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# Reductionism and Holism, Chance and Selection, Mechanism and Mind

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Abstract

Despite its rich and deepening panoply of empirical support, evolutionary theory continues to generate widespread concern. Some of this concern can be attributed to misunderstandings of the original concept, some to unfamiliarity with its current trajectories, and some to strongly held fears that it strips the human of cherished attributes. This essay seeks to deconstruct such misunderstandings, lift up current concepts of what evolution entails, and address some of the existential issues it generates.

Key Words: Evolution, neo-Darwinism, emergence, free will

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A philosopher friend recently asked me the following questions:

1) What is your understanding of evolution and its religious relevance?

2) Might you address the deep question as to whether the worldview implied by most standard science is mechanistic? Is it possible to

show that Neo-Darwinism does not affirm the mechanistic world view, that it provides for the causal efficacy of free and purposive action? Or, how you do see the worldview assumed and affirmed by mainstream science?

3) Can Neo-Darwinism itself be reformulated so as to make much clearer than is normally done that it has room for more dimensions of the total life process?

These questions have stimulated the remarks I offer below. I offer them in the context of a paper that Terry Deacon and I recently published in *Zygon* (1) wherein we consider various aspects of the evolutionary process, and human evolution in particular, from the perspective of emergence, with a focus on the moral facet of religious response. It is my hope that these two essays will illustrate that present-day "mainstream" evolutionary concepts are exciting, multi-dimensional, and have much to offer to the religious life. I also grapple, in this essay, with the question of why these concepts are so often misunderstood and so often the target of vilification.

Neo-Darwinism

I realized in starting out that I didn't know what Neo-Darwinism is. So I entered it in www.google.com. The #1 hit was to a site criticizing Neo-Darwinism and favoring the panspermia theory wherein life comes in from other planets. The next 3 hits were critiques offered by creationist/intelligent design organizations. As I continued to read, I came to understand that the term Neo-Darwinism serves as code for views of the evolutionary process that a variety of persons and groups are not comfortable with.

The original term, neo-Darwinian theory, was not an -ism. Rather, it referred to the coupling of two understandings: 1) the 19$^{th}$-century Darwinian understanding that selection acting on heritable variation would produce evolutionary change and 2) the early 20$^{th}$-century understanding that heritable variants arise by the apparently random process of gene mutation. While features of this synthesis have been summarized in various short phrases, the original version of the theory, in Julian Huxley's *Evolution: the Modern Synthesis* (1942), was book-length, and multiple additional layers of

understanding of the relationship between genetics and evolution have been accumulating in the ensuing 60 years.

Particularly interesting is that whereas there appears to be broad appreciation that atomic theory, for example, has deepened profoundly since its original articulation, bringing us quarks and strong and weak nuclear forces and the like, neo-Darwinian theory is described by Neo-Darwinism detractors in much the form that it was originally set forth. The additional layers of understanding -- the evolutionary role of gene duplications and of mutations in genetic regulatory elements, for example – are hard to find in web-site treatises on Neo-Darwinism.

So why is it the case that atomic theory has not become "Atomism" and its "Atomist" adherents the target of critical websites, whereas neo-Darwinian theory has become the nefarious Neo-Darwinism practiced by reductionistic materialistic know-it-all Neo-Darwinists? Why are there no proposals that "overturn" Atomism while proposals abound that "expose the fatal flaws" of a 60-year-old version of evolutionary theory called Neo-Darwinism? The answer, I can only presume, is that atomic theory does not seem to generate existential concerns while neo-Darwinian theory clearly does.

I will take up the matter of existential concern below. But at this juncture, given that the term Neo-Darwinism has come to carry such baggage, I suggest that it be jettisoned and that we just talk about present-day theories of biological evolution.

With that said, we can go on to examine the pejoratives "reductionistic" and "materialistic," which will lead us into our philosopher's question about "mechanistic."

## Reductionism and Holism

I am a bench scientist, a molecular geneticist/cell biologist, and have devoted my career to the study of a eukaryotic single-celled green alga called *Chlamydomonas*. My colleagues and I have made contributions to an understanding of how the organism carries out photosynthesis, how it swims, how it forms its cell wall, how it conducts its sexual cycle, and how the genes that encode various

sexual traits have diverged when two closely related *Chlamydomonas* species are compared.

