Cosmological Evolution: Spatial Relativity and the Speed of Life

Robert B. Sheldon[a] and Richard B. Hoover[b]

[a]USRA/NSSTC, 320 Sparkman Dr., Huntsville, AL, USA;
[b]NASA/MSFC/NSSTC, 320 Sparkman Dr., Huntsville, AL, USA

ABSTRACT

Three recent discoveries support the existence of an extra-planetary, cometary biosphere that is capable of spanning the galaxy: 1) the discovery of ancient cyanobacterial fossils on carbonaceous chondrites, which are widely believed to be extinct comets, 2) the observations and theory that all short-period comets have irreversibly differentiated by melting and undergo periodic remeltings, and, 3) the observation that comets can accrete inner solar-system material, including spores from other infected comets. While no direct observation of sub-cellular, fossilized viruses exist, their ubiquity and proximity with cyanobacteria suggest that the proposed cometary biosphere also carries a full complement of bacteriophages. Recent work transcribing viral DNA of bacteriophages reveals an active horizontal transfer of genes though a vector that doesn't itself benefit from the genes. Thus the cometary biosphere is capable of transporting genes throughout the galaxy that are not themselves expressed in space, suggesting that evolution may occur not just in time, but in space as well, making the Earth and its history less significant for a cosmological theory of evolution. That is, evolution is driven not by innovation, but by communication, albeit at a slow cometary speed and the transfer of a life ecosystem through a low bitrate channel can be modelled as a bootstrap process. Thus cometary evolution suggests that the history of earth represents the spatial relativity of a bootstrap process at the speed of life.

Keywords: comet, biosphere, cyanobacteria, astrobiology, panspermia, panzooia, microfossil, bootstrap, evolution

1. INTRODUCTION

Recent discoveries of fossilized life on all known carbonaceous chondrites [1–4], which are widely believed to be the remnants of extinct comets, widens the extent of the biosphere to include extraterrestrial bodies. If indeed all comets that come close enough to the Sun will partially melt [1, 5, 6], then comets may provide a mobile terrarium, ideal for the transport of life throughout the solar system [7]. Such a mechanism might explain the Viking Labelled Release experiment [8–10], stratospheric live bacterial precipitation [11], the discovery of amino acids on Titan [12, 13] and the Moon [14], as being the natural result of interplanetary infections. In addition, samples of cometary dust returned by the Stardust mission [15], revealed that comets can also accrete material in space, leading to the possibility that life can pass from comet to comet, only infrequently encountering a rocky body. We call such an ecosystem a "cometary biosphere" [16] and suggest that it is no longer limited to our Solar System, but may spread throughout the galaxy, wherever suitable comets are to be found. Our calculations, however, did not support the transport of life to the Andromeda galaxy, so that this present discussion is limited to our own Milky Way galaxy. (See also Gordon [17], who permit intergalactic travel by speculating a much higher speed of life.)

In our previous conclusions, we address the panspermia theories of Hoyle and Wickramasinghe [7, 18–20] that life began on comets, mainly by sidestepping the issue, arguing that cometary transport does not say anything about the origin of life. It may have begun on Earth and spread to space, or it may have begun in space and spread to Earth. The mystery of life's origins is tied up with the huge improbability of the chance organization of a reproducing cell or proto-cell [21]. Many scientists put the present odds at 10^{-100} or more, well beyond

the probabilistic resources of the entire big-bang universe, with or without comets [22, 23]. Until those odds get within ten zeroes or so of 1.0, it would appear fruitless to speculate on the suitability of comets as incubators for the first cell. However we may still learn a great deal about the progress of life through space and time by studying the cometary biosphere, which we call panzooia.

In this paper, we refine panzooia by examining whether cometary transport distinguishes between models of evolution. We argue that there are really only two metaphysical models for life: the random local model of Darwin [24] and the coherent global model of Arrhenius [25]. In section two, we address the temporal and spatial signatures of local stochastic processes, "noise", and how it differs from its global complement, "signal". In section three, we trace the historical development of this metaphysical distinction between signal and noise. In section four, we analyze local Darwinian evolution in these terms, and in section five, we propose an alternative global theory of evolution mediated by cometary transport. In section six, we examine the chimera of hierarchical evolution, finding it metaphysically incoherent. Finally, in section seven, we conclude with some consequences of this global model of evolution.

2. SIGNAL AND NOISE IN SPACE-TIME

Secure communication has always been of interest, from the time that parents shooed their children out of the room, and whose whispered secrets didn't carry through the door. But when communication channels became more public, with radio, and now the Internet, secrets were harder to keep. Accordingly encryption has been employed by school kids and the military for millennia, and likewise decryption. One of the early favorites was a transposition cipher, where letters of the alphabet were replaced with cryptic tic-tac-toe symbols, or by shifting a certain distance along the alphabet. The German Enigma machine used in WWII was just a modern version of such a cipher, and Von Neumann's brilliant solution for deciphering that code gave birth to the modern computer, using its enormous patience to search for non-random patterns in the coded message. And now in our modern world, the computer is routinely used to decipher Nature's encryption, looking for non-random patterns in the noisy confusion of global temperature trends, or cosmic background microwave radiation, for example.

This is the same magic applied to digital camera photos that came out too dark, perhaps because it was taken too far away from the podium for the flash to illuminate the diploma. But of course, the camera came with software to enhance photographs, or perhaps Photoshop, and after playing with the contrast and brightness, and maybe even the "sharpen" tool, a nearly black photograph of the back of someone's head suddenly became a diploma, though perhaps a bit grainy. What was the computer doing? It was suppressing the background, stretching the color tables, averaging over local pixels, trying to increase the signal-to-noise ratio. Similarly, the retina at the back of the eye, between the pupil and the optic nerve, has multiple layers of neurons that do all these Photoshop functions, and are also responsible for the "optical illusions" that are the mainstay of 1960's OpArt. The eye processes images for the same reason that NASA does it on Mars landers, to compress the information while eliminating noise, so that the limited throughput of the transmitter (optic nerve) is getting all the best information available.

But there's a difference between the retina and Photoshop, the Photoshop sliders are adjusted while looking at the entire photo, but the eye does this on the fly without global information. That is, the neurons in the layers at the back of the eye connect adjacent "pixels", performing all their functions with only local information. Like the road intersections in France that are labelled by the name of the next nearest town, travelling from Paris to Lyon requires knowledge of all the intermediate town names, or global information. Yet the eye eliminates some 90-99% of the bandwidth collected by the retina, before passing back to the brain the best 1-10% without any such "big picture" information, how is it possible?

By knowing what the noise looks like. Random noise always looks the same, like "snow" on old analog UHF TV signals. Noise has little spatial correlation, so if one examines it closely, little spots of white and black flicker randomly until the UHF tuner finds the signal. To distinguish the ghostly figures behind the "snow", we step back to see the whole screen and average the "snow" into a uniform gray, but the neurons in the eye can't "step back", they have to make the call by looking at just a few pixels to the right and the left. However, by stacking up these neuron "comparators" into layers, then the output of one layer goes into the next layer, and after a few layers, the neurons have averaged the noise into a uniform gray, and they don't pass on that information (by "firing" a neuron) unless it changes suddenly. (e.g., nematode navigation [26]).

