of disorganization.

We demonstrated the reasonableness of this idea by inspecting the definition of entropy in statistical mechanics as defined by Gibbs. We also reiterated the Organodynamics view of *degree of disorganization* as a function of component interrelationships – a view most certainly compatible with common usage.

To review, recall Gibbs' entropy formula:

$$\text{Entropy} = -K * \sum Pr(E) * \log(Pr(E))$$

The conclusion that we then drew was that *entropy measures only uncertainty*. And entropy *does not* measure degree of disorganization.

At this time, lets take this idea somewhat further and consider what it implies about the interplay between the two dialectics of *certainty/uncertainty* and *organization/disorganization* in Organodynamics. As a point of context, we have discussed *organization/disorganization* in terms of components. But this includes *organization/disorganization* among *systems* as well, since in Organodynamics a collection of interrelated systems would collectively form a composite system of which they are components.

First, it is interesting to note that in the context of Organodynamics and OPDs *complete disorganization* implies low entropy, not high entropy. Here is why. Consider an OPD wherein disorganization is at its maximum. This means that the organization with the maximum degree of disorganization (the empty set) has probability of 1, while the remaining organizations have probability of 0. But such an OPD has entropy of 0; which is the minimum possible. Thus, while the degree of uncertainty and the degree of organization are not deterministically related, they are nevertheless interdependent.

On the other hand, suppose that the entropy of a time step were at the maximum. Then the OPD describing this situation is uniform. But this means that all possible system organizations are equally likely. And this would imply that all degrees of organization would occur as often as each other, including both high and low degrees of organization. Thus, low degrees of organization could not dominate – as commonly assumed.

Moreover, in apparent contradistinction to the 2nd law, entropy of a stochastic process can decrease! This is demonstrated by [Kleeman3 2009, p5] by providing a counter-example. I shall interpret and summarize his explanation here.

Without loss of generality, assume that the stochastic process in question is a homogeneous irreducible Markov chain. Then, as we have discussed [Kemeny and Snell 1957], it has a limiting distribution – called its *stationary distribution*. So, its stationary distribution can be treated as the terminal distribution of the process. In addition, any stochastic process also has an initial conditions distribution. In order to prove our point, we must show that it is possible for the entropy of the initial conditions distribution to be no lower than the entropy of the stationary distribution.

This is easy to show, because the initial conditions distribution can be the uniform distribution, while the stationary distribution can be other than uniform, since there are countless examples of each. However, since the uniform distribution has the maximum entropy for the sample space involved, then we have demonstrated that entropy can be decreasing in a stochastic process.

Why then does statistical mechanics claim that entropy must be non-decreasing. Kleeman [Kleeman3 2009, p5] explains this as well. It seems that statistical mechanics assumes equilibrium conditions in the terminal state. However, equilibrium conditions by definition are defined stochastically by the uniform distribution. Therefore, the initial distribution can have no higher entropy than the terminal distribution. This explains why biological systems can demonstrate decreasing entropy over time, whereas an ideal gas in statistical mechanics cannot.

Stochastic Interdependence of the Principles of Organization

Thus far, we have discussed how stochastic interdependence imposes limitations on uncertainty. Given that *uncertainty* is an OCS organizing principle then we have linked stochastic interdependency to an OCS organizing principle.

But what does this say about the long run behavior of the other six OCS organizing principles? If we can show interdependency between uncertainty and the other six organizing principles, then we can extend these results to all seven of the OCS principles of organization. We shall discuss this now.

It can be immediately shown that this interdependency is not limited to the *degree of uncertainty (entropy)* with itself as a random variable. For example we have described above a number of cases in which the two OCS principles of *uncertainty* and *organization* can be shown to be mutually dependent.

Upon examination, we can reasonably assert that many – maybe all – the seven OCS organizing principles enjoy mutual stochastic dependencies. In probabilistic terms, this means that the probabilities of one of these variables tell us something about the probabilities of another one of these variables. In words, we could say that all of these probability spaces exert influence on each other. For example, *nestedness* influences *organization*; *organization* influences *reorganization*; *reorganization* influences *autocogeneration*, *nestedness* influences *emergence*; and they all influence *persistence*, which influence all the others. In fact, stochastic dependence is transitive.

The treatment of each of the seven OCS organizing principles as a random variable (or even a derived probability distribution), which can then be collected into a joint probability distribution, needs considerably more investigation. Such an investigation would certainly include the likely stochastic interdependency among all seven of the joint random variables.

The remainder of this article will proceed on the basis that the seven organizing principles are stochastically interdependent, and that they therefore exert influence on each other's probabilities.

Co-regulation of the Principles through Stochastic Dependence

We have suggested that the seven OCS organizing principles are stochastically interdependent. This means that these seven principles exhibit some degrees of probabilistic influence on each other. But this means that they also have a regulating effect on each other. We shall pursue this idea further in the next section on the fifth organizing principle, autocogeneration.

