Science and Belief in a Contingent Universe

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1. A Personal Cosmology:

In preparing for tonight's talk, I was impressed upon reading that part of the Cosmos and Creation Mission Statement that acknowledged that scientists often "develop their *own* cosmology - a cosmology that … is in touch with the feel of contemporary science". I see that as truly what should be our task in science – each to develop his/her own cosmology, contingent upon one's own personal experience. In acknowledging such plurality of narrative, I chose to entitle my third book "***A*** Third Window", instead of "***The*** Third Window", and it is in this same spirit that I am addressing you tonight, because my perspective on the dialogue between science and religion happens to be quite different from the usual.

It seems to me that the great majority of discussions on religion and science occur between theologians on one hand and physicists (those high priests of science) on the other. Alas, I belong to neither priestly community, being educated as an engineer and spending my professional career as a systems ecologist. So I liken my perspective to that of one in the trenches, watching bullets flying overhead, so to speak. It has long troubled me that few seem interested in what those of us huddled in the middle might want to contribute to the exchange. After all, ecology is considered by most to be a remote derivative of the physical sciences and thus have little new to bring to the dialogue.

I am here tonight to try to convince you otherwise. To mix a few scriptural metaphors, I am the voice of one crying from the chasm, "Raise high the valley and level the road between!" For it is my belief that a true reconciliation of science with theology, or for that matter, of science with the humanities, *cannot* be achieved unless we adopt a radically different metaphysical stance, born of ecology, that can bridge the chasm still separating the two domains.

2. The Chasm Persists:

There are widespread efforts to paper over the yawning gap between physics and theology, as though it doesn't really exist. I preface what I am about to say by confessing that I am no historian. Nevertheless, I would argue that the divide originated along with modern science and persists in large measure today. I see the division as growing out of a

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consensus between two disparate interest groups who both adopted a common tactic in the face of a socio/political background that we today would characterize as overbearing clericalism.

During the 16th and 17th Centuries, both on the European Continent and on the British Isles, it was clerics who judged what ideas were orthodox and which should be eliminated (oft-times along with those who espoused them). Everyone is familiar with the tribulations of Galileo and Bruno, for example. This climate fostered particular dangers for those occupied with the nascent and emergent sciences, even for those whose endeavors were supported by the institutional churches. Better to remain occupied with obviously inanimate phenomena than to chance censure or worse by uttering some idea that bordered upon the living or the transcendental.

At the same time there arose a number of thinkers who deeply resented clerical censorship and who secretly yearned for purely material explanations of reality that would undermine the beliefs upon which clerical power rested (e.g., F. Bacon, Hobbes, Halley and Wren). Instead of fear, it was ambition and resentment that drove the nascent materialists to sever any and all connections between natural events and the transcendental.

Whence, during the course of the 18th Century both groups contributed to an emerging set of metaphysical assumptions that could replace transcendental agency as the foundations for order in the natural world. The resulting metaphysic is commonly referred to as "Newtonian" in tribute to the individual whose formulations of law accidentally provided gravitas to material ambitions; although, as I will argue presently, the origins of this world view owe more to Leonhard Euler and Gottfried Leibniz. The metaphysic rested on 5 axioms, which at the beginning of the Nineteenth Century enjoyed almost universal acceptance among scientists (Depew and Weber 1995). The consensus held that nature possesses the following attributes:

- **Closure** – Only material and mechanical causes are operant in nature.

- **Atomism** – Systems can be taken apart and the pieces studied individually. The behavior of the ensemble is the sum of the behaviors of the individual parts.

- **Reversibility** – The laws of nature are reversible. They appear the same whether time is played forward or backward.

- **Determinism** – Given some small tolerance, ε, the behavior of a system can be predicted to within some corresponding tolerance, δ.

- **Universality** – The laws of nature are valid at all temporal and spatial scales.

This Enlightenment metaphysics was particularly effective at opposing religion, because it rendered Divine intervention unnecessary or even impossible. As Pascal apotheosized it, any spirit capable of knowing the positions and momenta of all particles in the universe would be able to use the laws of mechanics to predict all of the future and retrodict all of history. The Modern synthesis was truly Parmenidean in that everything that was and possibly could be was immanent in the current state of the cosmos. The only influence that God could have exerted was to set the whole thing into motion (the prime mover) and retire – a belief came to be known as Deism.