Table 1. Historical Metaphysics

circa 500BC		circa 1800AD	
Aristotle / Plato	Democritus / Leucippus	William Paley	Isaac Newton
Organic biology	Inorganic physics	Organic biology	Inorganic physics
Attractive forces	Repulsive forces	The Classification	The Calculus
Long-range	Short-range (contact)	Desire/Will/Intent	$F=md^2x/dt^2$
Friction (cislunar)	Frictionless (atomic)	Light=wave	Light=particle
Frictionless (translunar)	Friction (super-atomic)	Biology irreducible	Physics irreducible
Motion = cause	Motion = chaos	Organic chemistry	Inorganic chemistry
Eternal Matter + Demi-Urge	Eternal Matter + Chance	Long-range, large	Short-range, small
4 causes	2 causes	Design/Tool/Function	Time/Space/Matter
Final & Efficient	Formal & Material	Gravity??	

Mathematically, there are two separate processes going on in the eye, a spatial filter that looks for differences between pixels or edges, and a temporal filter that looks for differences in time or motion, though physically they are the same. The one eliminates spatial noise, which is uncorrelated in space, and the other eliminates temporal noise, which is uncorrelated in time (by being constant or random flickers). It may sound easy, but as soon as one tries to implement "machine vision", say, to have a computer pick up a toy on an assembly line, then all sorts of complications arise, such as compensation for camera motion and flickering lights, but the basic point remains the same–space-time correlations equal information, and their lack equals noise.

While we are moderately familiar with the use of computers to process spatial information, we are less familiar with their use to process temporal information. In the past 10 years, computers have become the standard platform for making movies, videoconferencing, and now YouTube, and all of these media are starved for bandwidth. So there has been considerable effort put into compression of video, sending only the bits that demonstrate some sort of change. A similar effort has gone into music, with the result that instead of a Beethoven's 9th on a CD, one can now put thousands of MP3 compressed songs into an iPod with apparently little degradation in the quality. Now songs and movies are time-redundant, containing more bits than are needed to convey the music or the video, so finding better compression algorithms are essential in speeding up, or storing more of them, not just in an iPod, but in the brain.

Both of these examples, the eye and the brain, are intended to show how information is stored without wasting bits on noise. So when we say that chaos is the opposite of information, we are speaking quantitatively, with specific algorithms in mind, evaluated by their ability to eliminate spatial noise and time-redundancy while conserving the information, in both time and space. This distinction between information and noise, between order and chaos, between design and chance, has been at the core of modern science and metaphysics for 25 centuries, ever since Aristotle and Democritus argued about the essential character of nature [27].

3. LOCAL VERSUS GLOBAL INFORMATION

Over the past 3 millennia, metaphysics has found two solutions defining the essence of matter and life(see Table 1) [27]. The Aristotelean solution argued that biology is the correct paradigm for both, with matter showing proclivities that were similar to biology, so for example, gravity is the "desire" of matter for like matter. In contrast, the Democritean materialist solution argued that physics is the proper paradigm for biology, so for example, the attraction of moths to light is a receptor process accounted for by non-living atoms bombarding a moth's brain. Over the last 25 centuries, the two paradigms have approached each other, with physics adding more and more "fundamental forces" showing long range behavior (like biology), while biology simplifying toward chemistry, attributing more and more behavior to deterministic conditioning involving chemical or physical (un-living) causes.

In the early 20th century, these two fields overshot each other, with physicists discovering the vitalist world of quantum mechanics (QM) with its dualistic, long-range, non-materialist behavior, and biologists discovering the materialist biochemical world of organic machines (See Table 2). Many have commented [28] on this strange phenomena of physicists sounding like dualist gnostics (e.g., QM theorist David Bohm), while biologists have

become ardent materialist reductionists (e.g. Neo-Darwinist Stephen Jay Gould). Since physics has made a round trip, from organic to material to organic interpretations, whereas biology has made only a one-way trip, from organic to material interpretation, perhaps physics will predict the future for biology.

That is, physics was initially dominated by Aristotle (up until the high middle ages), with its organic, long-range, biological explanation of elements and their attractions, only recently converting to reductionist Materialism. As great a physicist as Ernst Mach in 1850 held firmly to the conviction that atoms were a Democritean metaphysical invention without any real existence (since they had never been seen), despite their use by chemists to explain integer combinations of molecular reactions. Not until James Clerk-Maxwell applied the atom theory to gases ($\sim$1880) and then Ludwig Boltzmann calculated the statistics ($\sim$1890), did the skeptical physicists believe in their real existence. And of course, soon after came the first pictures of atoms, thereby putting to rest Mach's reservations.

One of the crucial points in Democritean atomism, is that atoms are all there is, there is no intelligence guiding them, no external influence affecting them, no creator adding or subtracting them, rather purely contact forces of collisions in the void could account for all manner of physical and chemical behavior. In addition to point-like atoms, this model also assumes the existence of absolute space and absolute time, such that all communication between atoms must trundle along at the speed of the fastest messenger, the temporal derivative of space. So the success of 19th century atomism, the concrete predictions of Boltzmann and Maxwell corroborated by experiment, implied that all physics phenomena were local interactions embedded in a clock-and-meterstick, space-time geometry.

Elaborating on this analogy, we can consider the effect of atomic forces on a bottle of air. If all the air in a lightweight bottle is magically put into linear motion, say, by igniting a mixture of hydrogen and oxygen in separate compartments, then the bottle will experience an unbalanced force on the inside, the bottle will spontaneously leap off the table. Soon however, the collisions with each other will turn this motion into random directions, the propulsion will cease, and the atoms will heat the bottle but no longer move it. The whole magic of heat engines is to find a method of extracting information, or work, from a hot gas before the regular order dissipates. Now we can only extract work if the system is left in an even more disordered state afterwards, or else we would be violating the 2nd law of thermodynamics that says information isn't free. In physics jargon, the opposite of information is disorder or "entropy", S, and this 2nd law states "in an isolated system the entropy must either stay constant or increase". Boltzmann is credited for explaining disorder as a mathematical quantity of a gas that could be counted, and was so proud of it that he had this equation engraved on his tombstone, $S = k \ln \Omega$, where $\Omega=$ the number of permutations or countable "states" of the system; ln= the logarithm function, and $k=$ the conversion of units from numbers to temperature called "Boltzmann's constant". (Not everyone agrees that Boltzmann or configurational entropy is the same as thermodynamic entropy, but they do agree they are linearly related [29].) Entropy is a mathematical way of saying there is only one way to organize all the socks in a drawer, but a thousand ways to decorate the floor with them, so that a measure of disorder, S, would say that a teenager's room will naturally tend toward socks on the floor, and can only be put back in order with work (or information) to reverse the process.