Energy and Entropy

Organodynamics represents *matter* with the constructs of *components*, *organizations* and *systems*. We now turn to how *energy* is represented in Organodynamics. In this section we go in search of a mathematical form that provides an adequate surrogate or proxy for energy.

Since OCS intends to completely abstract the concept of "the lifelike" beyond biological systems and even beyond physical systems, it is necessary to find some formal representation of energy that does not tie us exclusively to physical phenomena.

Although finding such a formulation of energy may seem unlikely and far-fetched, we shall show that not only does one already exist in mathematics and in physics, but also that we have heretofore, earlier in this article, incorporated it into the foundations of Organodynamics! No new construct will be needed.

Before exposing this construct, however, we intend to get at the very heart of the issue of energy, how it operates and what results it produces. That done, we shall then be in a position to reveal this remarkable construct and show that it does indeed expose the very essence of energy and its dynamics.

Energy and Entropy in Thermodynamics

We shall begin our search in the discipline of thermodynamics.

Energy Spread in Classical Thermodynamics

Classical thermodynamics focuses on energy and its behavior over time. One of the conclusions of thermodynamics is that energy "spreads", or disperses and dissipates. According to [Leff 2012], "A central thread is that energy tends to spread within and between macroscopic objects, and this spread is a surrogate for entropy increase."

Classical thermodynamics defines the function called *entropy* to measure this spread of energy.

Energy Spread in Statistical Mechanics

With the growing acceptance of the notion of the microscopic world of particles (atoms, ions and molecules) in the late 19th century, the need was seen to develop a new theory of thermodynamics that was postulated on the existence of this microscopic world within macroscopic objects. According to Professor Lawden [Lawden 1987], "This is the role of statistical mechanics, viz. to reinterpret the primary physical laws in the light of the chaos normally present in those macroscopic systems which are the common objects of experimental observation."

Statistical mechanics makes these observations:

1. The thermal state of a particle (e.g. its energy) can be calculated from its mechanical state (position and momentum).

2. The constituent particles (microsystems) of a body (macrosystem) are too numerous and too small to measure. Therefore it is more tractable to logically organize microsystems into categories where all microsystems in the same category have the same mechanical, and thus thermal, state. Such a categories are referred to as *microstates*. These microstates can be reasonably enumerated. Whereas classical thermodynamics deals with *objects* (macrosystems), statistical mechanics deals with microstates that collectively "constitute" macrosystems.

3. The set of all such microstates of a given physical system partition that system. Such a partition is called an *ensemble*.

4. Whether or not two particles (microsystems) exhibit the "same thermal state" depends upon the physical conditions under which they are being observed. For example, a closed system defines a different set of criteria for two systems to have the same thermal conditions than does a system where energy can be exchanged with the outside – as does a system in which both matter and energy can be exchanged from the outside. Thus, such criteria determine what the microstates of the system are – and therefore how it is partitioned. These criteria therefore produce three types of partitioning of microstates, and therefore three types of ensembles.

5. Because the mechanical or thermal properties of the particles are impossible to measure, they will be treated statistically. Thus, the relative numbers of particles in each microstate can change from moment to moment. These changes can be represented by a probability distribution for that ensemble for that moment.

6. The thermal properties of macrosystems (e.g. temperature) can be calculated as the sum (for extrinsic properties) or average (for intrinsic properties) of some combination of the properties of all of its constituent microsystems (microstates).

Maxwell was the first to introduce probabilities, and therefore statistics, into statistical mechanics – thereby giving it the name [Haw 2007].

Energy and Entropy in Statistical Mechanics

We just pointed out that the thermal properties of a macroscopic object are calculated from certain properties of its constituent microstates. For example, *temperature* is a macroscopic thermal property that is calculated from the collective properties of its constituent microscopic systems, including energy. Another example is *entropy*. Like temperature, entropy is a macroscopic thermal property that can be calculated by averaging certain properties of its constituent microsystems.

However, *entropy* is very different from other macroscopic thermal properties such as temperature. Entropy is different because the microscopic properties that are its input parameters *are not thermal properties* at all!

This distinction is key. In fact, entropy is calculated entirely from *the probabilities* of the microstates alone! This is made conspicuous by inspecting the formula:

Entropy = $-K * \sum Pr(E) * \log(Pr(E))$

The contention of Organodynamics is that, given these circumstances, it is very difficult to justify calling *entropy* a "thermal property". Since probabilities are the *only* parameters, it is obvious that some aspect of the randomness of the microstates strictly determines entropy.

But we have already seen that entropy is a measure of "energy spread" in classical thermodynamics. So it must seem quite surprising that *energy* is nowhere mentioned in this formula for "energy spread"!

But what specifically *is* being measured by entropy in statistical mechanics? It helps to understand that initially the "-" in the formula went with the expression "log(Pr(E))" to make

   "-log(Pr(E))", which equals "log(1/Pr(E))".

In other words, entropy varies inversely with probability. But this is also true of "uncertainty". As the probability of a phenomenon gets lower, its uncertainty gets higher.

