

TAKING BIOLOGICAL FORM TO THE NEXT LEVEL: SYNTHESIS AS A DIMENSIONAL PROCESS IN THE BIOCOSMOLOGY OF LIFE

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Abstract. *The current view of evolution of biological form is that it is due random chance mutations subject to Darwinian selective pressures, including sudden environmental challenges that induce periods of change. Repeated development of form within-species (as in the development of vertebrae) and between-species (structures responsible for locomotion) would seem to call for additional laws. This paper presents the thesis that forces at three separate levels – environmental, genetic, and physical – collaborate to induce form in a species. The genetic level is responsible for spontaneous mutations, the transmission of genotype, and the “fixing” of form (Lima-de-Faria). As discussed by Georges Chapouthier, duplicative genetic events can lead to the juxtaposing of repetitive structures which become functionally integrated. These events are prompted by environmental obstacles that reduce diversity while allowing for more successful biological variations. However, further principles must be invoked to account for the rungs of biological evolution. The notion of islands of energetic stability, supplemented by selective adaptation, can account for attainment of new levels of evolutionary complexity. Convergence between species and the attainment of successively different levels of complexity in phylogenetic lines also require a more nuanced vision taking into account the degrees of freedom and constraint available to motion and development, as postulated by Arthur M. Young in his work on the geometry of meaning. In this scheme, each degree or level of freedom has a bi-fold aspect culminating in the biocosmological notion of triune “synthesis” at the next higher level. This last, dimensional category of explanation is needed to round out the account of biological form arising from chance mutation, and gives meaning to the Aristotelian notion of “final cause” in the biological domain.*

Keywords: *Evolution, natural selection, phyla, genome, Biocosmology, synthesis, degrees of freedom*

Introduction: Inquiring about Evolutionary Forces

Is evolution just God’s way of playing dice? Surely there must be more than simple randomness at work. The Greek philosopher Aristotle observed that the frontal teeth seem to be sharp as a means for cutting things up, and that the rear teeth – the molars – appear to be useful for grinding food. He admitted these shapes might have arisen by accident as opposed to on purpose, but what about all the other coincidentally working parts of the body (Aristotle *Physica II* 198b24-29 in Barnes 1984)? Here was a philosopher who made anatomical observations on an alleged 110 different types of animals, from fish to sharks to chickens, and could not help but notice the rhythm and pattern in each.

There are naturally various nodal points in the development of human understanding of the natural world. Biocosmology points out an initial holistic intellectual period in which people saw metaphysical and theological forces behind the operation of the cosmos (Khroutsky 2006, p. 132). Thus, while Aristotle held to

the notion of efficient cause, he also felt that living organisms are shaped according to the soul they possess. Perhaps this sort of thought could be linked with vitalistic accounts of a morphogenetic field that guides the development of organisms (Briggs and Peat 1984, p. 218)? The second episteme, which reached its golden glory during the Western Enlightenment, views nature in a more objective and mechanical sense, though. The outlook is reductionist rather than holistic. To some extent this attitude will help us in our search for the sources of evolution.

In connection with this new frame of mind, Anton van Leeuwenhoek was the first to directly observe spermatozoa with the aid of a home-made microscope, overcoming the Aristotelian notion that the male contributes the nonmaterial efficient cause to the generation of the embryo (Aristotle *Generatione I* 716a5-7; Dobzhansky 1964, p. 21). Both male and female gametes would eventually be recognized as housing the haploid contributions to the paired chromosomes which transmit heredity between generations, and shape the next generation. Aristotle actually helped to breed this new empirical approach, yet he also had an organic, integrative side. The third episteme represents an integration or synthesis of the previous two, yoking scientific principles with an appreciation of the functionality behind biological developments, where functionality now assumes the more naturalistic role of soul.

In evolutionary theory there has been one such synthesis – the modern or “Grand Synthesis” merging Mendelian genetics with the Darwinian emphasis on the molding of populations (Dobzhansky 1964, pp. 127-9). According to this school of thought espoused by figureheads like Julian Huxley and Theodosius Dobzhansky, “Populations contain genetic variation that arises by random (i.e., not adaptively directed) mutation and recombination ... populations evolve by changes in gene frequency brought about by random genetic drift, gene flow, and especially natural selection” (Futuyma 1986, p. 12). Macroevolution (large morphological changes occurring between species, classes, and phyla) could accordingly be explained by microevolution, operating through the differential adaptive value of genotypes in ambient situations (Gilbert 2003, p. 778). It is quite natural to adhere to this theory as a logical way to explain circumstantial genetic variation – the size and shape of beaks, the color of moths, the spread of viral immunity throughout a population. But can such theory account for non-immediate, more wholesale trends in the development of new species with novel structures and capabilities? The Grand Synthesis offers major causal mechanisms for evolution without lending it direction. Two basic concepts of the Grand Synthesis must first be resolved – macroevolution and microevolution (Ibid.). Macroevolution refers to the dance of time – the large morphological changes that span phyla, classes, and species, and give them continuity. Microevolution in the classic sense refers to evolution within a species via the differential adaptive values of genotypes, or departures from random, non-preferential mating. Considered in a more universal context, though, microevolution is “involved in the realization of the given ontogenetic (developmental) level” (Khroutski 2006, p. 125). That is, microevolution is not directionally neutral, but owns the possibility of realization of the train of development. The functionality to be realized is the subject matter of the third episteme of intellectual understanding, but

the tools of explanation must go beyond mechanism, which affords necessary efficient causes for evolution, yet is insufficient to explain how a given line of evolution can be *realized*. In this light the Grand Synthesis, which arose in the mid-20th century, is a gatepost to a more comprehensive level of understanding – a forerunning synthesis leading to a more cognitively powerful Synthesis.