Giving a countable example: two dice are rolled repeatedly, writing down the sum, and the result binned as one of: 2-3-4-5-6-7-8-9-10-11-12. Plotting this histogram reveals a "bell-shaped" curve, with the most rolls occurring for bin "7", and the fewest for "2" and "12", because there are six ways to roll a "7": 1-6, 2-5, 3-4, 4-3, 5-2, 6-1; but only one way to roll a "2": 1-1. From Boltzmann's equation above, the entropy S of bin "7" is $k \ln 6 = 1.8k$, whereas bin "12" has $S_{12} = 0k$, so the entropy is maximized in bin "7". This bell-shaped curve, or Gaussian, is characteristic of random processes that are "fair", that have no outside influences on them. If instead, one discovers a triangle-shaped histogram with most rolls at "12", then chances are the dice are loaded (possessing internal information).

Now suppose there are as many dice as there are air molecules in the room, what would be the average if one added together all their pips and divided by the number of dice? A very, very good average: 3.50000000000000000000000 where the zeroes are significant. Why so many? Because there are so many air molecules in the room. The more dice that are averaged, the "sharper" the bell-shaped histogram curve becomes. It becomes so needle sharp, it can be called a law. Perversely, the more random particles that get averaged together, the more non-random and predictable the result becomes. So if instead the average comes

Table 2. Twentieth Century Metaphysics

	circa 1930AD	
	Charles Darwin / NDT	Albert Einstein / Niels Bohr
	inorganic biology	organic physics
time eternal		time begins
matter indestructible		Matter ephemeral
Space & Time invariant		Lightspeed invariant
Chance Universe		Contingent Universe
Biology←organic←inorganic chemistry		Physics→wavefunctions→ ∞ Hilbert Space
Math=Population Genetics		Math=Wave Mechanics + Cosmology
discrete, spatially fixed, local		continuous, non-linear, non-local
Species spatially discrete, temporally continuous		Atoms spatially continuous, temporally discrete

out 3.50000000001, we would know there was information added to the system at the parts per trillion level. Likewise, even if the average were 3.5 but the shape of the histogram were more triangular than Gaussian, we would know there was information added to the system, because the "wings" of the histogram have lower entropy (higher information) than the center.

Returning to atomism, the success of Boltzmann in describing the behavior of a gas as atoms, is just a restatement that atoms behave chaotically like dice rolls, that they lack direction, purpose, or inherent information (merely using up whatever information is put into to their original ordering). Now there have been some modifications to this word "local" to take into account magnetic and electric fields, which were discoveries of non-materialist Michael Faraday, but these modifications were later made more materialist by their reinterpretation as "virtual particles" mediating these long range forces. (Gravity alone remains stubbornly resistant to such particle analysis, with several famous scientists concluding that gravity will never be incorporated into a unified, materialist, particle theory.) So in simplified terms, signal or information is equivalent to long-range order, and conversely, anti-information or noise is equivalent to short-range interactions that produce Gaussians.

Therefore the QM discovery of long-range correlations (Einstein's 1935 EPR paper [30]) has been a source of metaphysical friction in the physics community (see Table 2). The QM "wings" on the histograms may not be noticed when there are millions of atoms and the peak is sharp, but looking at atoms one by one (Bell's Theorem) makes the correlations more obvious. Some take it to mean that materialism fails, viewing it as support for a dualist and gnostic reality (Niels Bohr's "Copenhagen"). Others view it as a math trick with no metaphysical connection to reality (cf. Barfield's "Saving the Appearances" [31]). Still others do violence to the metaphysics of existence by supposing that there are an infinite number of realities (Everett's "Many Worlds"). Yet others do violence to the metaphysics of causality by supposing that time goes both directions (Cramer's "Transactional"). But whatever interpretation is chosen, the one interpretation that cannot be true, is that of Einstein's "naive realism", or simple materialism [32]. Thus the past 50 years has seen a resurgence of "organic" or "long-range correlation" interpretations of physics, because empirical measurements have shown a long-range order that cannot be due to short-range, Democritean particles.

4. DARWINISM AS A LOCAL, CHAOTIC SYSTEM

Now when Darwin suggested that random mutations combined with natural selection would provide a chaotic explanation for apparent design and order in biology, he was making a mathematical statement about long-range correlations. He was saying that species behave like larger versions of atoms, without time-ordering (e.g., Lamarck's "purpose"), and without spatial-ordering (e.g., Margulis' "Gaia"). The opposite viewpoint was often called "vitalism" [33], that there existed some long term order, either attractive (Aristotle's "destiny"), or pre-designed (British Deism, Bergson's "impetus"). Despite Darwin's apparent waffling on the issue, modern Neo-Darwinists (e.g., Ernst Mayr, E.O. Wilson, Stephen Jay Gould) argue that all such "progress" in evolution is illusory, that there is no long-range correlation evident despite the archaeological record of increasing complexity through time. That is, the appearance of progress is driven by random, local processes, much as frost flowers form on a window, without any information beyond a local, undirected interaction (e.g., diffusion-limited growth).

Since the materialist atom knows of only local interactions, the long range order possible (as in crystals and frost flowers), is either predictable or accidental, merely the accumulation of many random steps. Neo-Darwinists argue that the order, which is visible in living things, is much like that of a crystal, a long-range spatial order slowly, and randomly, accumulated over time. Similarly the historical ordering of evolution itself, from simple to complex organisms, is likewise a consequence of short-time interactions (mutations), accumulated over space (species). This biological process is said to parallel the physical process of "emergence", or the appearance of complicated, large-scale properties based on simpler, small-scale physical laws (e.g., the 12 ice crystal structures, the low freezing point, the high boiling point, and the hydrologic cycle all resulting from the lowly hydrogen bond between water molecules). Emergence or no, Darwin's "survival of the fittest" hypothesis of mutually reinforcing space-time correlations makes it quite difficult for theorists to mathematically tease apart the two dependent correlation functions–the spatial and temporal–which is the step needed to ascertain their potential long-range order.

For example, if we ignore long-range order, and plug in a simple mathematical model of evolution as the accumulation of random mutation steps, the diffusion of information (or progress) has no "arrow of time", no "progress rectifier", no "success ratchet" that accepts only progress and rejects regress. This is because all such rectifiers are a result of long-range order. Making the task more difficult, is the apparent sparseness of the data, which are predicted to be smoother than observed. That is, rather than finding many organisms spanning the reptilian to amphibian transition, or the mammalian to marsupial transition, we find non-Gaussian distributed clusters of species. This is true whether we consider their shape (morphology) or their genes, and often the genes give a different grouping than the morphology (a complication we'll ignore, though highly revealing). This is even true when we express the differences chronologically, that long periods of apparent stasis are separated by short periods of extremely rapid change, i.e. the Punctuated Equilibrium hypothesis [34]. If the present large differences between species were the accumulation of small, random steps, then there should be smooth transitions in time and space ("missing links"), which are rarely observed. This "clumpy" character of the evolutionary data has been seen before in physics, where it is indicative of long-range correlations, such as 2nd order phase transitions, critical points, or "Levy-flight" transport [35].