And multiplying this product by its probability and summing is equivalent to taking the average of a set of "log(1/Pr(E))"'s. Thus, the formula for entropy takes the average of some things that vary inversely with probability. Shannon makes the argument that entropy, then, is a measure of the average *uncertainty* of the sample points of a probability distribution.

In statistical mechanics, then, the spread of energy becomes merely a specific case – a specific application – of the average uncertainty of "some things" – the microstates. The formula does not utilize the values of any of the mechanical or thermal properties of those microstates. Rather, it only utilized their probabilities.

Revisionist Energy Spread in Statistical Mechanics

In classical thermodynamics, the energy spreads to an increasing number of particles as time advances. The spread is cumulative. And therefore entropy increases.

But statistical mechanics, this "increase in entropy over time" has a more elaborate explanation. Statistical mechanics changes its focus from "particles" to how all of the particles of the macrosystem collectively exist in different microstates at any instant, and how that situation changes over time.

Each particle exists in ("exhibits") exactly one microstate at any moment. But statistical mechanics focuses on how states of all the particles are distributed across the set of all microstates (the ensemble) at any moment in time, and how that picture changes over time. The count of particles in each microstate defines a probability distribution for that moment. Statistically, then, for a given moment, an ensemble has a specific probability distribution that describes its spread of particles across the possible microstates. Of course such a probability distribution has an entropy value.

And at "the next moment", even though the ensemble still has the same set of microstates, the change in physical state of the particles will generally be such that the numbers of particles in each microstate will change. Thus the probability distribution for the next instant of the ensemble will also change. And so will its entropy.

This is how a change of entropy works in statistical mechanics – by switching from one probability distribution of its microstates at one moment to another probability distribution of its microstates at the next moment – with a change in entropy for each moment.

Entropy Increase in Statistical Mechanics

So, this "particle musical chairs" between microstates from moment to moment results in a change in probability distributions and entropies of the ensemble of microstates from moment to moment. The second law of thermodynamics says that this changing set of probability distributions will exhibit a corresponding increase in entropy over time.

However, there is nothing that we have said so far that would guarantee an increase in entropy from moment to moment! Such an increase would mean that there is some reason that when the particles collectively change microstates that it is much more likely that the new distribution of particles across the microstates will be much more "evenly spread" than before. (An even spread of probabilities is equivalent to higher entropy [Shannon 1963].)

In other words, statistical mechanics replaces "spread of energy" with "spread of probabilities"! More precisely, it reasons that "spread of energy" can be seen as a special case of "spread of probabilities".

Loschmidt pointed out that is was logically possible for the "particle musical chairs" to proceed in such a way that statistical entropy does not increase. It was left to Boltzmann to show why statistical entropy increases. He demonstrated that no matter what the probability distribution of ensemble of microstates is realized at any moment, the probability that the next one visited will have the same or higher entropy than the current one is astronomical.

The reason for this is that the set of all such probability distributions of an ensemble of microstates partitions the space of all such partitions. Boltzmann essentially showed that, given any particular probability distribution for an ensemble, the number of partitions of the microstates that yield the current distribution must be no larger than the number of partitions that yield higher-entropy probability distributions.

Thus, eventually (because of the law of large numbers), the state of the system will arrive at an ensemble probability distribution with the highest entropy. (This argument also assumes a certain degree of stochastic independence between time steps.)

However, unlike in classical thermodynamics where the entropy *can never* decrease, in statistical mechanics it has the possibility of decreasing. However, the probability of such a decrease is so astronomically small, that for all practical purposes entropy is non-decreasing in time [Haw 2007].

Violations of The Second Law in Statistical Mechanics

There is a common understanding that the second law of thermodynamics is a law of nature that cannot be violated. However, Loschmidt and Boltzmann showed by counterexample that it can be – but with extremely small probability [Haw 2007].

In addition, information theory demonstrates and explains that there are mathematical conditions under which entropy increases, and others under which it decreases. At the risk of oversimplifying, we can say that the deciding factor pertains to the degree of stochastic independence versus stochastic dependence between the time steps of stochastic processes. With considerable stochastic independence, entropy will increase in the right kind of stochastic process over time.

On the other hand, stochastic dependence will bend entropy toward a decrease over time – again with the right additional assumptions regarding the stochastic process. These are the assumptions obtain for lifelike systems.

And this is the essential difference between the behavior of systems in statistical mechanics and those in biology. Statistical mechanics assumes a certain degree of

stochastic independence and therefore entropy generally does not decrease. But biology, and Organodynamics, operates under conditions of stochastic interdependence, and therefore entropy can and often does decrease over finite time periods.

Does Statistical Entropy have a Broader Purview than Physics?

So we are making a pretty good case that entropy in statistical mechanics is not limited to physics, and that it is generally applicable. Let's review the points that we have made so far in favor of this position.

1. The formula for entropy in statistical mechanics completely ignores any thermal properties of the microstates.

2. The formula for entropy also ignores the fact that a microstate embodies a complex partitioning of the particles – the ensemble. In fact. The "microstate" in the formula could represent any sample point of any probability distribution.