1. Two Hypotheses Accounting for the Functional Realization of Evolution

At least two hypotheses exist to account for how evolutionary branches might attain the ultimate realization of their member organisms – A. the duplication hypothesis, and B. the geometric hypothesis. By *realization* I mean attainment of either optimal functional capability within a particular environmental setting or ecological niche, or the anatomic and physiologic specialization necessary to fit snugly within a milieu. The duplication hypothesis proposes that in addition to point mutation, evolution is driven by duplication at the genotypic and phenotypic levels. It can be conceptually represented by a triune thesis-antithesis-synthesis process (Khroutski 2006, p. 142). The geometric hypothesis proposes that evolution is bounded by certain dimensional constraints, and must jump to the next hierarchical level for a lineage to adapt further to a given niche. It can be represented by a mathematical derivatives model (1st derivative, 2nd derivative, etc.). There are opportunities for a merging of the two hypotheses, which will come out as this paper moves along. Model B. – the geometric hypothesis – has barely glanced the literature (mostly in the writings of philosopher-engineer Arthur M. Young). Its explanatory value for the process of evolution will occupy the second half of this paper.

1.1. The Duplication Hypothesis

This hypothesis centers around the possibility of a duplication event at the genetic or gross anatomic level aiding the process of evolution. One example of the duplicative process at work is the creation of species through *polyploidy*, in which more than one set of the same chromosome occurs in a given line of organisms (polyploidy usually refers to four or more multiples). Polyploidy can come about through one or more aborted mitotic divisions in the cellular reproduction process, resulting in chromosome doubling. Evidence from cytogenetic analyses, structural studies of fossil and extant species, and whole-genome analyses suggest that 60-70% of flowering plants have a polyploidy ancestry (Van de Peer et al. 2009, p. 725). A popular hypothesis regarding the evolution of the vertebrate genome contends that two rounds of whole genome duplication came about by polyploidy generating events early in vertebrate history (Friedman and Hughes 2003, p. 154).

The advantages of polyploidy are multifold: genome duplication could lead to faster adaptation to more accentuated or extreme environments; to functional diversity in a given lineage; and to a lowered risk of extinction through mutational robustness and functional redundancy (Van de Peer et al. 2009, pp. 725-7). An argument in favor of genome duplication is that it would seem necessary to expand the repertoire of gene-level regulators needed to develop more complex systems in a phylum. Thus, genome duplication has been invoked as an explanation of the rise of

paired appendages, hinged jaws, and a malleable immune system in fish (Ibid., p. 726). Lately, studies looking at the timing and proportion of between-chromosome duplications (expected by the polyploidy hypothesis) as opposed to within-chromosome duplications have refined the duplication model, suggesting a more frequent occurrence and retention of single gene and chromosomal block duplications rather than whole genome duplications in vertebrate evolution (Friedman and Hughes 2003, p. 160).

It should be noted that gene duplications can lead to either physiologic or anatomic consequences. Scientists have, however, identified a major cluster of semi-repeated genes responsible for bodily axis development – Hox genes – that are highly conserved across species, from *Drosophila* to humans (Gilbert 2003, pp. 289, 378; Barnes et al. 2001, p. 400). These sequential genes mirror the development of axial segments in fruit flies, for example. Interspecies differences in the number of gene duplications would also seem to have an evolutionary and medical significance. Humans have 15 members of a class of brain-related genes linked to autism (the centaurin-gamma family) whereas chimpanzees have 6, a difference of 9 gene copies (Minkel 2006). It is little wonder that more philosophical pieces on the nature of evolution have used longitudinal body development, segmentation, and brain structuring as examples of historic duplicative events.

Georges Chapouthier has reframed the duplication phenomenon in terms of two basic operations – juxtaposition and integration. He defines *juxtaposition* as the accumulative positioning of identical units, one next to the other, while *integration* is an enhancing and refining of the original units, which then become component parts of an embracing whole (Chapouthier 2009, p. 3). In his view, further juxtapositions and integrations send the organism to new, higher levels of structure. Chapouthier offers the existence of introns, portions of the genetic code which become excised during the cellular editing operation, as a genetic substratum for the gross anatomic effect of these two processes. In particular, silent intronic DNA stretches may become duplicated and form patterns which take on significance for the function of the organism. This proposal is not without medical significance, since influential silent introns, typically missed on genetic testing, are felt to be one indirect cause of heart arrhythmias in humans (Vincent and Zhang 2005). However, exons that are not spliced out but read by the cellular transcription machinery, as we have seen, may equally well and probably more commonly be responsible for duplicative anatomic structures.

On the human level, the combined process may be responsible for the emergence of complexity in the human brain (Chapouthier 2009, p. 7). Ontogeny recapitulates phylogeny. The embryologic process which molds a single brain vesicle gradually into five compartments (cerebellum, medulla, etc.) within the womb may reflect a genetic and morphologic juxtapositioning and integration that came about during early human evolution and its precursors. A conceptually more elementary but philosophically rich example Chapouthier provides is the development of simple multicellular organisms. Take the unicellular protozoan – a simple, singular cell. A plurality of copies of the simple cell, haphazardly pooled together (juxtaposed), forms

a *Gonium*. On a slightly higher evolutionary rung, the simple cells may become organized (integrated) into an orderly sphere – the *Volvox*. Youngsters make viewing of this green-tinged global cluster one of the first living entities they observe under a newly purchased home microscope. This simple line of development might be considered the basal layer of a whole armada of evolutionary sophistications leading to creatures friendly (*canis lupus familiaris*), neutral, and inimical (pinworms, roundworms) to humanity (the converse also being true). As a paradigm, it demonstrates the thesis-antithesis-synthesis triune common to philosophy and biocosmology. The single protozoan represents the thesis; the juxtaposed *Gonium* the antithesis; and the integrative *Volvox* the synthesis.