This evidence of long-range order need not invalidate short-range Darwinism since, after all, physics has successfully incorporated long-range forces into a materialist metaphysics. So the question becomes, can biologists also find a convincingly materialistic long-range ordering parameter that can explain this clumpy, non-Gaussian behavior, starting with random, local interactions?

4.1 The Local Interaction Dilemma

Physicists often deal with interconnected problems, which may sometimes be resolved by considering "timescales". The random collisions in atomic theory are fast, taking little time, whereas the information/work extracted from a gas is noticeably slower, taking much more time. Long term, cumulative correlations are smaller and slower in effect, and must be examined and averaged (accumulated) carefully. So to see the randomness of a Darwinian process, we need to count the number of states of the system at a short enough timescale to catch the uncorrelated, "fast" motion, find the Boltzmann entropy, negate it to find the information, and plot that information as a function of time, all the while being careful not to average over long intervals that would distort the accumulation (which presumably would produce the emergence of long-term order).

Following this prescription, many have argued [23,36] that unlike frost flowers, evolution shows a real increase of information, or a decrease of entropy, that cannot be accounted for by local, random, atomistic processes. It would be as if the frost on the window had formed the words "Stopping by Woods", which would be an unaccountable event. Despite early hopes that "genetic algorithms" that imitate natural selection would be highly efficient at extracting information from noise, 20 years of frustration finally led to a math theorem that rates them no more efficient than any other random search algorithm [37]. Cornell geneticist John Sanford [38] argues that none of the proposed rectifiers actually worked in practice, but much to his dismay, random mutation processes observed in the laboratory invariably produced a loss of information, an increase of entropy, as predicted by thermodynamics. And rather than extrapolate toward inevitable progress of the species, such laboratory results extrapolate toward extinction.

This is not to say that evolution is impossible, since it is undeniable that there has been an increase in complexity over time, but that if there be emergent order, it must occur at a larger temporal or spatial scale than the supposed gene/codon level explored by these experiments. While many Neo-Darwinists fear that going beyond point mutations is a reintroduction of anti-science "vitalism", the entire methodology of these experiments is materialist, so that rather than reintroducing a non-materialist vitalism, they merely redirect Darwinian theory away from a mystical dependence on emergent physics, at least, at the codon level.

4.2 Hierarchical Evolution as a Global, Coherent System

Indeed, the past 10 years has seen many biologists positing a long-range order in evolution, so for example, Harvard evolutionist Stephen Gould writes [39] that "hierarchy" in the action of evolution may act on more than one unit or one individual simultaneously, but on the whole organism or clade. Even earlier, U of Manitoba embryologist Richard Gordon writes [33] that evolution of the "cell-state splitter" (the mechanism taking a fertilized egg and converting it into a multi-cellular functional organism through a cell splitting and differentiation) can convert small changes of development into huge transformations of adult organisms. Thus evolution of higher order controls will take many fewer changes to create new species than counting the number of discrete functional differences (contra Berlinski [40]). By analogy with computers, there are many fewer steps needed in a heapsort than in a substitution sort, or by analogy with the military, an army is mobilized by a chain of command, rather than by a general barking orders to privates. Therefore, argues Gordon, evolution progresses with far fewer (and bigger) steps than realized, and therefore more rapidly and with less information, by evolving the embryo which develops the cellular machinery, rather than the cellular machinery directly.

In a similar vein, proteins are found to have an ordered structure larger than merely the sequence of their peptides. Using the Chinese written characters as a basis with similar long-range order, Axe [41] looks at how mutations in the vectors that compose a Chinese character are similar to mutations that affect proteins. The point of Gould, Gordon and Axe papers, is to argue that information is hierarchical, global, possibly even fractal. That is, a mutation at one point in a protein or in an embryonic development has long-reaching implications that are not local. Therefore whether we consider organisms, embryology or protein folding, information has global consequences, with mathematically distinct effects. Can we use this observation to give material atoms the ability to create long range order, can we find a rectifier for the blind, localized steps of evolution?

Many mathematical biologists think so. Physicist Michael Deem [42] argues that hierarchical evolution can even accelerate as it evolves a more efficient "gene transfer" process. That is, he not only proposes that entire genes can be swapped around, but even higher functional units like chromosomes. Evolution can function, he argues, on larger and larger scales so that the more complex and large-scale the organism, the bigger the evolutionary step permitted, and the faster evolution progresses.

So we have a problem with Neo-Darwinian paradigm: the posited introduction of information at the codon level to explain the historical increase in biological complexity (combined with the rectifier of population genetics) was contradicted by eighty years of experiment. Can we rediscover this rectifier, this long range order in a more hierarchical level, at perhaps the gene, or chromosome or even genome level? That is, if we cannot introduce information by swapping codons, (or peptides), can we find some process that swaps genes, swaps chromosomes, perhaps even entire organisms, can we find the mechanism that powers Gould's hierarchical evolution?

5. HORIZONTAL GENE TRANSFER

In 1948, maverick geneticist Barbara McClintock proposed that genes could move around on the chromosome, and thereby change their expression or performance [43]. After 35 years, in 1983, she finally received the Nobel Prize for her pioneering work on transpositions, suggesting that mutations or evolution can handle larger chunks of DNA than codons. But by itself, "jumping genes" do not provide the hierarchical evolution that Gould dreams of, since reorganizing the contents of a file cabinet may make it easier to find things, but doesn't create information that wasn't already there. Gould, Deem and Gordon need a way to introduce large chunks of new information into the genome, preferably in the form of genes or bundles of genes. Of course, this is what goes on in sexual reproduction, which, unlike grafting, cloning, parthenogenesis, bacterial multiplication and other forms of asexual reproduction, results in a brand-new mixture of genes. But if we consider the gene complement of the entire species, the genome, rather than the chromosomes of a single individual, sex is not much different

than jumping genes, rearranging the file drawers of a species without providing new information. What we are looking for is something like sexual reproduction, but between species.

It has already been found in bacteria, called "bacterial conjugation". If a bacteria contains a loop of extra DNA of a particular plasmid, which is separate and in addition to its own DNA, then the plasmid can cause the bacteria to form a transfer tube to another bacteria, not necessarily the same species, and transfer itself and perhaps some host DNA as well. In rhizobacteria, this process can transfer bacterial DNA into a plant cell nucleus, making cell products not native to the plant. We might consider plasmids as a naked virus, where they often bring antibiotic resistance, or other symbiotic benefits to their host. Notice also that this conjugation event does more than infect a new host with plasmids, it also can transfer genes between species of bacteria. Like viruses, this extraneous loop of DNA is usually not considered alive, but it does replicate. Thus these types of DNA should be seen as more than sub-living parasites, but as machines designed for horizontal gene transfer between species. These sorts of viruses are precisely the mechanism we needed to produce hierarchical evolution, and it would appear they are a very efficient one, evolved for this purpose.