3. Given the assumptions of stochastic independence of statistical mechanics (though unannounced), statistical entropy will be non-decreasing. This argument is easily waged on strictly mathematical grounds, and needs no physical inputs.

Therefore, it becomes increasingly difficult to argue that this statistical mechanics formula for entropy is in any way constrained to thermodynamics or even to physics.

Says Jaynes regarding the expression of entropy in statistical mechanics:

> The feature which was missing has been supplied…by Shannon in the demonstration that the expression for entropy has a deeper meaning, quite independent of thermodynamics…. Now, however, we can take entropy as our starting concept…. In freeing the theory from its apparent dependence on physical hypotheses of the above type, we make it possible to see statistical mechanics in a much more general light. Its principles and mathematical methods become available for treatment of many new physical problems [Jaynes 1957].

We conclude that this spread of energy in statistical mechanics – *statistical entropy* – is actually a more general *measure of uncertainty* for any phenomenon that can be partitioned into a set of alternatives and modeled as a probability distribution. In thermodynamics, this *uncertainty* happens to be realized as *energy spread*. But in another domain of application, its semantics will be unique.

Applications of Statistical Entropy in Physics and Beyond

How then do we "extract" the methods of statistical physics and apply them to "any situation that can be modeled with probability distributions"? Fortunately, statistical mechanics does a good job of keeping the physics "application" aspects separate from the statistical/probability aspects.

Statistical physicist E. T. Jaynes makes reference to these aspects:

> Furthermore, it is possible to maintain a sharp distinction between physical and statistical aspects [in statistical mechanics]. The former consists only of the correct enumeration of the states of the system and their properties; the latter is a straightforward example of statistical inference [Jaynes 1957].

Shannon made use of this distinction by analyzing communications messages and "correctly enumerating their states" so that he defined a sample space, and then assigned them probabilities as a result of his own empirical observations. As observed by quantum information theorist Vlatko Vedral [Vedral 2010], "Physical entropy has at first sight nothing to do with communications and channel capacity, but it is by no means

an accident that the two have the same form." He further points out "There has been a massive amount of work on extending Shannon's information theory directly or indirectly in a variety of disciplines."

So, as this author has analyzed it, here are steps one takes to apply the methods of statistical entropy to any field:

1. The responsibility of the field of application (e.g. thermodynamics, communications, biology, etc.) is to decide how to partition the components of the target application domain into a sample space of alternatives and a set of probability distributions over that sample space to represent a variety of conditions that occur within the domain over time. The probabilities determine the entropy and the behavior.
2. After that the application domain steps out of the way. The calculations of *entropy* values uses only the probability distributions supplied by the domain and completely disregards any domain-related aspects of these alternatives in its calculation of statistical entropy.
3. Variations in the supplied probability distributions and the resulting variations in entropy completely describe the dynamics of the phenomenology of the domain of application.

Energy and Entropy in Organodynamics

We are now in a position to specify how we will use statistical entropy as a surrogate for energy spread in Organodynamics.

Entropy as a Surrogate for Energy in Organodynamics

At this point it should be obvious how to treat the concept of *energy* in Organodynamics. The first decision we shall make is that we shall not model *energy* directly. Rather, we shall model *the behavior* of energy in the form of *its spread*.

Secondly, since Organodynamics is intended to be a generalized theory of "the living", we do not want to be constrained to biochemistry or even to physics. So then statistical mechanics – actually, information theory - provides us with exactly the construct that we need to represent both of these at the same time: *statistical entropy*.

The role of Organodynamics, as discussed above, is to identify a set of alternatives to which probabilities can be assigned. Of course, we have already done that by specifying that a set of *system organizations* of an underlying system. This set becomes our *sample space, to which we assign* probabilities. This specification is, in fact, the partitioning function of Organodynamics.

Once probabilities have been assigned to each of these *system organizations*, then we have the required probability distributions - *organodynamic probability distributions*, or OPDs. The bulk of the implementation responsibilities of applied Organodynamics will involve the observation and characterization of these sample spaces of system organizations and their attendant changes in probability distributions, and under what conditions, over time. This article has not provided much discussion on such empirical and experimental work. However, such work is the backbone of any scientific endeavor.

Once these probability assignments have been made, then the dynamics of these organic complex systems can be studied in the same way that the dynamics of macrosystems is studied in statistical mechanics – using the statistical entropy.

An investigator that is developing an organodynamic model should, at all times, continue to hold the understanding that various alternative *system organizations* represent the "objects", or "matter", insofar as they represent the components of Organodynamics and their interrelationships. And, the use of the OPD and its concomitant entropy represents some generalization or specification of the "spread of energy".

Conclusions about Energy and Entropy in Organodynamics

This section has presented an approach to abstracting and generalizing the aspects of energy in physical systems that promotes the "change of organization of matter". We have codified this as *statistical entropy*.