It didn't take long, however, before holes began to appear in this fabric. Carnot (1824) provided empirical evidence that real processes are actually irreversible. Then Einstein (1905) brought universality into question with his relativity theory. Soon thereafter Planck and others uncovered the indeterminate world of quantum phenomena.

Despite these exceptions, the notions of closure and atomism have survived tenaciously into the present. Encouraged by the absence of any violations of the four force laws of physics (strong & weak nuclear forces, electromagnetism and gravity), Nobel Laureates Murray Gell-Mann, Stephen Weinberg, and David Gross maintain that all causality originates from below and that there is nothing "down there" but the laws of physics (Kauffman 2008). Carl Sagan and Stephen Hawking (1988) expressed the opinion that "There is nothing left for a Creator to do.", while even a believer like Philip Hefner (2000) doubts that miracles can happen, lamenting that God "just doesn't have enough 'wiggle room'".

And so the chasm still yawns, with many in science convinced that the Modern synthesis will eventually encompass the middle realm, and in doing so will provide a full understanding of the phenomena of life. In reference to the persistent dialectic, Karol Wojtyla (1988), characterized the agonism succinctly by suggesting that a balanced conversation should consist of science purifying religion of error and superstition, whilst religion should warn science against idolatry and false absolutes. The exchange is hardly balanced, however. Examples of science "demythologizing" religious belief abound, whereas critiques of scientific beliefs are rare by comparison.

3. Redressing an Imbalance:

An Obscure History:

Today I hope to address this imbalance with insights gained from my personal "outsider's" cosmology, born of my perspective as engineer-cum-ecologist. In particular, I wish to suggest that the ontological status of the four (inviolate) force laws has been exaggerated. To begin, I cite the relatively obscure origins of how we have come to interpret Newton's second law of motion. Ask almost anyone familiar with at least freshman physics to state Newton's second law of motion and their reply probably will be something like, "The force exerted on a body is equal to the product of its mass times its acceleration", or algebraically, $F = ma$, where F is the force, m the mass of the body and a its acceleration.

The problem with this interpretation, it may surprise many to learn, is that Newton never formulated his second law in such algebraic fashion and argued strenuously against doing so (Dellian 1985, 1988, 2003, Jammer 2000). His statement in *Principia* was that impressed force is proportional to the change in momentum, or F is proportional to Δp, where p is the momentum of the body (p = mv, v being the body's velocity). It was not by chance that Newton presented his formula in terms of a geometric proportion rather than an algebraic equation: "Proportional" is not the same as "equal" or "equivalent". The law in its Newtonian rendition reads F/p = c = constant, implying that force and momentum are *heterogeneous* entities. It is important to note that Newton's geometric expression is discrete and *irreversible*!

The familiar algebraic formula was rather the invention of Leonhard Euler, based on the suggestion by Gottfried Leibniz that cause can be equated to effect (Dellian 2014), and it was this equivalence to which Newton vociferously objected. It came as a bit of a shock to me to learn that (at least in *Principia*) Newton never made the continuum assumption. His reluctance to do so is important, because the three "exceptional" disciplines mentioned above (thermodynamics, relativity and quantum physics) all appear to treat phenomena for which the classical assumption of continuity becomes problematic. These exceptions have prompted historian of science Ed Dellian (1985, 1989) to speculate that one might be able to begin with Newton's geometric formulation and work forward in a way that uniformly encompasses the three exceptional domains. I, of course, leave that task to theoreticians and mathematicians more talented than I, and note simply in passing that the Modern synthesis, referred to by most as "Newtonian", is a serious misappropriation and should be referred instead to individuals who had an interest in describing nature in purely material terms.