Should we say viruses are a mechanism evolved for this purpose? The study of the most abundant of these viruses, the bacteriophage, would reveal a machine designed for the single purpose of finding a bacterium and injecting DNA through its cell wall. Its a sub-sub-miniature, flying hypodermic needle: no extraneous parts, self-assembling, minimalist design, hugely efficient. In fact, viral surveys suggest [44] that there are 10 times as many phages as bacteria in sea water, or roughly 10^{30} tailed phages in the biosphere. Phages are only by size, a minor constituent of the biosphere.

Now we come to an important point. If Darwin's natural selection were tuned to multiply phages (at the expense of bacteria), they should be tremendously efficient, which they are in most respects except one. That is, with lifecycles shorter than a bacteria, with a multiplication factor of 200, with replication errors much higher than a bacterium, natural selection should be brutal and swift for these phages, making them ruthlessly efficient. Yet despite this evolutionary pressure, phages have enormous DNA variation, even containing DNA that has no useful purpose to the virus [44]. And it is more than merely mutations of the viral replication genes, but entire genes for things that a virus has no need at all, such as chlorophyll. Therefore more is going on with phages than merely natural selection at the codon level, and this provides ample support for the hierarchical model for phages. But most importantly, this can all be done mathematically.

The ease with which phages can be analyzed and their DNA transcribed has resulted in a large and growing database of transcribed phage DNA [45, 46]. This database can be searched for particular genes as well as processed digitally, much as photographs or music, with surprising results.

5.1 Genetic Data Show Global Coherence

Compressing the database of phage DNA reveals virus relationships, since related genes should compress nicely. Algorithms based on a hash function (Lempel-Ziff-Huffman) capture the amount of information at the local level [47], but algorithms that use global characteristics (fractal compression) seem to work better on this data base [48]. Evidently, the information in the genome is stored both locally and globally, which undermines the contention that the Neo-Darwinian "local mutation rate" is responsible for all the information in the genome, since such a process would not be expected to change the fractal dimension. So it would appear that these databases are supporting Gould, Gordon and Deem's contention that the genome is hierarchical.

Furthermore, the genes for the smallest cyanobacterial genome capable of photosynthesizing, are found in chopped up form in the phage database. This suggests that even should a catastrophic event, say, a meteor impact that boiled off all the oceans and exterminated photosynthetic cyanobacteria, nevertheless, phages plus a bacterium that lived in rocks a 100 meters below the ocean bed could collaborate in replenishing the oceans with photosynthetic bacteria. Another recent paper on the microbes of a hyper-saline lake, found that they shared similar genes for coping with the high salt content [49, 50]. It would seem obvious that some horizontal transfer of "salt-tolerant" genes was helping all the denizens cope with extended drought conditions.

Once horizontal gene transport is acknowledged, the entire field of genetic chronology using cladistics algorithms based on the most efficient or minimal binary tree of heredity must be modified. That is, instead of

assuming a "tree of life", with "descent with modification", we now have "modification without descent" producing a "bush of life". Changing the cladistics algorithm to look for the minimal set of horizontal replacements, Dagan [51] claim that $81\pm15\%$ "among 539,723 genes distributed across 181 sequenced prokaryotic genomes" show HGT.

These examples demonstrate that "survival of the fittest" is not even true as a tautology, because survival has little to do with self-fitness, but rather the beneficial intervention of a virus. Only if we consider the collective genome of all the species in the pond, could we invoke a "survival of the fittest ecology" but not "survival of the fittest specie". In other words, the fittest ecology is the one with the most collaborative species, the one with the highest viral infection, the one with the worst immunities. If this transmutation from "species" to "ecologies" still seems consistent with the accepted evolution paradigm, then ponder that Darwin introduced this tautology to explain "The Origin of Species", not "The Origin of Ecologies". The differences are profound, for the ecology has no desire to allow cyanobacteria to mutate into palm trees, if anything, the survival of the ecology requires the stasis of the species. Thus ecological natural selection has the opposite effect hypothesized by Darwin, of stabilizing the species against extinction events or mutations. Saying this one more way, mutations cause rising entropy, so it is natural to discover that life, which battles entropy from birth to death, also battles entropic mutations over the longer cycles of drying ponds, changing climates and millennial ice ages.

But if all this effort goes into keeping the genome viable, keeping the ecology stable, how then can hierarchical evolution occur? Have we not contradicted our earlier supposition that phages are capable of rapidly modifying the flora and fauna of an ecosystem, and thereby speeding evolution?

The obvious answer is nevertheless the most unsatisfying. The phages bring in genes external to the ecology. So, for example, when the Salton Sea, formed by a flood on the Colorado River in 1905, started to go from fresh to salty, salt-water diatoms from the ocean 80 miles away, started growing, apparently blown in by the wind. And with these organisms came a fresh lot of DNA for the phages to start dissecting and transcribing. In the same way, when the Earth's oceans had converted the reducing atmosphere of the Hadean into the oxidizing atmosphere of the Pre-Cambrian, suddenly new life forms appeared on the scene. Where did they come from, blown in from what extra-terrestrial coast?

5.2 The Cometary Biosphere as a Global, Coherent System

This is where the recent discovery of fossil cyanobacteria on carbonaceous chondrites (meteorites thought to be extinct comets) is most illuminating. In SH07, we argued that infected comets could spread cyanobacteria not only throughout the solar system, but more importantly, from comet to comet, making the collection of infected comets around the Sun or any star, a biosphere of greater size and mass than that of Earth. Such a cometary biosphere should have its own complement of phages, just as we have seen from seawater. However, unlike cyanobacteria, phage fossils would be indistinguishable from crystals and to date we have had no evidence of them (Figure 1). Yet these invisible phages would be capable of transporting quite advanced genes throughout the biosphere, regardless of their origin, or the organism that finds them useful. "The Selfish Gene" [52] was intended to draw attention away from Darwin's species to the apparently independent existence of genes, but now it appears that a better title for the book would have been, "The Altruistic Gene" [53].

Therefore the thesis of this paper, is that the punctuated equilibria observed by Eldredge [34] is not due to some long-range modulation of the point-mutation rate caused by geographically isolated communities, but rather by the sporadic transport of new genes through cometary transport. If the transport is relatively unlikely, then long periods of stasis will be separated by rapid information injections, mediated by phages. For example, the chitin protein that forms the outer coat of invertebrates need not have evolved on Earth, nor require the transport of trilobites by comet, but merely the arrival of an interplanetary comet carrying phages with the chitin gene. Earth-based phages would then insert this gene into many hosts where it could form the basis of a new species or genus.

That is, we have converted the evolutionary history of the Earth's biosphere, the temporal progress of life on Earth, into a spatial series, by multiplying by the speed of comets. Then the sporadic or punctuated nature of evolution represents the "graininess" of the diffusive process, the density of information and its temporal transport, so that the clumpiness of the data is not an artifact of collection, nor attributable to unlikely events
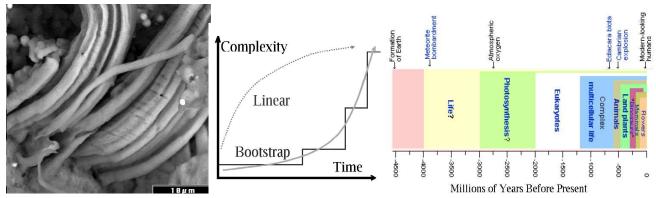
Figure 1. Panel 1: Electron micrographs of large cyanobacterial *Microcoleus* fossils observed by R. Hoover, with small coccoidal and sub-coccoidal forms unidentified, but potential viral. Panel 2: Schematic complexity versus time for linear and bootstrap processes. Panel 3: Complexity versus time for Earth evolution (wikipedia).

such as asteroidal impacts and sterilization of the planet, but the result of the transport physics. That is, it may represent Lévy-flight transport of low density information through the galaxy.