In so doing, we have not had to introduce any new constructs into Organodynamics. It turns out that the required constructs, the OPD and its statistical entropy, is already present in the theory.

We have shown that we have abstractions of both matter and energy in Organodynamics. "Matter" is represented as *components*, *organizations* and *systems*. "Energy", or "energy spread", is represented as *statistical entropy* that was introduced in statistical mechanics and further developed and applied by information theory.

Autocogeneration

Autocogeneration encapsulates two interrelated ideas: 1) self-creation, and 2) self-regulation. Collectively, Organodynamics calls these two ideas *self-management*.

It may be helpful to position the ideas of autocogeneration among other disciplines that have influenced it. Organodynamics' legacy of *self-creation* is *autopoiesis* [Maturana 1974; Maturana and Varela 1998; Maturana 2002] and *autocatalysis* [Kauffman 1993; Kauffman 1994]. On the other hand, Organodynamics' legacy of *self-management* is *cybernetics* [Wiener 1961] and *system dynamics* [Forrester 1961]. Autocogeneration brings the fruits of these disciplines together to produce a synergistic model.

What is Autocogeneration?

Autocogeneration is the self-creation and self-management of a system by its components.

Self-creation is the creation of components by other components and the subsequent creation of relationships among those components. This results in a new system, because both components (population) and their relationships (organization) have been brought into being. Thus a system has been brought into being. Consequently, a system has created itself by virtue of its (soon to be) components creating each other and their organization. The notion of components creating each other is the textbook case of autopoiesis [Maturana 1974]. The notion of components organizing those components, which then is necessarily a system, is an idea put forth by the Organodynamics.

Self-management is the persistence of what was self-created. This is accomplished via the alteration of probability distributions (OPDs) in such a way that persistence of organization is maintained. Of course, whenever the persistence of organization is maintained, then we have two OCS principles that are maintained: organization and persistence. Moreover, because of the stochastic dependency enjoyed among the seven organizing principles, the other five principles are influence in one way or another.

Autocogeneration provides a number of mechanisms that promote this self-management. Some of these are discussed below.

Mechanisms of Self-management in Organodynamics

All autocogenerative mechanisms leverage the stochastic interdependence of the seven OCS organizing principles. *Autocogenerative regulation*, or simply *regulation*, is the leveraging of *stochastic interdependence* in organodynamic processes with the result of enhancing the persistence of the organodynamic process.

Structural Mechanisms

Organodynamics observes a number of structural relationships in operation within biological systems, and abstracts these as constructs within its mathematical framework.

Piecewise-Homogeneous Markov Chains

The organodynamic processes used in Organodynamics are finite step, finite state Markov chains. This choice is a simplifying decision designed to make the theory easier to work with. In practice, not all biological processes fit the definition of Markov. So, this choice is too limiting in practice. The extension of the theory to general dependent stochastic processes, though addressed here, is also suggested for further research.

Organodynamics begins with homogeneous Markov chains whose conditional probability distributions are OPDs. It then builds them into more complex structures that are based upon these simple chains. The next step beyond these homogeneous chains is essentially a concatenation of a finite number of these homogenous chains into a Markov chain called a *piecewise-homogeneous Markov chain*, which is the basis of more complex mathematical structures that populate the Organodynamics framework.

Concurrent Organodynamic Processes

Next, Organodynamics considers multiple piecewise-homogeneous Markov chains "in parallel". This means that the time steps of these multiple chains are shared points in time. This allows them to be treated as concurrent piecewise-homogeneous chains.

In addition, the organodynamic transforms can be used to map multiple OPDs at one time step to a single OPD at the next time step. This mechanism permits the conjoining of two or more concurrent piecewise-homogeneous chains into a single chain.

Recall also that some of the organodynamic transforms discussed earlier are "split" transforms. This means that they map a single OPD in their domain to multiple OPDs in their codomain. This mechanism is recruited to map a single OPD of one piecewise-homogeneous chain to multiple OPDs, each in its own distinct piecewise-homogeneous chain.

Together, these mechanisms provide a simple network paradigm that has been constructed from mathematical elements. These elements include OPDs, Markov chains and organodynamic transforms.

Routines and Loops

It is conceivable that piecewise-homogeneous Markov chains can exhibit periodic behavior. That is, a sub-sequence of the stochastic process may repeat itself. In such a case, it is possible to develop an indexing scheme that permits the specification of the process by listing the repeating sub-sequence but that also indicates the repetitions involved along with a variations enjoyed by each repetition.

We shall assume that such an indexing scheme can be developed, and in Organodynamics we shall provide such a scheme. Within such a scheme, such a repeating sub-sequence will be called a *routine*. And, the repetitions will be referred to as a *loop*. These constructs effectively provide a programming mechanism that also lends itself to a graphical representation – specifically a network representation. In Organodynamics, we shall leverage these construct to develop a network-articulated modeling paradigm for organic systems.