1.2. The Geometric Hypothesis

A third example Chapouthier provides – the hydra-shaped polyp – is both illustrative of the process he wishes to demonstrate, and revealing of cracks in the evolutionary theories discussed so far. The hydra is a didermic (two tissue layer) single polyp (the thesis). Polyps may collect together to become a *Gonium* (antithesis). Through time the polyps may become evolutionarily specialized into different sorts – digestive and reproductive, and form an orderly colony called a *siphonophore* (the synthesis) (Chapouthier 2009, pp. 5-6). No doubt this collective development is a result of genes operating under selective pressures, i.e., the Grand Synthesis – need to grow, a nutrient constrained environment, and biological competition. However, why should selective pressures result in a more complex type of organism, versus the simpler solution of producing faster growing individual polyps, which would divide and overcome by sheer number an environmental constraint? (Here we are talking about an open setting as opposed to a limited one inside an artificial petri dish.) Has Mother Nature never heard the admonition “Divide and conquer”? It is unclear why there is a tendency, and a rather universal one at that, to advance in a more complex rather than a simpler but more efficient direction.

Chapouthier also mentions tridermic creatures (such as the starfish) as the next evolutionary rung. But if synthesis is the rule, why should didermic siphonophores evolve into tridermic organisms? A much better alternative would be lateral evolution – refinement of the different types of polyps in the combined organism, plus an expansion in size to outcompete nearby inhabitants. The adult human intestine averages 8.5 meters (28 feet) in length (Kraus 1993) – surely a hydroid-like siphonophore could evolve to at least that length if not more, like the stringy kelp beds off Catalina Island? From a fresh perspective, though, one might attempt to get around the fixation on perpetual horizontal evolution by considering that evolution may follow a vertically-inclined repetitive synthetic process. Once a type of synthesis becomes instantiated, a new level of synthesis intervenes. Indeed, Chapouthier views life as a mosaic, where one level of development supervenes over and contains a more subordinate yet autonomous level, unceasingly so (Chapouthier 2001).

This type of logic leads to the following statement: “In theory these processes can be repeated ad infinitum to produce higher levels of complexity. In practice, at least in biology, there are limits, e.g., combinations of colonies of organisms”

(Chapouthier 2009, p. 2001). The reader should not be fooled, however. In particle physics there is the constant question of whether any baryonic particles (containing protons and neutrons) exist which are more fundamental than quarks. In cosmology the unanswered conundrum lingers – whether a grand singularity lies at the heart of the inflationary expansion of the universe, or the Zeno-like regression to point zero is infinite? This is the classic “infinite regress” problem of systems theory, which transcends multiple fields (Salthe 1985, p. 83). A sense of proportion, beyond simply saying that there are environmental constraints on the system which limit the regression, should be introduced into a model of synthetic process.

What must be appreciated is that dimensional constraints innately exist which guide evolution. They are part of the way nature is constructed. A. Lima-de-Faria explains:

The picture has been drastically changed in recent years by the finding that the elementary particles, the chemical elements and the minerals have each had an autonomous evolution. Hence, three separate evolutions occurred before the biological one emerged. Evolution does not start at the biological level or at the level of the chemicals that lead to the formation of macromolecules such as DNA or protein.

Evolution is a phenomenon inherent to the construction of the universe. It actually starts with the formation of elementary particles at the dawn of the conversion of energy into matter. ...

Most important is the fact that, since biological evolution was anteceded by these three levels, it became a prisoner of these previous evolutions. The laws and rules that they followed created the frame from which biological evolution could not and cannot depart. (Lima-de-Faria 1988, p. 18)

As an example, the shells of mollusks are built of calcium carbonate molecules intercalated with keratin-like proteins specified by DNA translation and transcription. The calcium carbonate atoms are responsible for the basic shape of the shell. De-Faria argues the generated protein only specifies whether the shell is to be a long or short spiral, or a large or small sphere, i.e., it “fixes” the form, but the shell will inevitably come about due to physical forces (Ibid., pp. 31, 287). His book has countless examples of repeated patterns in leaves, flowers, horns, and appendages, together with their analogues from physical nature. Duplication and repetition are built into the opportunities for mutation and translocation available to DNA base pairs and blocks of genes. The main question is whether such changes respect a pattern or are a free-for-all.

Genetics does not offer a compelling reason why natural selection on the whole should work towards greater organism complexity. Admittedly, exceptions to the rule exist, such as the return of mammals to the sea leading to whales, and the degeneration of the appendix in humans to a vestigial artifact, but generally evolution yields complexity. Thermodynamics plays a role. The second law states that the entropy or disorder of an isolated system never decreases. The universe moves in the direction of greater disorder. This principle is often associated with the unidirectionality of the time’s arrow (Briggs and Peat 1984, p. 158). However, unlike nonliving systems hurtling towards thermodynamic equilibrium with the surrounding

environment, living systems maintain themselves far from equilibrium (Ibid., p. 163). This positioning overcomes the drive towards disorder, and allows for the formation of increasingly complex structures (Buenstorf 2000, p. 126). Mutations may lead to changes in the relative fitness of interacting organisms, resetting the energy balance in their physiologic dynamics and leading to increasing degrees of order. Successive reproductive cycles result in organisms that are increasingly sophisticated and further from thermodynamic equilibrium (p. 127), all while the entropic arrow of time advances forward. Refinements within organisms can also occur based on the optimization of growth rate and energy efficiency, and competition between organisms (Ibid., p. 129; Westerhoff et al. 2009, p. 3886). One can, therefore, see how a gene duplication could result in greater complexity and in a few generations become integrated into the genome of a biological lineage. The direction of increasing complexity is based on the physical principles embedding life.