Our experiments are "reductionistic" in the sense that they focus on genes and proteins and not the whole organism or its ecological context. From a physicist's perspective, of course, our experiments are not reductionist at all since we pay no attention to individual atoms or quarks, albeit we are fully aware that these levels of organization are "down there" and have everything to do with what we attend to; indeed, their existence is fully implicit in our experimental design and interpretation. By the same token, we are fully aware that the molecular facets of *Chlamydomonas* that we are studying have everything to do with the whole organism and its ecological context, and should we obtain an experimental result that is inconsistent with these "larger" understandings – e.g. if our data indicate that a protein operates in a certain way after boiling and we know that *Chlamydomonas* is killed by boiling -- we would conclude that this property of the protein, albeit of possible interest for some reason, is irrelevant to the organism as a whole. Again, by the same token, scientists studying the ecology of *Chlamydomonas* try to keep what is known about its genes and proteins fully in view as they ask their "larger" questions, just as they also understand that the *Chlamydomonas* ecosystem is but a tiny part of an enormous biosphere which is but a miniscule part of an enormous universe. That is, the ecologists are also reductionists.

So who are the "holists"? I would respond that no scientist, and no scholar in any field for that matter, is a holist when asking a specific question, since specificity is by definition focused on some facet of the whole. But I would also respond that all scientists are holists in that we are all aware, when making a specificity move at whatever "level," that the specifics reside in wholes, where wholes are emergent from parts and hence have different properties from individual parts.

Systems Thinking

A critique that is often leveled at molecular-level biologists is that we have ignored the existence of complex systems in our reductionistic fervor to analyze genes and proteins, that we eschew

the “holistic” concepts articulated in complexity theory and its synonyms.

Without in any way disparaging the important theoretical contributions made to our understanding of complex systems by the likes of Prigogene and Kauffman, an understanding that organisms are made up of complex systems has been a core understanding of biology since the inception of the field. Metabolic pathways, embryology, neural networks, animal behavior, and so on can only be understood as complex systems, and as a graduate student 40 years ago this was the implicit grounding of everything that I was taught.

But once the modern-day principles of complex systems thinking are grasped – once one understands the thermodynamic constraints and possibilities, the importance of initial and boundary conditions and the interdependence of events – biologists in recent decades have gone ahead and sought to understand a specific system by studying its parts: How does microtubule sliding participate in the emergent system called flagellar motility? How does cell migration participate in the formation of a nervous system during embryology? How does sequential expression of homeobox genes set out the animal body plan? In asking such questions we have in no way lost sight of the system as a whole; rather, we are asking questions of the system that allow us to better understand how it acquires its holistic properties.

As it turns out, the upshot of taking this approach is that molecular-level biologists are in fact now in a position to take on systems-based research more directly, where genome projects, widely reviled for their reductionist focus, have provided many of these opportunities. Genome-based technologies now make it possible, for example, to identify all the proteins that participate in such complex systems as repair of environmentally-induced DNA damage or the responses of a plant to desiccation or the metastatic growth of a tumor. Some of the proteins identified are those that we already knew something about from previous studies, others are new foci for investigation, and the meta-project is to figure out how they all interact, in space and time, to generate the resultant complex traits.

Importantly, scientists are flocking to explore these opportunities, documenting that it is not so much that we were ever uninterested in complex systems as that we didn't have productive ways to study them. A case in point is Marc Kirschner, for decades at the forefront of research in molecular cell biology and molecular evolution, who has recently founded and chairs a well-endowed Department of Systems Biology at Harvard Medical School.

With these observations in mind, we can return to biological evolution and consider a typical finding (2) from my website explorations:

> Darwin deliberately stressed the reductionistic, physicalist aspects of his theory in order to eliminate any hint of the involvement of a designer or a vital force in his explanation of the development of living things. Rather, the rhetoric of Darwinism is of a 'force' (selection) acting upon essentially passive objects considered in isolation (organisms). It is the rhetoric of physics. And physics has also profoundly influenced molecular biology; genes are described as strings of chemicals to which mutations happen. It may be, however, that the rhetoric of evolution in the next century will be much more in terms of Kauffman's work on self-organization and the development of complexity, of interdependent organisms exploring together the possibilities of greater complexity.