Lingering Disparities:

As for the early challenge by Carnot, I would argue that it has never been adequately refuted. Reversibility at microscales cannot in general be reconciled with irreversibility at macroscopic dimensions without undue assumptions. The second law of thermodynamics, which is first and foremost empirical in nature, placed the atomic hypothesis in jeopardy (because empirical fact always trumps theory). For a full half century, physics felt itself besieged as theoreticians struggled with rescuing their Parmenidian worldview. It finally fell to Ludwig von Boltzmann and Josiah Willard Gibbs late in the 19th Century to create an extremely simple and hypothetical model (an ideal gas) subject to very narrow constraints and less than realistic assumptions (the Ergodic Hypothesis) whereby reversibility at the microscale, along with imported stochasticity, leads to a description of irreversible ensemble behavior. With that demonstration, the controversy came to an abrupt end! A single hypothetical construct was accepted as proof of a universal maxim. Given Popper's (1954) later emphasis on falsification, it remains a mystery why this "reconciliation" is still accepted?

Enter Logical Dissonance:

Irreversibility also points to a logical inconsistency in the effort to extend reversible mechanics into the highly dissipative and irreversible domain of life. In science, and especially in engineering, logic is intimately related to the units or dimensions by which actions are measured. The reversibility in the laws of force has been shown by Aemalie Noether (1983) to be logically equivalent to conservation. That is, one can take any reversible law and from it derive a "potential function" that does not change over time. Physics thus can be seen as a description of the world in terms of timeless, Neo-Platonist essences.

Time, however, is an intimate part of living dynamics. Life proceeds by changing from one distinguishable state to the next, almost always in irreversible fashion. The transitions between distinguishable states are separated by measurable time, and a sequence of such transitions is referred to as a process. In fact, life itself is process (a verb) comprised of other processes; it is not a thing (a noun). Popper (1990) ecstatically proclaimed as much, calling it a network of physical and chemical processes. Pierre Thielhard de Chardin (1959) also recognized life as coming out of process.

Nowhere did this fact become more evident to me than when I encountered Enzo Tiezzi's (2006) description of a dead deer. The thermodynamicist Tiezzi ran a Tuscan estate near Siena that was plagued by deer grazing on his olive trees and grapevines. In frustration, he shot a deer and then was immediately transfixed as he looked down at the dead animal. "What is different about this deer than when it was alive only tens of seconds ago?" he asked himself. Its mass, form, bound energy, genomes – even its molecular configurations – all these things remained virtually unchanged in the minutes after death. What was missing, however, was the configuration of processes that had been co-extensive with the animated deer – the very phenomena by which the deer was recognized as being alive.

Despite this overt identification of life with process, the bulk of effort in biology continues to be expended on casting the phenomena of living systems, as Francisco Ayala (2009) has described it, within the framework of "objects moving according unchanging laws". Now, because science deals mostly with equations, we can interpret Ayala's statement in terms of the equation, "Life is (=) objects moving according to universal laws". As every beginning student knows, while the appearances of the two sides of an equation can differ greatly in their formulations, both sides must express the same essence – they must have the same dimensions (units). As the aphorism goes, "one cannot compare apples with oranges". Neither can one equate temporal processes with timeless conservative laws.

Process involves transitions among heterogeneous kinds, which raises yet another logical problem. Gregory Bateson (1972) noted as how physics deals almost entirely with homogeneous, universal descriptors, like mass, charge and energy. The role of homogeneity was also important to Walter Elsasser (1981), who researched the logical foundations of the universal laws of physics. Elsasser noted that Whitehead and Russell (1927) in their *Principia Mathematica* demonstrated that the force laws of physics are logically equivalent to operations made among *homogeneous* sets. Such logic, however, was not appropriate to operations among *heterogeneous* groups. Elsasser concluded, therefore, that laws akin to the universal force laws could never arise among the heterogeneous types that constitute living systems.

Facing the Complete Problem:

Defenders of the totalizing reach of physical laws are likely to reject Elsasser's critique by noting that heterogeneity can always be dealt with in formulating what is called the boundary statement that must accompany each and every application of the universal laws. In order for the fundamental laws of physics to be universal, they must be cast in the broadest possible terms, i.e., in terms of the universal variables identified by Bateson. Even the simplest of real problems, however, possesses its particulars. Those specifics are called the "boundary value problem", and the statement of any real problem remains incomplete (and insoluble) until those particulars can be clearly stated (Ulanowicz 2013).