The term “degrees of order” used above is important, because the logic so far does not account for the jump from one level of organization, say, didermic (two tissue layer) to another – tridermic (three layered). The degrees notion must be explored more deeply. Arthur M. Young explains how it may be tied in with evolution:

The greatest symmetry (three axes) occurs with molecules, the least with animals, suggesting a correlation of symmetry with constraint. ... We may say of crystals that they have no freedom, while plants have one degree of freedom (their ability to grow) and animals have two degrees of freedom (their ability to move about two-dimensionally on the surface of the earth). ... But there is also a position open for a kingdom with three degrees of freedom and no symmetry. (Kunz indicates a tendency toward asymmetry in the human face. There is also left-and right-handedness and the recently discovered fact that the two sides of the human brain have different functions.) (Young 1976, p. 39)

If we can view evolution itself as a growth process, then Young’s proposal might shed light on why nature jumps from one level of organization to the next. While it is true that a Thanksgiving pumpkin can grow to wheelbarrow size, this happenstance is more the exception than the rule. If a potato is planted in good soil and gets bigger, it will form a bud to continue the growth process. Likewise, a heavy jellyfish is a flat jellyfish. Jellyfish either bud or form new, immature jellies as they grow. As they fill-up an ecological niche or the niche changes, species will be forced to change, first in small, but as time rolls along cumulatively broader ways. They will evolve in the direction of greater complexity, which at critical points means attaining a new level of functional capability. The new range of functional capacity will be accompanied by genetic and morphologic changes in the lineage.

2. The Flow of Evolution

Arthur Young accounts for evolution as a classic process of descent, or loss of freedom, and ascent, or regaining of freedom, with a gain of complexity at each step. The flow in his system describes a V-shaped arc, where the highest level in the “V” allows three degrees of freedom, and the simplest and most complex entities to form.

The second level allows two degrees of freedom. Level IV at the bottom allows zero degrees of freedom; the simple and complex are one and the same at this vertex level of the “V” (Ibid., p. 41). In the sequence below (Table 1.), Young (pp. 86-7) identifies the various substages of the animal kingdom (elsewhere he also goes into the plant kingdom):

Animal Evolution Version 1
Table 1.
(After Arthur M. Young)

<u>Substage</u>	<u>General Property</u>	<u>Biological Property</u>	<u>Example</u>
1	potential	unicellular	bacteria
2	binding	colonies	sponges
3	identity	one organ	coelenterates
4	combination	many organs	mollusks
5	growth	segmentation	annelids
6	mobility	side segments	arthropods
7	dominion	brain integration	chordates (vertebrates)

This scheme intuitively seems to make sense, but on closer examination has a number of logical overlaps that lead to strange consequences. For the fifth substage and greater, Young, like many evolutionists, places a premium on segmentation. The motivation behind this priority is that by the fourth substage, animals have evolved the full variety of organs we know today, and the only direction for evolution to take is repeat development, as the duplication model professes. Perhaps Young’s claim that *metamerization*, the arrangement of organs in sequence, is more easily generalized (Ibid., p. 124). For example, some types of annelids and arthropods display metamerization without significant segmentation. However, the phylum *Mollusca* displays considerable variety which might for some comparisons, despite lack of metamerization, compel placement in a higher substage than simple arthropods and annelids. For example, the octopus, a member of the phylum *Mollusca*, is known to pick up and carry tools to use later on. And urochordates (tunicates), despite being the closest evolutionary cousin to vertebrates, lack side segments.

Though the structure of Young’s system is well conceived, the assigned attributes need unpacking. Two arrays are discernable – an anatomic, and a system level array. As discussed in a previous article by the author, the anatomic array would proceed from more to less complex as follows: [(cerebral/cortical) -> (subcortical/nervous) -> (respiratory/circulatory) -> (digestive/excretory) -> (reproductive-gestational/musculo-skeletal)]. (Modell 1994, pp. 201-2) Likewise, the system level array would proceed as: [organism -> system -> organ -> tissue -> cell]. Unfortunately, some organisms with simple neural elements, such as comb jellies,

lack organs, and some organisms with organs, such as earthworms, lack a respiratory system. The stage of an animal group along one array does not guarantee its stage along the other; the two are at best correlated. One difficulty in assigning an animal to a given rung of complexity using the above standards is that they are highly structural. When one visits a zoo, it is the type of activities in which the animal engages that alert the onlooker to its degree of sophistication. Perhaps there is a more process-oriented standard that might be used to judge evolutionary stage?

Earlier in his book *The Reflexive Universe*, Arthur Young refers to the components of any cycle of action that has a repeating quality: position, velocity, acceleration, and control (Young 1976, p. 44). The scientifically-minded will recognize these terms as mathematical derivatives: velocity is the first derivative (changes in position yield velocity); acceleration is the second derivative of position (changes in velocity yield acceleration), and so forth. *Control* is the engineering term for moderation of acceleration, like a foot pressing on a brake pedal. Young also hunts for a fourth derivative term to complete the cycle, for which he assigns (or reassigns) position. However, position is the baseline concept – a proper designee for fourth derivative would be the simple act of starting or stopping the motion altogether, i.e., initiating or terminating the motion. One final distinction is that quantities like velocity and acceleration are two-sided – they have both a linear and an angular component. Linear or central change is change in rate, and angular or radial change is change in direction.

In physics each of these terms can be represented as a tangent perpendicular to the vector of the prior term; velocity is tangential to fixed position. According to this four-level system, the number of derivative levels is not infinite, but bounded by the types of changes that can affect cyclical motion. A prior derivative also “integrates” the area covered by a subsequent derivative; position represents the sum of incremental changes carved out by velocity. In this paper we wish to adopt the opposite perspective – that a higher derivative stores a piece of information (represented by the constant in the calculation of an integral) that cannot be captured by a lower derivative.