Historic Response

Some organodynamic transforms tend to change the probability distributions in such a way that sample points with high probabilities at one time step have low probabilities at the next time step. This is how organodynamic transforms implement "negative feedback". These transforms generally produce self-altering results. Obviously, "positive feedback" can be implemented by preserving probabilities across one of these transforms. These transforms generally produce self-reinforcing results. Other transforms do neither. Thus, OPDs can support the types of feedback loops (negative and positive) that are celebrated in both cybernetics and system dynamics.

In addition, it is also possible for there to exist transforms that select, based upon current conditions, whether it is going to use a self-altering OPD or a self-reinforcing OPD. Organodynamics refers to this pattern as *regularity selection*. Regularity selection is powerful because it dynamically selects a feedback mechanism – positive or negative.

Darwin alludes to (but does not name) *regularity selection*, not within an organism, but pertaining to the ability of species – depending on conditions – to produce either more or less species within a genus, when he cites the mechanism at work:

> The larger genera tend to become larger; and throughout nature the forms of life which are now dominant tend to become still more dominant…. But…the larger genera also tend to break up into smaller genera [Darwin 1859].

Natural Selection

Natural selection [Darwin 1859] is the foundation of regulation in organic complex systems, owing to its power, elegance, simplicity and self-management. Natural selection is not limited to biological systems. It occurs in non-living systems. An extra-biological example is "molecular evolution" [Morowitz 1992; de Duve 1995].

At every step of an organodynamic process, whether within or between the lives of organisms, the options are provided by random chance, but the realization is provided by natural selection. Says [de Duve 1995], "Natural selection operates blindly on material offered by chance."

Under natural selection, an existing system either 1) replicates itself; or 2) it produces a random variant of itself; or 3) it fails to do either. In turn, the replicate 4) may or 5) may not replicate itself; and the variant 6) may or 7) may not replicate itself. Cases 1) and 4) are instances of positive feedback; while case 6 is an instance of negative feedback.

Moreover, which of the two above mechanisms (positive or negative feedback) is realized depends upon which mechanism encourages the persistence of the next time step. Thus, natural selection, exhibits all three of positive feedback, negative feedback and regularity selection as defined by Organodynamics.

Thus, natural selection is a simple, self-fulfilling strategy of organodynamic self-management; and is therefore the foundation for autocogenerative regulation mechanisms. Moreover, *natural selection* can be found in non-biological systems (e.g. *molecular evolution)* – even though "the struggle for survival" [Darwin 1859] may not be at work there.

Limitations of Natural Selection as a Regulation Mechanism

As a regulation mechanism, natural selection is short-termed. In any one generation, a trait may be passed up (lost) which would ultimately prolong the lifespan of an organism or species. Thus, the mechanism may not be optimal, but it often "good enough". This

property of natural selection is a product of the random and non-intentional ("blind") nature of the mechanism.

In biological systems, a further limitation is that the products of natural selection throughout the lifetime of an organism are lost to its offspring because they are not fed back into the reproduction mechanism (DNA). But there appears to be no logical reason why it would be impossible for a non-biological organodynamic process (organism) to feed back adaptations that it has acquired during its lifetime to its reproductive system in the manner mistakenly assumed for biological systems by Lamarck [de Duve 1995].

On the other hand, the effect of language and culture in the past several thousand years by homo sapiens has effectively externalized these traits acquired during organism lifetimes outside of the reproductive mechanism so that they can be effectively fed back to subsequent generations – and in so doing has possibly compromised the mechanisms of Neo-Darwinian theory [de Duve 1995].

Nestedness

The third OCS organizing principle, *nestedness*, enjoins Organodynamics to provide a mechanism for representing systems whose components are also systems. To answer this call, Organodynamics provides a nomenclature, which is capable of representing both nested and simplex systems.

This nomenclature, the *composite systems nomenclature*, represents nested systems to any finite number of levels of organization. The essential schematic principle of the nomenclature is this: At any level of organization, the components of that level are defined to be the *organizations* of the systems at the level below.

The resulting nomenclature can specify any composite system with a finite number of levels of organization, each having a finite population. Admittedly, the specification of an organic system with any degree of complexity is, to say the least, unwieldy. But this would be true for any such nomenclature, as is often the case with chemical specifications [MacCuish and MacCuish 2011]. Nevertheless, this nomenclature is essential for implementing Organodynamic models using computer software.

Emergence

OCS recognizes two types of emergence. These are described in this section.

Process Emergence

The first type of emergence distinguished by Organodynamics is that of *process emergence* – also called *historical emergence*. Process emergence is the exhibition of a systemic property at one time step when it was not so exhibited in the previous time step of the process.

Complexity theorists most often use the term "emergent" to mean *process emergence*. Organodynamics recognizes process emergence, but does not emphasize it.

Systemic Emergence

Systemic emergence is the exhibition of a systemic property by a system when none of its components exhibits the same property.Organodynamics is profoundly interested in *systemic emergence*.