There are several misconceptions here to lift up right at the start. 1) Darwin, an ardent and accomplished naturalist, would have decried a definition of organisms as passive objects acting in isolation. 2) While it is true that self-organization, complexity, and interdependence can be discussed without reference to genes and mutations, selection is a central dynamic in Kauffmanian theory (3). 3) Most importantly, self-organization and the development of complexity in biology are not abstract ethereal processes. They occur in cell-based organisms that are constructed from macromolecules, and those strings-of-chemicals-to-which-mutations-happen are the instructions for generating the macromolecules that go on self-organize and interact. Any informed present-day "rhetoric of evolution" will include both the parts and the wholes, both the

emergent properties and the genomes that encode them, and I cannot but imagine that this will always be the case.

Materialism

Not only is it the case that self-organization and complex systems are not abstract ethereal processes in biology; they are also not abstract ethereal processes in general. Kauffman's formulations are steeped in the material, chock-full of physicality and thermodynamics. Yet they are often described, approvingly, as somehow taking us beyond the material.

Poor matter. This magical stuff, undergirding everything that we know to exist (including the minds that hold our understandings of existence), is so very often given such disparaging qualifiers as "mere" matter or "just" matter or "only" matter. Indeed, a central problem that I have with some versions of the Gaia hypothesis is that there is a way that it asks us to value the non-living participants in the biosphere – the rocks and the gases -- by saying that they are alive.

I myself prefer the perspective of religionist Michael Kalton (4):

> What the poet Robinson Jeffers has referred to as "the massive mysticism of stone" surrounds us, inviting us to discover the patterning that lives in geologic time or even cosmic time, these being substrate to patterns manifest in the rapid complexity of life time. What is it from which we have emerged, and to which we return at death? It cannot be less than us, for we are formed of it, belong to it, manifest it.

Chance and Selection

Evolutionary theory is often misunderstood to claim that everything somehow happened "randomly." I participate in a listserv that focuses on exploring the concept of religious naturalism (religious orientations derived from our understandings of nature (5)), and this sentiment is well stated in the following posting:

> My hunch, based on my experience as a member and leader in the liberal United Church of Christ, is that people are there on a

> Sunday morning because they can't accept that the wonders opened up by science, astronomy, etc. are all a matter of chance. They have rejected traditional views of a God in heaven judging HIS sinful creation, but awe without purpose and meaning behind it is just as meaningless to them.
>
> They might find much support in the concept of religious naturalism were it not that they are looking for truth and values beyond chance, and indeed beyond human experience.

I would agree that if one's only understanding of the natural world is that it is all just a matter of chance, one might well look elsewhere for sources of meaning. But that's not the core message I get from the natural world. I encounter a natural world that is brimming with meaning in and of itself, just by being itself, wherein serendipitous creativity (as theologian Gordon Kaufman so wonderfully puts it (6)) generates countless emergent properties that build on themselves. These include the lives that we live, lives that are like no others given the cultures we have created and the sensibilities we transmit through them. From my perspective, what more meaning might one want than the astonishing FACT of it all?

But back to the matter of chance.

"Serendipitous" creativity is of course a word that connotes chance, and chance for sure plays a big part in the creativity of the universe. But to say that the wonders of the universe are all a matter of chance is a misunderstanding. Chance on its own wouldn't have accomplished much of anything. Chance offers up the variation - the possible atoms, the possible molecules, the possible lifeforms, the possible ecosystems. Chance is the generator of creativity, the grist in the mill, that allows new things to happen.

But chance is inexorably coupled with selection, which operates on that which is created by chance to generate atoms that hold together and molecules that fold into useful shapes and lifeforms that are adapted to their environment and ecosystems that sustain their participants. Serendipity means chance with a positive outcome, and positive outcomes are the product of selection, in all its countless guises, be it selection for stable atomic nuclei or selection for

thermodynamically favorable molecular outcomes or selection for viable ecosystems, including the cultural ecosystems that humans construct and inhabit. Selection generates that which has carried on.

"Selection," of course, has its own set of problems in that it's another one of those discomfiting words. The website quote above includes an interesting example of this. The writer expresses dismay that "the rhetoric of Darwinism is of a 'force' (selection)," and that this thereby "eliminates any hint of the involvement of … a vital force."

I would respond that if any known force makes the cut as a vital force, it is natural selection acting on emergent properties.

Mechanism and Machines

So we are now positioned to consider our philosopher's query about "mechanistic" worldviews. To what extent is an organism like a machine – i.e. mechanistic -- and to what extent is it not?