A major distinction between the purely mathematical concept of a derivative and how it plays out in real life, at least in biological life, is that change has a qualitative and not just a quantitative aspect, each new level of change reflecting a novel but logically consequent character. Position thus represents a state of fixity; velocity a state of advancement; acceleration a condition of cyclicity; control a condition of synthesis (like the orchestration of an orchestra); and the upper limit a state of initiation/conclusion.

If we consider that fixity permits zero degrees of freedom of motion; velocity permits one degree of freedom (along a line); acceleration two degrees of freedom (in a plane, e.g., a planet circling the sun), etc., then we can assign Young’s “degrees of freedom” to evolutionary substages (Table 2.). New additions to Arthur Young’s diagram are as follows: (1) the descent-ascent scheme is relinquished for one based on a layering of derivatives; (2) because there is no longer a vertex or nadir in the evolutionary journey, the zero degree of freedom level (positional) has two rather

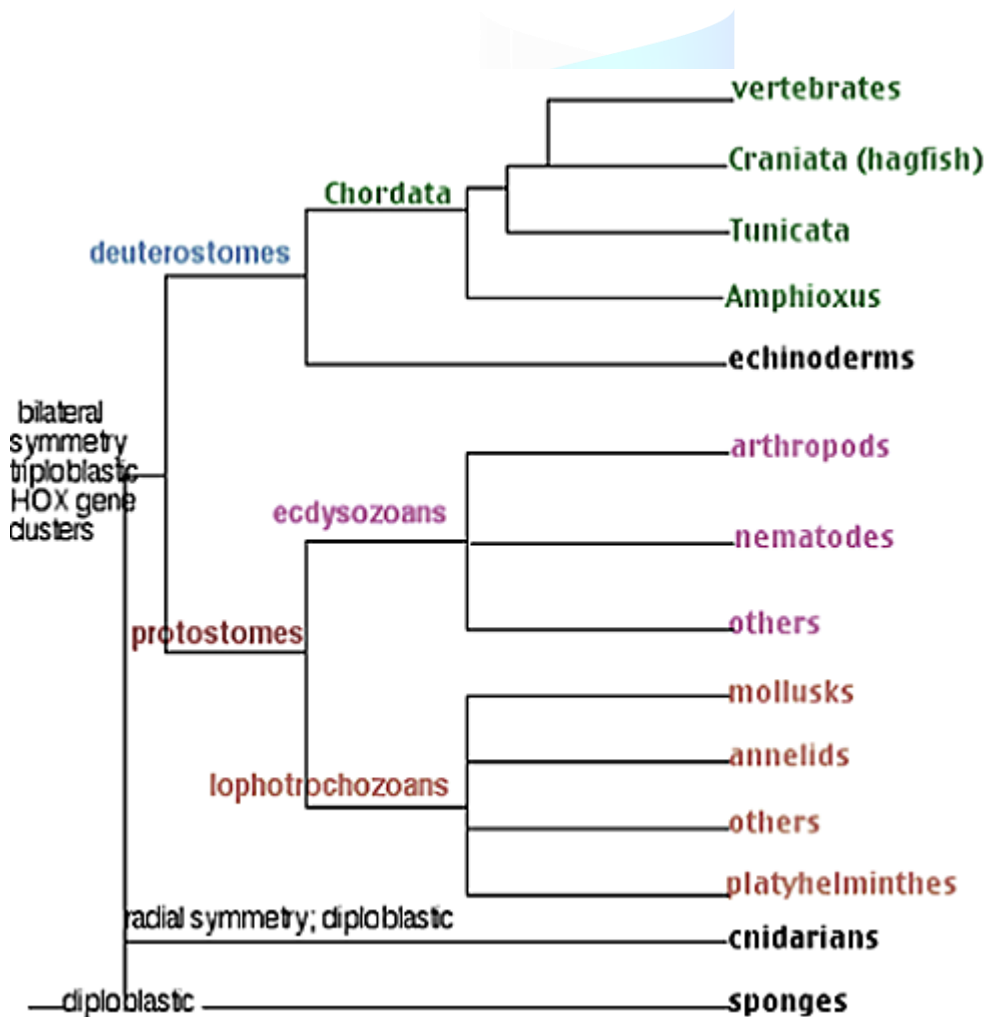
than one term (formerly its own contrapositive); (3) a fourth degree of freedom accrues from ability to start or stop motion; (4) each degree of freedom has a linear or central and an angular or radial component; and (5) degrees of freedom are most easily represented from minimal to maximal freedom up the diagram. In the diagram below, the qualitative meaning of each level is further articulated in the “Biological Property” column. An example phylum is shown for each of the levels, which will be further explicated in the next section.

**Animal Evolution Version 2
Table 2.**

<u>Degrees of Freedom</u>	<u>Mathematical Property</u>	<u>Biological Property</u>	<u>Example</u>
4	4 th derivative linear	initiating	vertebrates
4	4 th derivative <u>angular</u>	resolving	cephalopods (e.g., octopus)
3	3 rd derivative linear	harmonizing	urochordates (tunicates)
3	3 rd derivative <u>angular</u>	synchronizing	mollusks
2	2 nd derivative linear	oscillating	hemichordates (acorn worms)
2	2 nd derivative <u>angular</u>	undulating	annelids (earthworms)
1	1 st derivative linear	passing	echinoderms (starfish)
1	1 st derivative <u>angular</u>	filtering	porifera (sponges)
0	0 th derivative linear	containing	colonies
0	0 th derivative angular	supporting	protozoa

3. Fleshing out a Geometric Model of Evolution

In Table 2., each of the levels represents a dimensional space that a biological lineage on its evolutionary journey is free to occupy. It is an abstract space just like an environment is a physical space and an ecological niche is a combined physical-conceptual space. More formally, biologists have constructed evolutionary trees of diverse organisms. The time horizon is very important in these diagrams (Barnes et al. 2001, p. pp. 26-7, 32; Futuyma 1986, pp. 290-1; Horvath 1980, p. 144). Oftentimes such trees are depicted left to right, most primeval to most recent, and vertically, simplest to most complex:



Scientists have arranged these trees by the number of homologous characteristics between taxa, and more recently by genetic similarity. The trees are well-organized, but are descriptive (*a posteriori*) rather than analytic. In other words, they describe what has happened without answering why. The type of system that I am describing here, or that Young or Chapouthier is presenting, is an explanatory template that fits over the observed branches of an evolutionary tree, not a substitute.