This model does more than explain the non-Gaussian statistics of "punctuated equilibrium", for it presupposes that there is a large body of information outside the Earth, residing in the cometary biosphere, panzooia. If we consider evolution to be a process of increasing information and increasing complexity, then our model suggests that informational complexity is not driven by innovation on Earth, but by communication to Earth.

Does this replace or supplement the "hierarchical evolution" model of Gould, Deem and Gordon? We argue that it does both. Gould and Gordon hypothesized a mechanism for rapid evolution, but did not supply a source of information, merely asserting that it was internal or "emergent". We supply an external source of information and a mechanism, but argue that much of the hierarchical model still remains true, as this external information percolates throughout the biosphere, modifying ecologies and lifeforms in a cascading manner. But before we develop our model further, we need to explain why Gould and Gordon are metaphysically inconsistent with a Darwinian, internal, diffusive, local source of information, and may actually require an external source of information.

6. CAN HIERARCHICAL EVOLUTION SAVE NDT?

Does hierarchical evolution save Neo-Darwinian theory? An immediate objection arises from the putative existence of the machinery in the first place. For if there exist machinery for accomplishing random swapping of genes, what is its origin? If the probability of a million monkeys creating Shakespeare by randomly moving around paragraphs of text in Microsoft Word is so much better than typing it out a letter at time on a typewriter, what then is the likelihood of both the text and the tools, of Shakespeare + IBMPC versus Shakespeare + Royal? It would seem that the entropic cost of a PC far outweighs the entropic profit of moving around paragraph-sized chunks of text.

But there are more serious objections. Even supposing that truly clever paragraph processors can be made with low entropic cost, making it profitable for monkeys to leave their Royals behind, there remains a second metaphysical problem. For a hierarchical mechanism must also evolve itself, as Deem has argued, since the machinery of this gene swapper is also made by genes. This produces an evolutionary feedback far stronger than natural selection, for the organism can now directly change its progeny. An electrical analogy is an op-amp with feedback that is now capable of oscillatory behavior completely absent in a feed-forward network. A computer analogy is the unpredictability of a Turing machine computation when using operational feedback. A psychology analogy is the irreducible concept of self-awareness. Nor is it possible to save biology from this fate by finding some physical explanation that limits this feedback to a subset of the biology, for Gould has argued that hierarchical evolution would include more than individual organism units. Imagine, the microbes in a shrinking pond decide globally to evolve salt-tolerance, or the humans on the planet Earth decide globally to

Table 3. Evaluating Metaphysics

Good	(Bad)	TopDown	BotmUp	A&P	D&L	WP	IN	CD	AE
Wide Scope	(Narrow)	Excel	Poor	Excel	Excel	Good	Good	Good	Good
Complete	(Incomplete)	Excel	Good	Excel	Good	Good	Poor	Good	Poor
Self-consistent	(Inconsistent)	Excel	Good	Excel	Good	Good	Good	Poor	Poor
Human Behavior	(Robot)	Excel	Poor	Excel	Poor	Excel	Poor	Good	Poor
Predictive	(Postdictive)	Excel	Good	Excel	Poor	Good	Excel	Good	Excel
Science Enabling	(Disabling)	Good	Excel	Good	Excel	Good	Excel	Excel	Excel
Recursive	(Axiomatic)	Yes	No	Yes	No	Yes	No	No	No
Teleology	(Denies)	Yes	No	Yes	No	Yes	Maybe	No	Maybe

reduce carbon emissions. Thus this behavior Gould posits is experimentally indistinguishable from Aristotelean teleology, the very thing Gould is careful to exclude!

Can we have feedback or recursion without teleology? The short answer is no. For recursion introduces a coherence in time such that past events determine the future at long timescales, longer than a breeding lifetime, longer even than a specie lifetime. That is, the production of an oxygen atmosphere some 2 billion years ago was a requirement for the Precambrian explosion of animal lifeforms 1.5 billion years later. It is precisely these long timescale effects that Aristotle called teleology, and provide an "arrow of time", or "rectifier" to the process of evolution. This was the major conclusion of Kurt Gödel's incompleteness theorem, that the mere inclusion of recursion prevents the system from being described by simple (local or incoherent) axioms. It becomes impossible to exclude teleological statements from the logic system, thereby destroying Bertrand Russell's program of removing metaphysics by logic. That is, the mere inclusion of feedback permits teleology, if not demands it since co-operating self-determining evolution should be orders of magnitude more efficient than random evolution, and so would dominate the gene pool were it allowed.

Since hierarchical evolution demands teleology, can we make that teleology internal or "emergent", and so save a modified form of Neo-Darwinian Theory? Not without difficulty, for if global information is self-created, then it must exclude any and all external sources, for the slightest admixture of external information will formally poison the thesis. The entire history of life on Earth must be encoded in the smallest seed, the origin of the first primitive cell, and the resources of time and environment must be sufficient for the first life seed to develop information and complexity without external help. Since the first seed, by all accounts, was too primitive to encode the information presently available in the Earth's ecosystem, then that information must be available in the "laws of physics" dynamics or the environmental boundary condition statics. Those who place it in the dynamics (deDeuve [54], Davies [21]) espouse a form of Bergsonian "vitalism", whereas those who place it in the statics (clay minerals, cosmic rays) are engaged in a shell-game with information. In both cases, laboratory experiments should be able to distinguish between static and dynamic information emergence since spontaneous local emergence should not have temporal contingency, yet have so far been unable to find any informational emergence at all. Therefore not only is there no support for "emergence", there are definite upper limits to its potential rate of occurrence.

The discovery of cyanobacterial fossils, while not conclusive of external information, certainly casts doubt as to the idea of a purely local phenomenon. For once remote locations are permitted to influence the Earth, defending a local source of information emergence becomes an unnecessary restriction. Who is to say that life didn't evolve on Mars and migrate to Earth? But once a remote location of information is allowed, we have made the history of life on Earth irrelevant, for we do not know whether local innovation or remote innovation is responsible for a particular evolutionary step. And if it be remote innovation, we have no history or scientific record that can defend evolution, say, over devolution, or emergence over decadence. Once we permit remote information at all, we have lost all ability to chart the progress of that information with time. Even supposing that we could draw a circle around the solar system, and suggest that life evolved locally here, the evidence of comets on hyperbolic orbits out of our solar system suggest that it would not have remained here.