Stuart Kauffman of the Santa Fe Institute captures the essential aspect of systemic emergence in the following passage:

> But the collective system does posses a stunning property not possessed by any of its parts. It is able to reproduce itself and evolve. The collective system is alive. Its parts are just chemicals. [Kauffman 1994]

It is *systemic emergence* that gives systems the quality that "the whole is greater than the sum of its parts". This is the motivation behind Organodynamics' considerable interest on systemic emergence. Notice that systemic emergence can be ascertained for a system within a single time step; whereas process emergence requires multiple time steps – and therefore the existence of a process.

Persistence

The introduction of this article discussed the nature of *evolutionary transformation* in organic complex systems. It was established that *evolutionary transformation* means a kind of *improvement* in these systems.

We have made the case that the *degree of certainty* of organic systems is an improvement over that of non-organic systems. This case is based upon the assumption that organic systems are *dependent stochastic processes*. We relied upon the mathematics of information theory to show that dependent stochastic processes reduce overall uncertainty. This allows us to further argue that the degree of uncertainty of an organic system, as measured by both Shannon and Gibbs entropy, can be non-decreasing in contradistinction from the laws of thermodynamics. This in itself is the persistence of relative certainty, and a significant kind of "improvement" required by evolutionary transformation.

But the essential question regarding the seventh organizing principle, persistence, relates to the persistence of *organicity* itself. By *organicity* is meant the continued existence of an organic complex system. As we have said, this requires the co-exhibition of all seven of the OCS organizing principles including organizationality, nestedness, reorganizationality, autocogeneration, emergence and persistence.

Thus, the <u>persistence of organicity</u> would be the ultimate "improvement" of *evolutionary transformation*. The final question raised by the theory of Organodynamics is

> "Does the complex interplay of the stochastic interdependence of the seven organizing principles within an *organodynamic process* improve the persistence of organicity?"

In this article, we have presented an argument that organodynamic systems provide a limited expression of *evolutionary transformation* insofar as they enhance the *degree of certainty* of those processes in the form of reducing their joint entropies. Moreover, this improvement can be significant, because in cases of high degrees of interdependency, the uncertainty added by additional time steps can be none (entropy rate = 0).

We have also argued the proposition that the "improvements" provided by organic complex systems go considerably beyond "improved certainty" to provide a complex dynamic among the seven OCS organizing principles that result in the prolongation the *persistence of organicity* of organic complex systems.

While this article has not provided the conclusive arguments required to make this case, it has provided a considerable formal framework that is expected will prove useful in the further investigation of these matters.

Organodynamics: The Modeling Paradigm

The mathematics of Organodynamics, presented in the previous section, provides the intellectual equipment required to develop analytical and simulation models of organic

complex systems. However, its usefulness would be enhanced and its audience increased if it were wrapped inside of a modeling paradigm that is more intuitive, and that provides a general analogy to scientific and engineering problem domains.

It turns out that all of the mechanisms for the formalism presented in the previous section can be understood as a general network structure that can be configured to provide a model of an organic complex system. In fact, these mechanisms can be partially ordered into a hierarchy of increasingly complex network structures that are each composed of simpler structures in the hierarchy.

Modeling Organic Systems as Networks

In this way, the entire formalism can be repositioned as a "network construction kit" with which one can develop models of organic complex systems. This is accomplished as follows: Each mechanism of the formal model is renamed so as to represent a network element. (We say that it is "wrapped" in a network element.)

Some of these network elements are elementary and can be used to compose higher order ones. For example, "nodes" and "edges" are elementary elements. Multiples of them can be collectively used construct a higher-level element called a "graph". Multiple graphs can be composed together to yield higher-level composite network elements.

Ultimately, we reach the highest-level network defined by this modeling paradigm – the *Organodynamic web*. This structure is the universal modeling element of the Organodynamics modeling paradigm. Just as the concept of a "circuit" is an infinitely flexible topological entity that can be use to design any electronic device; so too the Organodynamic web is an infinitely flexible structural type that can be used to model any organic complex system.

The Network Element Nested Type Hierarchy

Let's now take a brief look at the hierarchy of network element types that constitute the Organodynamic modeling paradigm. As mentioned above, this is a nested hierarchy of network element types. Each type in the hierarchy is composed of the element types at the level of the hierarchy beneath it.

The lowest level of this hierarchy contains element types (segments and nodes) that "wrap" (hide) the mathematical mechanism that were defined in the formal (mathematical) section above.

The highest level of the hierarchy has one element type: the Organodynamic web. Once an Organodynamic web model of a system has been constructed, a complete Organodynamic model of an organic system has been developed.

Let's take a brief look now at the network element types of this hierarchy.

Segments of a Markov Chain

The lowest level network element in the Organodynamic modeling paradigm is the *segment*. A *segment* wraps a finite homogeneous Markov chain. The modeler thinks of a *segment* as an elementary network element that represents a "non-branching" section of consecutive time steps in a stochastic process where all of the time steps have the same transition matrix.