For example, one might wish to calculate the trajectory of a cannon ball. The appropriate law would be Newton's second law of motion in the presence of gravity. The specific trajectory and impact point cannot be calculated, however, until one stipulates at least the location of the cannon, the muzzle velocity and the angle of the cannon with respect to the earth — items that comprise the boundary statement. That is, laws can never be considered alone. They must always be accompanied by a boundary statement, which constitutes an integral and requisite part of the problem formulation. In order for the laws to produce a determinate result, it must be possible to formulate the boundary statement in clear, closed form. Furthermore, as every modeler knows, it is the boundary stipulations that "drive" the laws.

Now, in order for universal laws to remain inviolate, it is necessary that they can be paired with any contingent (arbitrary) boundary statement. Obviously, if one could point to particular boundary conditions which the law could not accommodate, then by definition the law would no longer be universal. In practice, boundary statements that are definitive (clear and unequivocal) give rise to results that are determinate. Nothing, however, prohibits an investigator from choosing boundary conditions that are stochastic (blind chance). In fact, Boltzmann introduced stochasticity into his reconciliation in precisely this way. Thus, reversible laws themselves remain indifferent to what is driving them. Clear boundary drivers yield determinate outcomes; "messy" stipulations yield untidy outputs (the latter an analogy to the familiar aphorism from computer science, "Garbage in – garbage out",).

A Contingent World?

That one might encounter stochastic output is not in itself a troubling prospect, because there exist highly effective tools from probability theory that deal with blind chance. Mainstream probability theory is built upon the assumptions that chance events are simple, directionless, indistinguishable (homogeneous) and repeatable. Only an incrementally small fraction of contingent events satisfy all those assumptions, however. What happens, then, when contingencies appear that do not conform to these assumptions?

Elsasser (1969), for example, argues that in a heterogeneous world compound events are always occurring that are entirely unique; that is, each is distinguishable and, in the absence of any selection, non-repeatable. Furthermore, nothing dictates that they remain directionless. Elsasser demonstrates how, whenever more than about 80 distinguishable chance events combine, the resulting amalgamation will be physically unique. He comes by this number through a simple argument involving combinatorics: Physicists generally agree that there are roughly 10^{81} elementary particles in the entire known universe, which in turn is reckoned to be about 10^{25} nanoseconds old. Therefore, at the very most, about 10^{106} simple events could have occurred since the Big Bang. Any number larger than this magnitude Elsasser calls “enormous” and warns that such numbers transcend the bounds of known physics. It takes approximately only 75 distinguishable tokens before the possible combinations among them exceed 10^{106}. It follows that in the realm of ecology, where even the simplest of ecosystems consists of hundreds or thousands of distinguishable entities, one is continuously encountering unique events. With a combination of 80 distinguishable entities, an interval of more than a million times the age of the universe would have to transpire before that particular combination could be expected to occur again by chance. I refer to such contingencies as “radical” chance events, and they evade treatment by the laws of probability theory.

In the other direction from blind chance occur a host of arbitrary events that exhibit varying degrees of bias. For example, when dice are not true, one observes bias for or against certain values; or when a predator ingests a prey item, the probabilities of ingestion are usually skewed from the random frequencies of encounter. One speaks in either case of “conditional” probabilities. Still less random, Popper (1990) identifies “propensities”, whereby one outcome predominates, but other results may occasionally occur. For example, during the early twentieth century over nine of ten young immigrants to America married someone from their own ethnic group, although a few would venture to take native-born spouses.

One thus sees that Monod’s crisp dichotomy between “chance and necessity” is a gross oversimplification. Instead, there exists an entire spectrum of contingencies ranging from radical chance at one extreme to blind chance, conditional probabilities, propensities and finally to deterministic phenomena. Not even intentionalities can be excluded from boundary constraints. (Someone has to fire the cannon!) Any sort of contingency may appear in boundary conditions on universal laws, and in most cases the reversible laws will produce outputs that reflect their respective inputs.