Consequently, supporting any kind of temporal coherence in the form of hierarchical evolution or "local teleology" drives us to global coherence and "galactic teleology" in which the requirement of a local, emergent,

Gaussian information source is an unsupported restriction of the theory. There really are only two stable, self-consistent theories of information acquisition: the bottom-up, local, emergent, Gaussian, diffusive, innovative model of Neo-Darwinian Theory; and the top-down, global, teleological, non-Gaussian, conductive, communication model of panspermia/panzooia (see Table 3).

7. BOOTSTRAPPING

If indeed only two self-consistent models are available, we should investigate the characteristics of a global, coherent, external model for cosmical evolution. Let us consider a time 4 billion years ago, when a sterile rocky Earth cooled sufficiently to permit life. A galactic repository of biological information mediated by a low-bitrate cometary transfer to a newly created rocky planet becomes an information bottleneck. Just as entire ecosystems cannot be transported by comet, so also complete genomes of advanced lifeforms cannot be transported by comet. Rather, a self-sufficient, self-regenerating ecosystem must be "booted up" from cyanobacteria and viruses. The problem is similar to that of "bootstrapping" a computer, or starting a car, or raising an infant, namely, using information to recursively improve its complexity state.

The wikipedia entry on bootstrapping lists multiple fields that employ the term, but they all have in common three or four characteristics: a reservoir of information, a client that needs that information, a narrow bandwidth pipe to carry the information, and, optionally, an even narrower pipe to acknowledge receipt of information. In order to maximize the throughput, the client process recursively modifies the bandwidth of the pipe, such that information flows more rapidly the longer the process continues. For example, Adobe software first loads a small program that initiates a download of a compressed file which is decompressed locally. Since the client must digest prior information before connecting at higher speed, the information flow will tend to increase by discrete units. Since the process is recursive, the increase is non-linear. If only two steps are taken the process can be approximated as quadratic, if three steps then a cubic, and after many steps the series approaches an exponential, albeit in a discrete, stepwise approximation.

In contrast, a linear, diffusive information gain has neither the stepwise features nor the exponential increase, but is comparatively smooth. If complexity is taken as the average over the entire system, then a linear system actually behaves more like a (1 - exponential), since increasing the average complexity requires the average information density to increase. But if the information arrives in a 1-D pipe while the density is proportional to (Volume element)$^{-1}$, then increasing the density requires an increasingly long period of time, not unlike watching a JPEG picture downloaded over the Internet, where the image successively refines at longer and longer times. Thus the bootstrap and linear information transfers have opposite curvature, the bootstrap with an accelerating positive 2nd derivative, and the linear with a decelerating negative 2nd derivative with time (see Panel 2 of Figure 1).

So the two theories of evolution should be separable by the qualitatively different ways that information shows up in the client. A brief acquaintance with evolutionary timeline reveals a much faster complexity growth than linear, with punctuated or stepwise increases in complexity (Panel 3 of Figure 1). Thus it would seem that not only is genomic coherence mandated by the data (hierarchical evolution), but temporal coherence (teleology) is also.

Any NDT fix that attempts to introduce coherence into a bottom-up Darwinian paradigm has essentially become indistinguishable from a top-down Aristotelean metaphysic. And while Aristotle can handle any admixture of random variation without losing coherence completely, Democritus cannot include the slightest bit of coherence without also admitting teleology. In the final analysis, bottom-up metaphysics is far more restrictive since it is defined by a prohibition of teleology, whereas top-down has wider scope since it is defined by an admission of teleology. If we are to do science in the 21st century, it would seem advantageous to consider more rather than fewer models of evolution, including those possessing global space-time coherence.

REFERENCES

1. R. B. Hoover, E. V. Pikuta, N. C. Wickramasinghe, M. K. Wallis, and R. B. Sheldon, "Astrobiology of comets," in *Instruments, Methods, and Missions for Astrobiology VII*, R. Hoover, G. Levin, and A. Rozanov, eds., **5555**, pp. 93–106, Proc. SPIE, (Bellingham, WA), 2004.

2. R. B. Hoover, "Mineralized remains of morphotypes of filamentous cyanobacteria in carbonaceous meteorites," in *Instruments, Methods, and Missions for Astrobiology VIII*, R. Hoover, G. Levin, A. Rozanov, and G. Gladstone, eds., *Proc. SPIE* **5906**, pp. 166–182, Sep 2005.

3. R. B. Hoover, "Comets, carbonaceous meteorites, and the origin of the biosphere," *Biogeosciences Discussions* **3**, pp. 23–70, Jan. 2006.

4. R. B. Hoover, "Microfossils of cyanobacteria in carbonaceous meteorites," in *Instruments, Methods & Missions for Astrobiology X*, *Proc. (SPIE)* **6694**, Oct. 2007.

5. R. B. Sheldon and R. B. Hoover, "Evidence for liquid water on comets," in *Instruments, Methods, and Missions for Astrobiology VIII*, R. Hoover, G. Levin, A. Rozanov, and G. Gladstone, eds., *Proc. SPIE* **5906**, pp. 127–145, Sept. 2005.

6. R. B. Sheldon and R. B. Hoover, "Implications of cometary water: Deep impact, stardust and hayabusa," in *Instruments, Methods, and Missions for Astrobiology IX*, R. Hoover, G. Levin, and A. Rozanov, eds., **6309**, p. 63090L, Proc. SPIE, (Bellingham, WA), 2006.

7. F. Hoyle and C. Wickramasinghe, "Comets - a vehicle for panspermia.," in *Comets and the Origin of Life*, C. Ponnamperuma, ed., pp. 227–239, 1981.

8. G. V. Levin and P. A. Straat, "Viking labeled release biology experiment - interim results," *Science* **194**, pp. 1322–1229, 1976.

9. G. V. Levin, "Analysis and interpretation of Viking labeled release experimental results," tech. rep., 1979.

10. G. V. Levin and P. A. Straat, "A search for a nonbiological explanation of the Viking Labeled Release life detection experiment," *Icarus* **45**, pp. 494–516, Feb. 1981.

11. M. Wainwright, "How do bacteria reach the stratosphere?," in *Instruments, Methods & Missions for Astrobiology X*, *Proc. SPIE* **6694**, Oct. 2007.

12. F. Raulin, M.-J. Nguyen, and P. Coll, "Titan: an astrobiological laboratory in the solar system," in *Instruments, Methods & Missions for Astrobiology X*, *Proc. SPIE* **6694**, Oct. 2007.

13. F. Raulin, "Astrobiology and habitability of Titan," *Space Science Reviews* **135**, pp. 37–48, Mar. 2008.

14. K. L. F. Brinton, J. L. Bada, and J. R. Arnold, "A reexamination of amino acids in lunar soil," in *Proc. of Lunar Planet. Inst.*, **24**, pp. 193–194, Mar. 1993.

15. D. E. Brownlee and Stardust Mission Team, "Science results from the stardust comet sample return mission: Large scale mixing in the solar nebula and the origin of crystalline silicates in circumstellar disks," in *Bulletin of Am. Astr. Soc.*, **38**, pp. 953–+, Dec. 2006.