Nodes of a Markov Chain

Also at the lowest level of network elements is the *node*. A *node* enables, as time progresses, concurrent branching of a segment into multiple segments, or the joining of multiple segments into a single segment.

"*Node*" is essentially a paradigmatic "wrapper" around the formal structure named *split and join organodynamic transforms* that were introduced in the previous section on *Organodynamics: the formal theory*.

Edges of a Markov Chain

The second level up the network element hierarchy is the *edge*. An *edge* is the concatenation of a consecutive set of *segments*. These are also non-branching. The purpose of an edge is to represent a nonhomogeneous Markov chain. Thus, an *edge* represents a consecutive, non-branching, set of *segments*.

Organodynamic Graphs

Now that we have the basic network elements of *segment* and *node*, and also the *edge*, we want to be able to join multiple segments or edges to a single *node*. Such a higher-level network construct we call an organodynamic graph. Note that an organodynamic graph is a third level construct – having as it does elements that are *edges*, which are second level constructs.

Simplex Organodynamic Webs

We shall now construct a fourth level construct – the simplex organodynamic web.

The *simplex organodynamic web* consists of multiple organodynamic graphs joined into a unified single construct. At this point, we can have both multiple edges joining to a single node (per the organodynamic graph) as well as multiple nodes that join single edges.

In addition, this construct will wrap the formal mechanism described in the formal section above as the *routine*. You will recall that the *routine* is a looping mechanism that enables the modeling of feedback and regulation. This type of behavior is characteristic of the autocogeneration organizing principle of OCS. With this construct, we finally have a near-comprehensive, if incomplete, model of the whole system we are modeling.

Composite Organodynamic Webs

The third OCS organizing principle, *nestedness*, provides for the components of some systems being systems in their own right. This *system nesting* can continue to any finite number of levels. This construct is the fifth level up the hierarchy of network constructs. Nested systems can add considerable complexity – and thus fidelity - to an Organodynamic web.

Joint Composite Organodynamic Webs

We now come to the sixth and final level of network constructs of the Organodynamic modeling paradigm hierarchy – the *joint composite organodynamic web*. This construct is also the third, and most complete, version of the Organodynamic web. All three version of the organodynamic web are capable of providing a comprehensive model of a whole organodynamic system. Or, in the context of biological systems, we would say an entire *organism*.

Even so, the composite organodynamic web leaves something out; and the simplex organodynamic web leaves even more out. The reason for providing these three graduated levels of organodynamic web is that doing so provided flexibility to the modeler according to his needs for fidelity and appetite for complexity. The joint composite version is as complete as it gets in Organodynamics and provides the maximum fidelity. But it is considerably more expensive to model.

The joint composite organodynamic web exists to correct an oversight of the previous constructs. The oversight is this. The previous constructs require that the modeler know exactly which time steps that nodes will occur. This amounts to the modeler knowing exactly when edges will split or join. For example, the modeler must know *when* two molecules will form a bond. This assumption is essentially deterministic. So, an element of determinism has crept into the model, where it is not generally wanted. In actuality, such an event is also stochastic in nature, and is treated as such in this final version.

The joint *composite organodynamic web* will most likely be reserved for applications that demand it. While it is considerably more realistic, the use of joint probability distribution is more difficult to use by non-mathematicians owing to its non-intuitive nature.

Summary and Considerations

Summary

OCS presents a conceptual theory of lifelike systems by identifying, selecting and then generalizing certain *organizing principles* of biology. Members of the class of systems that embody this theory are called *organic complex systems*, and of course include the biological. Applications of the theory are expected to be in the engineering of artificial life, the identification of extra-terrestrial non-carbon-based life, and others.

These organizing principles manifest the quality identified by OCS as *evolutionary transformation*. Evolutionary transformation is the capacity for a system to decrease its disorder over some time period, in apparent contradistinction to the second law of thermodynamics. However, OCS demonstrates in its formal framework how there is no contradiction between the second law and evolutionary transformation because their assumed conditions differ. In evolutionary transformation, chance in the form of stochastic interdependence breeds order from chaos.

OCS then presents a formal mathematical framework, named *Organodynamics*, which embodies all seven organizing principles. Finally OCS provides a modeling paradigm based directly on Organodynamics and a modeling methodology to guide the construction of these models.

OCS anticipates that organic complex systems can be contrived that manifest only in probability, or information, space. There, the physical concept of *energy* would need to be abstracted. Such an abstraction has already been presented above in the form of *entropy*. This generalization has been beautifully expressed by [Jaynes 1957]: "Thus entropy becomes the primitive concept with which we work, more fundamental even than energy."

Call for Further Research

While OCS is an ambitious theory, only the basics have so far been developed. Much work is yet to be done, and collaboration is essential. Beyond this introductory article, an unpublished manuscript has been authored that lays out considerable detail on all aspects that have been discussed in this article. Included in this manuscript is a table of

suggested further research items [HollandJG-I 2011; HollandJG-I 2011; HollandJG-I 2011].

It is hoped that this article will encourage an interest in further research in these matters by other investigators.

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