Are Universal Laws Sufficient?:

The last item in the litany of problems with the totalitarian view of universal physical laws is the question of sufficiency. The overwhelming combinatorics among heterogeneous systems renders the universal laws incapable of determining outcomes. Basically, this follows from the fact that the number of fundamental laws is small – for example, the four force laws of physics plus the two laws of thermodynamics. Although the number of possible combinations among them may seem large (say, 6! = 720), it absolutely pales in comparison to the combinations among a mildly heterogeneous system (say, $35! \approx 10^{40}$). As a consequence, there can be billions or trillions of combinations of a given heterogeneous system that are capable of satisfying exactly each configuration among the fundamental laws. The laws are not violated and they continue to constrain possibilities, but they cannot discriminate among the almost innumerable system configurations, each of which exactly satisfies any chosen mix of those laws.

We further recall that whenever one is unable to articulate a boundary statement clearly, the associated problem remains insoluble. Such is very often the case with highly heterogeneous systems, because their combinatorics rapidly grow unmanageable. This inflation of possibilities is perhaps best exemplified by Kauffman's "exaptations" (Longo et al. 2012). Evolutionary theory suggests that organs or structures emerge to adapt a given species to a particular environment. It occasionally happens, however, that a structure which arose in response to one set of conditions will serve an entirely different function in another environment. The classical example is the evolution of the swim bladder in fish. The cavity, as it originally developed, served as a proto-lung for fishes in oxygen-depleted environments to survive by gulping air. Some such fishes emerged from the water and the vacuole developed into a full lung. Others escaped back into oxygenated waters, where the empty space changed its function to serve as a buoyancy regulator. There is simply no way one could have cast a boundary statement so as to include the virtual infinity of all possible such exaptations that might have occurred.

Some might argue that the problem of insufficiency is merely epistemic and not ontological, but Elsasser's warning against exceeding the extent of the physical universe suggests that the limitation is ontological as well.

4. Order Withal:

Order among Processes:

None of the limitations on the laws of force disqualify them as outstanding human accomplishments, nor denies them a proper role in creating the order apparent in living systems. It's just that their role is one of support and constraint, not determination. Although the laws are not violated, neither are they the totalizing agency that most perceive them to be. But not all is chaos in world of the living, and so what, if not the universal laws, does *determine* order in biotic systems?

We have argued that life is process, not substance, and it appears that processes, once extant, are able to interact with one another. Some collections of interacting processes form stable configurations, which in their turn give rise to enduring forms. (It is too rarely mentioned that configurations of processes can create structures.) We thus are prompted to search for manifestations of stable order among what might be called "an ecology of processes". Our first clue in this search was provided by Gregory Bateson (1972), who wrote, "In principle, then, a causal circuit will generate a non random response to a random event."

An Agency for Order:

Following Bateson, we thus focus upon chains of processes in which the first and last links are identical, i.e., cycles of processes. In examining such loops, a particular subcategory is found to be prominent among living systems and to impart direction to consequent dynamics: Autocatalysis (“auto” meaning “self” and “catalysis,” the act of quickening) is any cycle of processes for which each constituent process catalyzes the next one in the sequence (Ulanowicz 2013). In Figure 1 for example, if process A facilitates another process, B, and B catalyzes C, which in its turn augments A, then the activity of A indirectly promotes itself. The same goes, of course, for B and C. In general, A, B, and C can be objects, processes, or events, but our focus will be upon sequences of processes, and while those linkages can be deterministic (mechanical), our interest is mostly with the contingent.

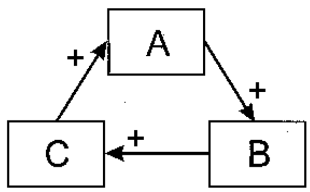
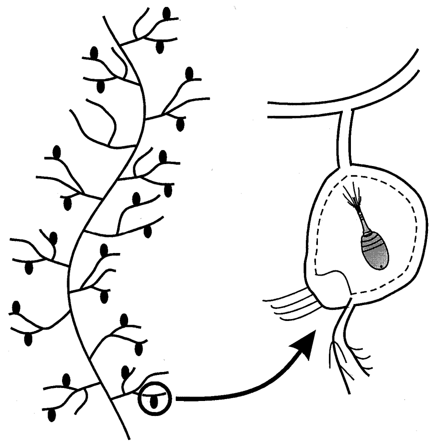


Figure 1: Schematic of a hypothetical 3-component autocatalytic cycle.