16. R. B. Sheldon and R. B. Hoover, "The cometary biosphere," in *Instruments, Methods & Missions for Astrobiology X*, *Proc. SPIE* **6694**, Oct. 2007.

17. R. Gordon and R. B. Hoover, "Could there have been a single origin of life in a big bang universe?," in *Instruments, Methods & Missions for Astrobiology X*, *Proc.(SPIE)* **6694**, Oct. 2007.

18. J. T. Wickramasinghe, N. C. Wickramasinghe, and W. M. Napier, "Liquid water in comets: implications for astrobiology," in *Instruments, Methods & Missions for Astrobiology X*, *Proc. SPIE* **6694**, Oct. 2007.

19. F. Hoyle, N. C. Wickramasinghe, and D. A. Williams, "Bacteria in Space," *Nature* **306**, pp. 420–+, 1983.

20. F. Hoyle and C. Wickramasinghe, *Lifecloud. The origin of life in the universe*, London: Dent, 1978, 1978.

21. P. C. W. Davies, *The 5th Miracle: The Search for the Origin and Meaning of Life*, Simon & Schuster, New York, 1999.

22. H. P. Yockey, *Information Theory and Molecular Biology*, Cambridge University Press, Cambridge, 1992.

23. F. Hoyle, *Mathematics of Evolution*, Acorn Enterprises LLC, Memphis TN, 1999.

24. C. Darwin, *The Origin of Species by Means of Natural Selection: Or, The Preservation of Favored Races in the Struggle for Life*, D. Appleton and Company, London, 1889.

25. S. Arrhenius, *Worlds in the Making: The Evolution of the Universe*, Harper and Bros, New York, 1908.

26. H. Suzuki, T. R. Thiele, S. Faumont, M. Ezcurra, S. R. Lockery, and W. R. Schafer, "Functional asymmetry in caenorhabditis elegans taste neurons and its computational role in chemotaxis," *Nature* **454**, pp. 114–117, 3 July 2008.

27. R. B. Sheldon, "Historical development of the distinction between bio- and abiogenesis," in *Instruments, Methods, and Missions for Astrobiology VIII*, R. Hoover, G. Levin, A. Rozanov, and G. Gladstone, eds., *Proc. (SPIE)* **5906**, pp. 444–456, Sept. 2005.

28. P. C. W. Davies, *God and the New Physics*, Simon & Schuster, New York, 1983.

29. T. L. Duncan and J. S. Semura, "The deep physics behind the second law: Information and energy as independent forms of bookkeeping," *Entropy* **6**, pp. 21–29, 2004.

30. A. Einstein, B. Podolsky, and N. Rosen, "Can quantum mechanical description of physical reality be considered complete?," *Phys. Rev.* **47**, pp. 777–780, 1935.

31. O. Barfield, *Saving the Appearances: A Study in Idolatry*, University Press of New England, Hanover NH, 1988.

32. J. Clauser, M. Horne, A. Shimony, and R. Holt, "Proposed experiment to test local hidden variable theories," *Phys. Rev. Lett* **23**, pp. 880–884, 1969.

33. R. Gordon, *The Hierarchical Genome and Differentiationi Waves: Novel Unification of Development, Genetics and Evolution*, World Scientific & Imperial College Press, Singapore & London, 1999.

34. N. Eldredge and S. J. Gould, *Punctuated equilibria: an alternative to phyletic gradualism*, pp. 82–115. Freeman, Cooper, San Francisco, 1972.

35. I. M. Sokolov, J. Klafter, and A. Blumen, "Fractional Kinetics," *Physics Today* **55**, pp. 110000–55, Nov. 2002.

36. W. Dembski, *The Design Inference: Eliminating Chance Through Small Probabilities*, Cambridge: Cambridge University Press, 1998.

37. C. Igel and M. Toussaint, "Recent results on no-free-lunch theorems for optimization," *ArXiv e-prints* , Mar. 2003.

38. J. C. Sanford, *Genetic Entropy & the Mystery of the Genome*, Ivan Press, 2005.

39. S. J. Gould, *The structure of evolutionary theory*, Harvard University Press, Cambridge, 2002.

40. D. Berlinksi, *The Devil's Delusion: Atheism and Its Scientific Pretensions*, Random House, New York, 2008.

41. D. Axe, B. W. Dixon, and P. Lu, "Stylus: A system for evolutionary experimentation based on a protein/proteome model with non-arbitrary functional constraints," *PLoS ONE* **3**, e2246 2008.

42. M. W. Deem, "Mathematical adventures in biology," *Physics Today* **60**(1), pp. 010000–+, 2007.

43. B. McClintock, "The origin and behavior of mutable loci in maize," *Proc. Natl. Acad. Sci.* **36**, pp. 344–355, 1950.

44. N. H. Mann, "The third age of phage," *PLoS Biology* **3**(5), 2005.

45. K. A. Crandall and J. E. Buhay, "Genomic databases and the tree of life," *Science* **306**(5699), p. 1144, 2004.

46. D. Benson, I. Karsch-Mizrachi, D. J. Lipman, J. Ostell, and D. L. Wheeler, "Genbank," *Nucleic Acids Res.* **36**, pp. D25–30, Dec 2007.

47. M. C. Storrie-Lombardi and H. C. Pinkart, "Co-evolution of cyanophage and cyanobacteria in Antarctic lakes: adaptive responses to high UV flux and global warming," in *Instruments, Methods & Missions for Astrobiology X*, *Proc. SPIE* **6694**, Oct. 2007.

48. T. Holden, R. Subramaniam, R. Sullivan, E. Cheung, C. Schneider, G. Tremberger, Jr., A. Flamholz, D. H. Lieberman, and T. D. Cheung, "Atcg nucleotide fluctuation of deinococcus radiodurans radiation genes," in *Instruments, Methods, and Missions for Astrobiology X*, R. Hoover, G. Levin, A. Rozanov, and P. Davies, eds., *Proc. SPIE* **6694**, Oct. 2007.

49. H. C. Pinkart and M. C. Storrie-Lombardi, "Diversity, evolution, and horizontal gene transfer (HGT) in soda lakes," in *Instruments, Methods & Missions for Astrobiology X*, *Proc.(SPIE)* **6694**, Oct. 2007.

50. H. Ochman, J. G. Lawrence, and E. A. Groisman, "Lateral gene transfer and the nature of bacterial innovation," *Nature* **405**, pp. 299–304, May 18 2000.

51. T. Dagan, Y. Artzy-Randrup, and W. Martin, "Modular networks and cumulative impact of lateral transfer in prokaryote genome evolution," *Proc. Natl. Acad. Sci. U.S.A.* **105**, 2008.

52. R. Dawkins, *The Selfish Gene*, Oxford University Press, Oxford, 1976.

53. F. Carrapiço, L. Pereira, and T. Rodrigues, "Contribution to a symbiogenic approach in astrobiology," in *Instruments, Methods & Missions for Astrobiology X*, *Proc. (SPIE)* **6694**, Oct. 2007.

54. C. de Duve, *Vital Dust: Life as a Cosmic Imperative*, Basic Books, New York, 1995.