Nature has established six kingdoms, among them eubacteria, plants, and animals. An explanatory scheme is most useful when it is applied to a delimited subject matter, so in this paper I have chosen to focus on the animal kingdom. It would be better to have a more microevolutionary than macroevolutionary outlook, showing direct, continuous changes through time, but the fossil record gets spotty the further back in time we go. Better to take representative examples of related organisms that through their relative complexity show the way that nature evolves. I could also have made my examples very specific by sticking to one species and showing variation through time, maybe in body type, appendage shape, or physiology, but the pattern of evolutionary forces is more clearly depicted if broader examples – several phyla – are introduced. Single species examples are good for depicting functional adaptation through genetic variation, especially in medical contexts, though. I have chosen to leave the phylum *Arthropoda* out of Table 2. The protostomal ancestors of arthropods split from other animal phyla at a very early stage – 550 million years ago. Their embryology, in terms of orientation of cavities

that develop into mouth and anus, is opposite that of vertebrates and their forerunners, and their skeletal structure, or exoskeleton, is also the inverse of the vertebrate lineage. *Arthropoda* is a categorically densely populated phylum that in some respects would fill-out half the levels in Table 2., thus deserving a separate treatment in its own right. In what follows I will be focusing on soft-bodied creatures.

3.1. Zero Degrees of Freedom

The two levels with zero degrees of freedom pertain to animals that are constrained to one place. A current can take them away, but short of that, their position will be relatively fixed. Protozoans are single-cell organisms with capability for a limited range of motion. The attribute of “support” (Table 2. Biological Property column) describes them in three ways: A. the presence of a cell membrane acts as a support for the inner cellular contents; B. the organism finds external support in the watery milieu in which it swims (versus simply diffusing throughout the medium); and C. the organelles provide a physiologic basis of support for biochemical functions. Protozoa divide through asexual cell division, forming more individual daughter cells that behave much like the parent cell.

Individual cells can gang together to form the combination entities or colonies Chapouthier describes (order Volvocales, genus *Gonium*) (Chapouthier 2009, p. 5). Volvocacean cells form organisms, e.g., a *Volvox* or a *Pleodorina*, anywhere from 4 to 50,000 cells in size (Gilbert 2003, p. 34). At best, the constituent cells are either somatic or sexual, with no further differentiation of cell types. The resultant organism is spherically-shaped, with a hollow core surrounded by a matrix of flagellated cells and a cementing jelly – it is a containment vessel. The fact that the cells are all glued together means they can travel together, admittedly in haphazard fashion, rather than going off on separate tangents. The *Volvox* was first described by van Leewenhoek in 1700, having evolved some 200 million years ago, relatively recently compared to other simple multi-cellular organisms having their start more than 500 million years ago.

3.2. One Degree of Freedom

Animals in these two levels are involved in a travelling type of motion to find food. They can spin, move forward, or let water move through themselves in the case of sponges and calcified corals. Included herein are *Porifera* (sponges), *Cnidaria* (corals, true jellies, sea anemones, hydra, and sea pens), *Ctenophora* (comb jellies), and *Echinodermata* (star fish, sea urchins, sea cucumbers, etc.). *Cnidaria* and *Ctenophora* (comprising the now less frequently used term *Coelenterata*) are part of the subkingdom *Radiata* – they are radially symmetric. Sponges filter food out of the water that flows through them. The food is captured in tiny chimney-like structures that can also regulate the water flow. *Cnidaria* also filter food out of water, and engage in predation through injection of tiny venomous barbs and absorption into chains of polyps. The earliest accepted animal fossils are somewhat modern-looking cnidarians, estimated to have lived about 580 million years ago.

Echinoderms are more active in their mechanics – their bodies work on

hydrostatic principles. Fluid-filled vascular canals exchange gases. Tiny tube feet kept firm by water pressure fasten onto passing food and transport it to a central mouth. Unlike coelenterates, the food is then passed down a complete but compact digestive tract containing a pharynx, stomach, intestine, and anus. By varying internal water pressure, echinoderms can extend and contract their tube feet for longitudinal locomotion (Barnes et al. 2001, p. 254). Some, like brittle stars, are active crawlers and can evade predators. Sea cucumbers actively pump water through their body cavity. The linear aspect of echinoderms thus pertains to internal and external motion, as opposed to the lateral passage or filtering of food across polyps in coelenterates. Although pentaradial, echinoderms evolved from animals with bilateral symmetry, which is still exhibited in their larval stage (Long and Byrne 2001, p. 302). Molecular analyses suggest that echinoderms are a sister group to more evolutionarily complex organisms called hemichordates (Bromham and Degnan 1999). Echinoderms share partial Hox gene sequences with chordates, suggesting class-specific duplication, diversification, and partial deletion of Hox genes from a common ancestor existing some 540 million years ago (Long and Byrne 2001, p. 309).