An ecological example of autocatalysis resides in the aquatic community that develops around a family of aquatic weeds known as Bladderworts (genus *Utricularia*, Ulanowicz 1995). All Bladderworts are carnivorous plants. Scattered along the feather-like stems and leaves of these plants are situated small visible bladders (Figure 2a). At the end of each bladder are a few hair-like triggers, which, when touched by any tiny suspended animals (such as 0.1-mm water fleas), will open the end to suck in the animal, which then becomes food for the plant (Figure 2b). In nature the surface of Bladderworts always hosts the growth of an algal film. This surface growth serves in turn as ready food for a variety of microscopic animals. Thus, Bladderworts provide a surface upon which the algae can grow; the algae feed the micro animals, which close the cycle by becoming food for the Bladderwort (Figure 3).



(a) (b)

Figure 2: (a) Sketch of a typical "leaf" of *Utricularia floridana*, with (b) detail of the interior of a utricle containing a captured invertebrate.

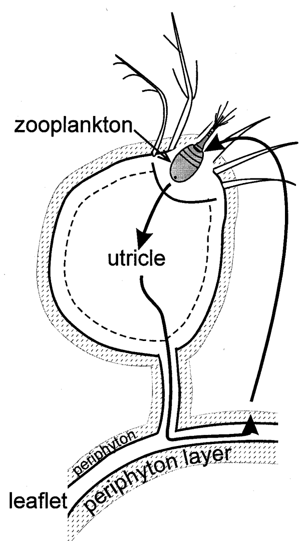


Figure 3: Schematic of the autocatalytic loop in the *Utricularia* system. Macrophyte provides necessary surface upon which periphyton (speckled area) can grow. Zooplankton consumes periphyton, and is itself trapped in bladder and absorbed in turn by the *Utricularia*.

Such autocatalysis among living systems, when it interacts with random singular (chance) events, can give rise to dynamics not usually associated with mechanical systems (Ulanowicz 2009). Most importantly, autocatalysis exerts *selection* pressure upon all its participating elements. If there happens to be some contingent change, for example, in the surface algae that either allows more algae to grow on the same surface of Bladderwort (e.g., by becoming more transparent) or makes the algae more digestible to the tiny floating animals, then the effect of the increased algal activity that contingent event induces will be rewarded two steps later by more Bladderwort surface. The activity of all the members of the triad will be increased. Conversely, if the change either decreases the possible algal density or makes the algae less palatable to the micro animals, then the rates of all three processes will be attenuated. Simply put, contingencies that facilitate any component process will be rewarded, whereas those that interfere with facilitation anywhere will be decremented. Autocatalytic configurations are thus both self-advancing and self- preserving. As well, such selection increases the probabilities of activity along certain pathways, providing an example of Bernard Lonergan's (1997) "emergent" probabilities.

One consequence of autocatalytic selection is absolutely essential to life, but is almost universally ignored – namely, the mutual beneficence of autocatalysis induces a centripetal flow of resources into the loop (Figure 4): The dynamics of selection imply that any increase of resource taken in by a component process will be rewarded. Because this result applies to each member of the cycle, all the avenues of resources into the autocatalytic loop tend to be amplified. That is, autocatalysis works to increase the amount of resources that are pulled into its orbit. Such centripetality, or radial attraction, is evident, for example, in coral reef communities, which sequester major concentrations of nutrients well over and above those in the oceanic desert that surrounds them.

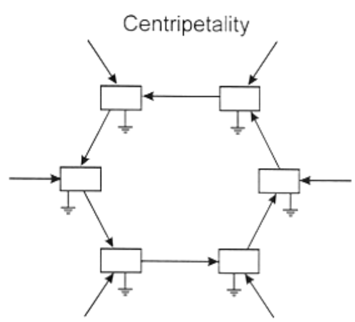


Figure 4: Centripetal action as engendered by autocatalysis.