In approaching this question, it is germane to first explore how we feel about machines. Most people, in hearing this question, likely harbor the hope that the answer will be that an organism is very different from a machine. This hope arises, I would suggest, because most don't hold machines in very high existential regard. While we may admire machines and what they are able to accomplish, they are, after all, things, constructed of "mere" matter (activating our difficulties with matter), and they are, in the end, automatons, a noun that we are concerned might apply to organisms like ourselves. Indeed, I hear this concern in our philosopher's query: "Is it possible to show that Neo-Darwinism does not affirm the mechanistic world view, that it provides for the causal efficacy of free and purposive action?"

To develop the machine metaphor, let's take a familiar machine, the stuff underneath the hood of a car. What's important about this machine, and indeed any machine, is not what's under the hood but rather what it generates, its emergent property, in this case car motility (automotiveness). A machine has purpose and value only to the extent that it produces an emergent outcome with purpose and value.

Granted that, it follows that the more flexible a machine, the more purposes it can serve and hence the greater its value. A car engine that can operate at only one speed is not as valuable as one that can operate at many speeds, so much thought is put into designing gears and accelerators and drive shafts that can bring about this result. A car engine can't run without fuel, so much thought is put into designing fuel tanks and indicator gauges that minimize this occurrence. Motility that can't stop is dangerous, so much goes into designing effective brakes. A car that can only operate at one ambient temperature is not as adaptive as one that can operate at many, hence antifreezes, cooling devices, and so on.

Importantly, as these valuable systems are designed and modified, the engineer, in the end, is constantly monitoring the whole car: Does it still move adaptively? Add a new fuel injection system, say, and many other parts may need to be modified such that this innovation is commensurate with the whole point of a car.

And now to organisms. If we look at a trait like motility, found throughout the biological kingdom in numerous manifestations, we find ingenious mechanisms – yes, mechanisms – that allow for different rates of speed, different means of providing and monitoring fuel, different ways to start and stop, and different ways that movement continues under an array of environmental conditions. There are two critical differences, of course. 1) During biological evolution, the new ideas and their modifications and integrations are offered up by chance mutations and not by the mind of an engineer, so the time scales are vastly different and the innovations are not thought-through-in-advance on the basis of culturally transmitted knowledge. 2) A biological machine like a muscle is not assembled from pre-fabricated parts like a car engine; rather, it is the outcome of embryology, with muscles and their innervating nerve cells differentiating from precursor cells that differentiated from precursor cells that ultimately go back to the fertilized egg, all under the aegis of elegant systems of activation and constraint, hormones and cell-cell contacts, and differential gene expression. At the level of construction, that is, the two projects have nothing in common: car engines are built top-down, muscles are built bottom-up.

But in the end, the overall product can be said to be the same: machines that move. And importantly, natural selection isn't looking at the parts or the construction modality. Natural selection doesn't "see" genes or proteins, doesn't "know" about embryological stages. Natural selection evaluates whether a creature can carry on, or not, in the context it finds itself to be in. Natural selection monitors adaptivity, monitors fitting in.

So where does this leave us with "free and purposive action"? I would say there's little problem with "purposive": organisms, like machines, are nothing if not purposive. Watch a "lowly" bacterium or amoeba moving up a gradient towards a food source, or a "lowly" plant bending towards a light source, and it's all about purpose. So this leaves us with the matter of "free."

## How Free Is Our Will?

If a car salesman were to tell you that the car under consideration operates freely, with no constraints, you would doubtless not buy it. A car (and an organism) must be mechanistically reliable if it has any chance at all of generating its purposive emergent properties. When a carburetor starts to operate freely, the car is taken to the shop for a tune-up. This is not to say that the carburetor (and the organism) is without choices, but the choices (how much air to mix with the gas, what constitutes a food gradient) are under exquisite regulation.

But I suspect that our philosopher's question is not about a carburetor and probably not about an amoeba either. And likely not even about a spider or a snake. The heart of the question as I hear it is this: If one buys into the "Neo-Darwinian" claim that humans share common ancestors with amoebae and snakes, then does this mean that WE are as mechanistic as they are and hence without "free will"?

Granted that debates on free will fill countless volumes of philosophical reflection with little consensus, I nonetheless believe that evolutionary perspectives can offer insight on this topic. I will first make some general observations and then explore some of the concepts more closely.