3.3. *Two Degrees of Freedom*

While a two dimensional plane can be traversed by a two dimensional figure, the same can be accomplished by a one dimensional figure. Wormlike *Animalia* are diverse in their origin, but they are all able to cover a plane in an assortment of ways, both straight and curved. A subset of their diversity can be represented by two of their phyla – *Annelida* and *Hemichordata*. Annelids include earthworms, ragworms, and leeches. Many species contain multiple identical segments, each with a pair of parapodia that enable locomotion. *Echiura* and *Sipuncula*, small marine annelids, are nonsegmented, though. In segmented species, the individual segments are able to sequentially change shape, resulting in peristaltic undulations that further the action of the parapodia (Barnes et al. 2001, p. 254). Unlike echinoderms, more developed annelid species have a circulatory system that recirculates the blood. In earthworms, for example, the forward interconnecting vessels – 5 aortic arches – function as hearts. Earthworms, however, do not have a respiratory system to speak of; they respire through the skin. The blood circulation and locomotion occur through undulatory movement. Early annelids arose about 480 million years ago; earthworms 250 million. Molecular data and a similar spiral cleavage pattern in embryonic development suggest a phylogenetic relation between annelids and mollusks through a more basic *Trochozoan* ancestry, challenging previous beliefs of a close fit with arthropods (Shankland and Seaver 2000, p. 4434; Haszprunar 1996, pp. 4, 21-3).

A quite different animal phylum, *Hemichordata*, consists of acorn worms and tentacled deep water worms. It consists of about 90 species of marine worm-like animals. Size ranges from a few millimeters to 4.7 feet. All hemichordates have three body sections – a proboscis, collar, and trunk. The proboscis is used for burrowing in the mud. Acorn worms have a pharynx containing gill slits used in respiration. Oxygenated water is drawn through the mouth and expelled through the gills. These animals contain a beating muscular heart that contracts and forces blood through

sinuses and longitudinal blood vessels. The oscillatory action of both the heart and the respiration distinguishes acorn worms from earthworms. The action is centralized, whereas respiration and circulatory action in earthworms happen longitudinally along the body axis. Hemichordates have homologs of many vertebrate genes, as well as dorsal nerve cords that ancestrally reflect structures in the chordate nervous system (Bromham and Degnan 1999, p. 170). Acorn worms arose about 500 million years ago.

3.4. *Three Degrees of Freedom*

Animals in this domain gain ability to maneuver in volumetric space. They are the evolutionary progeny of what has come before in terms of structure and function. Mollusks are clearly a broad phylum with 85,000 different species, extending from flat chitons to opening and closing mussels to creeping snails and slugs, and ultimately cephalopods. I will be placing cephalopods like squid and octopi in a more complex level than their other molluscan relatives, and will deal with them shortly. *Urochordates* (tunicates) are more limited in their diversity and mobility, but both phyla share complex behavior that needs to be emphasized. Both animal categories originated about 500–540 million years ago.

Clams and bottom dwelling mollusks have a foot containing transverse muscles they can use for crawling, digging, and even swimming for a short distance, i.e., negotiating 3-dimensional space (Hickman 1996, pp. 188-9). The foot actually carries balance sensors. The nervous system consists of 2-3 nerve cords that run ventrally along the body, with ganglia or nerve concentrations distributed at the oral, pharyngeal, foot, and bodily levels. Mollusks brush a tongue-like organ, a radula, back and forth against teeth to loosen-up food. Jet propulsion via movement of water through a siphon is used to escape enemies. These actions, not to mention the opening and closing of the shell in bivalves, is coordinated, or synchronized when one considers several actions are happening at once. Support comes from a shell secreted from the mantle, which can be flat and segmented, as in chitons, hemispheric in bivalves, spiral in snails, or degenerate in slugs. The ventral nerve distribution and outer location of body support show how organisms can have an important peripheral as opposed to central orientation of anatomic features.

Tunicates, which include appendicularians, salps and sea squirts, are filter feeders. They have incurrent and excurrent siphons, and filter their food through pharyngeal gill slits. Salps are barrel-shaped, free-floating tunicates that have tiny groups of nerves considered to be the prototype for the more complex nervous systems of chordates, of which vertebrates are a subphylum. Appendicularians are free-swimming tunicates that possess a dorsal nerve cord and central notochord. Regular beating of their tail generates currents which concentrate food in the mouth area. Some larval forms, also possessing a dorsal notochord, swim with their tail in a strong wave-like motion like tadpoles. The siphons of sessile tunicates open and close in a harmonious action with the other members of their colony. Fan worms are quite sensitive, and on the slightest touch can react by retracting into their tube in the blink of an eye. These actions are quite sophisticated (I have used the term “harmonious”),

and go way beyond repetitive motion. Phylogenetic analyses show that tunicates are the closest living relatives of chordates – animals with a notochord or backbone precursor, despite their mollusk-looking appearance (Delsuc et al. 2006). The notochord, whether frank or vestigial, shows a central anatomy as opposed to the exterior mantle of mollusks.

3.5. *Four Degrees of Freedom*

The third degree of freedom connotes control over movement in a 3-dimensional space, for example, proper timing between the different musicians spread apart in an orchestra. The fourth degree of freedom relates to control over the control, which means starting and stopping either on a periodic basis (a noncentralized, i.e., distributed form of temporal control) or conclusively (centralized control – the entire operation has a beginning and ending). Organisms at this level must be so constructed to grant them adequate autonomy to embrace this level of initiative in their constant actions. Appendages and nerve connections must be arranged to allow fine motion. Some variety of cephalization (lobe formation) or tight nerve interconnection would seem to be a requirement. The vertebrates (most complex of the chordates) and cephalopods (complex form of mollusk) meet these requirements.