This ratcheting-up of activity and its accompanying centripetality together constitute what commonly is referred to as "growth." Growth, especially in the geometric proportions described by Thomas Malthus, played a major role in Darwin's narrative. Unfortunately, the later disciples of Darwin have found it convenient to allow the growth side of the evolutionary story to atrophy to the point where it now appears simply as a given that does not warrant further attention. But Darwin's full dynamic was a balanced dialectic that could be paraphrased as "Growth proposes, natural selection disposes" (Stanley Salthe, personal communication, 2011). Contemporary discussions of evolution strongly emphasize the eliminative role of nature, commonly referred to as "natural selection," but the enormous advantages imparted to some species via their participation in autocatalysis appear almost nowhere in the Modernist narrative.

Comments about centripetality in living nature are rare. Two individuals who appreciated its importance came at the phenomenon from radically different perspectives. The noted philosopher and detractor of Christianity, Bertrand Russell (1960), called centripetal dynamics "chemical imperialism" and claimed it was the drive behind *all* of evolution.

His appraisal is likely close to the mark. Although competition plays the central role in the conventional evolutionary narrative, it doesn't take much effort to uncover what actually drives competition: Place two autocatalytic systems within a field of finite resources and their centripitalities eventually will intersect. It follows that competition will not take place unless centripetal drives are already active at the next level down. Hence, the mutualism that generates centripetality is a primary agency, whereas competition itself is a derivative phenomenon that plays a decidedly secondary role.

I should stress that, like with many other natural phenomena, normative assessment of centripetality will depend on its context in the natural hierarchy. Russell, for example, cast a negative spin on centripetality by characterizing it as "imperial". Indeed, centripetality defines a proto-self that accompanies all living systems. Similarly, Daryl Domning (2014) finds it helpful to portray the effect as "original selfishness" – a prototype of Original Sin. Chardin adopts an entirely different perspective. If love can be regarded as a particular form of beneficence, then it makes perfect natural sense for Chardin to identify love as the fundamental law of attraction (Savary 2007). His further claim that love is the physical structure of the universe (Chardin 1969) also accords with Bonaventure's (Delio 2005) declaration that the love shared among the Holy Trinity is the basis of all action. As with the parables of Jesus, a degree of understanding of theological statements can be achieved via the images they project onto the natural world.

I must pause to mention that, in order for autocatalysis to ratchet up its activity, the related system must possess some form of memory or hysteresis. In this age of obsession with DNA/RNA, most will probably envision some molecular structure as the repository of the necessary memory. But one should recall that the autocatalytic dynamic itself is structured and stable and can function as a rudimentary form of memory. The highly-structured polymers of nucleic acids we now deem essential for life are likely the products of earlier configurations of processes (Deacon 2006). Once encoding had emerged from those more diffuse process forms of memory, their inherent efficiency and greater durability allowed them to extirpate their progenitors (a form of temporal supervenience).

It is helpful to take account of how autocatalytic configurations evolve through time. Each new feature of a given repertoire is the result of selection exercised by the autocatalytic structure on some new incident form of contingency, be it radical, blind or somehow already ordered. That earlier configuration in its turn came into being through a previous inclusion of some other contingency, and so forth back into the past. The system at any time is built upon a history of serial contingent events that could be referred to as "frozen contingencies". The development of the system can thus be seen as indeterminate, but nonrandom. Any particular inclusion of a contingency is not totally random, because it was selected by the configuration as it existed at the time of encounter. A large number of other contingencies were not selected, because they did nothing to advance the program of autocatalysis. At the same time it is impossible to predict the exact nature of the contingency next to be selected, in the same way that one cannot predict the nature of an exaptation. The pathway built upon such a dynamic remains perforce indeterminate. As we will see yet again tomorrow, the universal laws of physics serve to constrain what is possible, but they are insufficient in a heterogeneous world to determine exactly what will happen.

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