Evolution, we have said, continuously offers up innovation. The conspicuous innovation during hominid evolution is the language-based human brain that, in turn, generates what we call "conscious self-awareness" or the "narrative self." We consider at length elsewhere the remarkable properties of the human mind and scenarios for its evolution (1), so I will only make two points here.

1) Whereas it is not known, and may never be known, what language was originally "for" (hunting? mating?), it is clearly the case that once instantiated, it set up a co-evolutionary dynamic of language, mind, and cultural transmission of ideas that has obviously been enormously adaptive for our species; indeed, this dynamic generates the niche (human culture) that we immediately inhabit, contributing to our myopias about the other niches we inhabit.

2) The origination and selective advantage of possessing a narrative self is similarly obscure, and indeed one speculation suggests that the narrative self was at first not under direct selection at all but rather arose as a by-product, an unintended consequence (a "spandral" in the terminology of Stephen Jay Gould) of selection for language and cultural habitation. Importantly, once a "spandral" arises and proves to be adaptive, it becomes a putative substrate for future rounds of natural selection, and I believe that there are few who would disagree that the narrative self has been a central player in the evolutionary/cultural trajectory of *Homo sapiens*.

However narrative selves came into being, and however much they are reducible to their underlying, and mechanistic, neural substrates, they are quintessentially emergent, and one of their emergent properties is a sense of free will, a sense that we have the capacity to make free choices. I would put this sensibility on an equal footing with our sense that we see red or smell a flower or love our children. Such psychological experiences come to us – we do not somehow force them into being – and I would argue that they have the same claim to being "natural," "real," and "true" as the neural mechanisms that make them possible or, for that matter, as any emergent property on offer.

To explore these assertions more closely, let me tell a story that may be helpful in thinking about the narrative self and its relationship to the rest of our minds.

> The stairway in my house goes up 5 wide steps, reaches a platform landing, and then goes up another 5 wide steps. On the wall of the landing are shelves that house what we call the museum, a collection of shells and bones and feathers found on the beach.
>
> One recent afternoon, home alone, I had added something to the museum and took two steps backwards to view the resultant effect. As it turned out, I was already at the edge of the landing, meaning that when I took the two steps backwards I was in mid-air above the stairway.
>
> I calculate that what happened next took place within about half a second, and entailed two aspects of my mind that I'll call Ursula 1 and Ursula 2.
>
> Ursula 1: What's going on? I'm in mid-air. Oh no, I must have stepped off the landing. Idiot! [Visual image of the stairs below, including the severe right angles of the wooden step-edges and the wooden floor at the bottom] Jeese, if I fall backwards on those stairs I'm going to cream myself. [Visual image of Gray's Anatomy diagram of the human spine and the effects of the edges slamming into vertebrae of arched falling back] Christ, I could break my back. [Visual images of lying at bottom of stairs with broken back] Gads, I'm all alone here. [Visual images of dragging myself to phone and calling 911, then of ambulances pulling in and EMTs spilling into the front door]
>
> Ursula 2 : With body held vertical, rotate 180 degrees in a perfect mid-air pivot so facing forward. Plant left foot firmly in middle of first step when land on it. Keeping that footing, lean body to right, where there's a wall, and slam shoulder into wall. Put right foot down. Motion ceases.

So what do we have here? Ursula 2 is clearly a machine, and a good thing too, since if my fate had been in the hands of Ursula1 the outcome would undoubtedly have been a disaster. Reliably, and without rehearsal, she did what needed to be done: Assess the situation, figure out the solution, and initiate the requisite sequential neuromuscular pathways. Impressive as hell. And of course, squirrels do such things routinely. They're also impressive as hell. Admire as we may the design features and adaptivity of what's under the hoods of our cars, the internal combustion engine with all its ancillary gadgets doesn't hold a candle to the simplest of brains, let

alone a squirrel's, where memory and perception are integrated to initiate and carry out behavior appropriate to the circumstance.

But what about Ursula 1? Although I could not formally prove this claim to a skeptic, it is my deep conviction that Ursula 1, my narrative self, also has a fully neural substrate, a machine that accesses and integrates perceptual and memory and emotional systems and generates emergent analyses of cause (must have stepped off landing), self-evaluation (idiot!), and scenarios of possible future outcomes (broken back) and possible responses to those outcomes (calling 911). The brain-based sources of Ursula 1 might be called Ursula 0.