Cephalopods are mollusks that have a prominent head, and arms or tentacles. The class *Cephalopoda* consists of octopuses, squid, cuttlefish, and nautiloids. Only the last category retains an exterior shell. The soft bodied arrangement allows for more intricate and speedier movement. The nervous system in this class is the most complex of invertebrates. The brain-to-body mass ratio falls between warm- and cold-blooded vertebrates. Sense of vision is keen. Cephalopods have chemo- and acceleration detection receptors. Octopuses can also use their tentacles for tactile depth perception. Tentacles and arms have unique features allowing for independent control of each sucker on every appendage. Special supportive features of the nervous system include a brain with 25 functionally unique lobes situated above the esophagus (Barnes et al. 2001, p. 430), large axons that run the length of the body, and thick central nerve cords within the tentacles. Locomotion is via jet propulsion with high speed start and stop motions. This anatomic arsenal is used for delicate feeding, escaping predators, and mating. Cephalopods originated about 520 million years ago.

Vertebrates include jawless fishes, bony fishes, sharks, amphibians, reptiles, birds, and mammals. Common features include a vertebral column or dorsol notochord, a spinal cord above and gastrointestinal tract below, and a frank or vestigial tail. The stiff, supportive notochord, found in all chordates, is replaced by a segmented series of bony vertebrae. All vertebrates either have gills, or embryonic gill arches that transform into other structures such as jaws and ear parts.

Vertebrates originated about 525 million years ago; the first jawed fishes about 490 million. The nervous system consists of a brain, spinal cord, and an intricate lacework of peripheral nerves feeding the body and appendages. The brain and appendages vary with species. Fish brains have 3 paired lobes as well as the

cerebellum and myelencephalon. They move by alternately contracting muscles on either side of the backbone, with the overall motion also guided by fins. The human brain consists of a cerebrum with 4 paired lobes, a bi-lobed cerebellum, and the pons and medulla. The cerebral cortex sustains higher cognitive processes. The number of digits, joints, and appendage structures and capabilities varies with species. Vertebrates are capable of very intricate motions that are further nuanced by decisions on whether to remain active or passive. Despite ongoing controversy, genome and gene family analysis suggests part of the anatomical and physiological complexity of vertebrates may be due to two ancestral rounds of genome doubling (i.e., tetraploidy) (Furlong and Holland 2002).

The anatomy of vertebrates and cephalopods clearly differs, with vertebrates having appendages that come off a central axis; cephalopods having arms and tentacles that emerge radially from the oral area. Vertebrates have a wider ensemble of actions, which in higher vertebrates translates into phases of activity that have an initiation and end. The sophistication of both varieties lends them to organized social behavior.

Conclusion: The Return from Science to Philosophy

The scheme developed herein makes compatible the notion of an overall organizing structure for evolution with the established practice of basing evolutionary trees on cladistic and molecular genetic analyses. For example, one study of deuterostomes, so defined by the fate of their initial opening during embryogenesis, detected significant homologies between subcategories (Blair and Hedges 2005). The investigators looked at 217 encoded proteins, and found significant support for urochordates being the closest relatives to vertebrates (based on 59 proteins, 17,400 amino acids), and for a pairing of hemichordates with echinoderms (based on 9 proteins, 2,382 amino acids). This kind of scientific data is quite valuable. But following scientific data alone, one arrives at an evolutionary tree that shows neither rhyme nor reason. It is based purely on adaptive radiation. The system above provides a context for viewing how evolution fills a function-related phase space.

Duplicative events, as suggested by Chapouthier, are part of the explanation. They probably created the category of vertebrates to which we belong. The juxtaposition-integration process can itself occur repeatedly, as the different levels of evolution outlined above indicate. Furthermore, looking at the tendency for chordate evolution and molluscan evolution to follow two separate streams – central and radial – may demonstrate embryologically fixed organizing trajectories adhered to throughout the march between phyla, and certainly between species. The above scheme uncovers evolution for what it is – a chain of development in the gaining of functional capacity. The concept of a *basic cosmist functionality* (Khroutski 2010, p. 73; 2006, pp. 132, 137) – that every living thing is a function of Process and has its own realization – is essentially correct. Nevertheless, we are all accustomed to thinking of creatures like ourselves, warm blooded mammals, as being unique on the evolutionary ladder, but cephalopods are not far behind, and given the right conditions (adequate temperature and oxygen), it may very well have been that

insects could have occupied our position (and still might according to some future alternative histories). On a smaller note, it would be useful to apply a scheme like the geometric model to other groups such as insects and plants to see how it works out and contributes to our understanding of evolution.

The question remains: “What is driving this process?” Is it a pull from an elusive teleologic force, or a push from random mutations? Mutations, deletions, and duplications are part of the story, but in this modern scientific era, now 150 years downstream from Darwin, thermodynamics shows the way to a physical driving force for biological complexity. These biophysical forces collectively are Aristotle’s efficient cause as far as life goes – “the proximate source of change or rest” (Bambrough 1963, p. 214). But the final cause (“an end ... the purpose of a thing”), as outlined in this paper, is the attainment of the next more complex level of functional capability as delimited by a pre-existing physical dimensionality. Refinements at the systems level (musculoskeletal, nervous) will subtend this overall functional movement. Variations will have both a random and a systematic, adaptive component, adding to the beauty and uniqueness of the process.

These elements provide a rational basis for the Biocosmological emphasis on final cause in biological evolutionary processes (Khroutski 2010, p. 69). They also suggest that patterns can be discerned which have both universal import and predictive value – a proper scheme is both abstract and specific. To borrow from Emmanuel Kant, however, no scheme is an end-in-itself. Intellectual systems are the instruments of the prevailing frame of mind. An inquiring society of scholars can only hope that its efforts are moving in a constructive, holistic direction, and not the opposite.

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