And here we arrive at the crucial existential interface: Given that Ursula1 is emergent from Ursula 0, what is the nature of their relationship to one another? At one extreme, is it the case that our narrative selves are in some sense just watching a movie of what Ursula 0 generates (whatever that means)? Or are we directors of the movie, telling Ursula 0 what to come up with next for us to watch (whatever that means)? When we engage in making a choice, is it just Ursula 0 doing this and then telling Ursula 1 about it, or do our narrative selves have input into the process, or do they somehow control the process?

It is my understanding that brain neuroscientists, while deeply interested in these questions, are still far from having answers, their current focus being on trying to figure out what Ursula 0 and Ursula 1 are all about (they've made huge progress on Ursula 2) so that they can better understand how they interrelate. But the prevailing hunch is that it's going to be a complex kind of synergy, where sometimes we're just watching and sometimes exercising levels of director-like causality. Even when these relationships are understood more deeply, however, even when we have some notion of what we're talking about when we say things like "watching" and "exercising causality," it won't affect our *sense* that our narrative selves are making the choices that they make, because that's the way the experience of choosing comes to us. Any other players in the dynamic are as inaccessible to our narrative selves as is Ursula 2's process in executing the pivot.

In a claim that I could again not formally prove, it is my conviction that squirrels have Squirrel 0 (and Squirrel 2) but not Squirrel 1. That is, they access and integrate memory and emotional systems and generate analyses of cause and scenarios of future outcomes and responses, but these processes are not, as near as I can tell, experienced by narrative squirrel selves. In saying this I am in no way demeaning the minds of squirrels. I am only saying that evolution wound up endowing humans with an additional kind of experience, the narrative experience of experience, which is apparently rooted in our unique capacity for language.

The most interesting thing about narrative selves is that they are not experienced as being brain-based even though they are. They are experienced as disembodied, immaterial, virtual; we carry a sense that there's an "I" in there that's somehow watching and directing the movie of our lives and falling asleep at night and waking up in the morning and, yes, dying at the end of a lifetime. The fact that the emergent property of narrative self-awareness turns out to manifest itself in this peculiar virtual modality *just is* the qualia of the emergent reality of narrative self-awareness.

So I can now circle back to my earlier assertions and say that Ursula 1, my virtual self, feels like she's making free choices all the time, even as it is the case that the brain activity that undergirds this sense is chugging away in fully mechanical modes of operation. I would say that this experience, and all the experiences we have in this virtual modality, are both real and astonishingly rich, potent, and fruitful. Indeed, it could be said that our collective self-experience as choice-makers has much to do with much of the good, and much of the evil as well, that has transpired in our brief history as a species. To return to our philosopher, the causal efficacy of our sense of free will is in this sense indisputable.

If religious relevance is to be found in biological evolution -- and I myself find it all over the place – then surely it is here. Billions of years of mutation and selection produced reliable, mechanistic molecular pathways that undergird perception and response in all creatures. Hundreds of millions of years of mutation and selection in animals allowed the cooption of these pathways into nervous systems and brains. Within the last million years, self-aware hominids, and

then humans, popped through with "minds of their own," minds that not only think but experience thinking, minds that not only love but experience loving, minds that not only choose but tell themselves, and one another, about the choices they've made and plan to make. A core religious response is a sense of profound gratitude for the lives that we are given, and I offer such gratitude to the countless chances and selections that have brought all these wondrous outcomes into being.

The Dalai Lama can take us out. Maybe it's not so important, he said, whether consciousness is an emergent property of biological evolution or whether it's something that comes from without. Maybe what's more important is what we do with it.

References


(1) Goodenough, Ursula, and Terrance .W. Deacon. 2003. From Biology to Consciousness to Morality. Zygon 38, 801-819.

(2) Evolution and Theology http://www.meta-library.net/ghc-evo/rheto-body.html

(3) Kauffman, Stuart. 1995. "At Home in the Universe: The Search for Laws of Self-Organization and Complexity." New York, Oxford.

(4) Kalton, Michael. 2000. "Green Spirituality: Horizontal Transcendence." In *Paths of Integrity, Wisdom and Trasncendence: Spiritual Development in the Mature Self*, ed. M.E. Miller and P. Young-Eisendrath. Routledge.

(5) http://iras.org/interest_grps\religious_naturalism.html

(6) Kaufman, Gordon D. 1995. In the Face of Mystery: A Constructive Theology. Cambridge, Harvard University Press.