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Review

Symbiogeny and the rhizomatic

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ABSTRACT

Enhanced communication between scientists and philosophers might help to overcome the reductionism and linear arborescence that have dominated thought on the origins and evolution of biological forms since the 17th Century. In the 20th Century, Alfred North Whitehead complicated thinking on origins with his concept of novelty, and Gilles Deleuze and Félix Guattari challenged concepts of linear evolution with their notion of rhizomatic difference and repetition. Supported by abundant empirical data, François Jacob and Jacques Monod ventured into new theoretical territory with their concept of cybernetic interactions, and Lynn Margulis, among others, demonstrated how eukaryotic cellular constituents arose from exogenous rather than autogenous sources. This new paradigm of endosymbiogenesis spun off notions of horizontal larval transfer, set-aside cells, and symbiogeny, the theory that eukaryotic cellular films and independent cells combined and evolved into tissues in metazoan organisms. Philosophy may thus open up new avenues of thought to biologists.

KEYWORDS: endosymbiogenesis, symbiogeny, rhizomatic, Deleuze, Guattari, Jacob, Margulis, Monod, Whitehead

INTRODUCTION

Data collection is not the obstacle faced by biologists interested in studying the fundamental properties of living things such as their origins and the evolution of biological forms. The difficulty is crossing over intellectually from metaphysical doubts and speculation to empirical properties. Indeed, with the exception of biologists examining premises regarding extra-terrestrial life, research on life's fundamental properties hardly enters the laboratory. This deficit is overcome, however, when experimental scientists work in creative harmony with conceptual philosophers.

Our objective in "Symbiogeny and the rhizomatic" is to illustrate this harmony and document its richness. In particular, we trace links between experimental investigations surrounding the work of Lynn Margulis on endosymbiosis and the philosophical reflections of Alfred North Whitehead on novelty and of Gilles Deleuze and Félix Guattari on difference and repetition epitomized by their notion of the rhizome. Hopefully, the present endeavor will encourage biologists and philosophers to find grounds for fruitful exchange.

A hiatus between biology and philosophy is of long standing. Indeed, the failure of many contemporary biologists to examine metaphysical questions can be traced to the reductionism of 17th Century Aristotelian natural philosophers. These proto-biologists reduced life to a concept of species identified as collections of individuals sharing perceptual qualities of anatomy and physiology. John Ray added reproduction to these qualities, and in the 18th Century Comte de Buffon added the notion of a reproductive community to the definition of species.

In the 19th Century, romantics and modernists found the essence of natural, healthy life in species rather than in individuals. Individuals inevitably died, but species embodied life from the beginning and

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for all time. Following the advent of evolutionary thinking, however, Goethe adjusted the view of species to a "manifestation of secret laws of nature" [1]. According to him, life "develops normally when it makes countless individual elements conform to a rule, determines and conditions them; when, however, the individual elements prevail and stand out in an arbitrary, indeed seemingly accidental fashion, then those phenomena are abnormal" [2]. Thus, morphological harmony among members of a species expresses the health and beauty of life.

The microscopic dissection of living things had the potential to overcome these teleological habits of thought, but the prominence of Theodor Schwann's version of the cell theory only added cells to the typology of species. Likewise, Darwinism offered an opportunity to break from romanticism only to see competition turned into the premier quality of species. In the twentieth century the rediscovery of Mendelism and Morgan's genetics might also have sent biology in new theoretical directions, but variation and inheritance were merely brought under the umbrella concept of species.

Ernst Mayr's views of species as concrete reproductive entities [3] became dogma, and Watson-Crick base pairing established a molecular foundation for homogenizing life and explaining sameness. Even the vast amounts of new data accumulated through sequencing DNA have been manipulated to conform to conventional models of species, and arborescence has been scaled upward to encompass genera, families, orders, classes and phyla. In fact, branching evolution is now extended to encompass all living things from life's beginning to the present [4]. Even Carl Woese' famous dissection of small sub-unit ribosomal RNA (SSU rRNAs) [5] that led to the recognition of "'kingdom-specific' conserved elements (sequences that are conserved only in Eubacteria, the Archaebacteria, or the Eukaryotes)" [6] failed to weaken faith in life's continuity.

In the 21st Century, biology's doctrine of life's origin and universality was solidified in the doctrine of primordial transitions: viruses (or viroids) became prokaryotes (or their ancestor) and prokaryotes became eukaryotes (or the progenote [7]). The absence of a nucleus in viruses and prokaryotes remained problematic, but the solution was widely thought to reside in filial models of compartmentalization employing transitions and the gradual accumulations of differences.

Nothing whatsoever in Darwinism and genomic evolution remotely extends to the origins of life or major evolutionary lineages. The default model is, however, locked in the disciplinary grip of "royal science" that "has at its disposal a metric that can define a conceptual apparatus or autonomy of science (including the autonomy of experimental science)" [8].

Some thinkers began appreciating the problems of imprecision in biology's language. Analogizing life with color, the philosopher Alfred North Whitehead postulated that it "is nonsense to ask if the colour red is real. The colour red is ingredient in the process of realisation. The realities of nature are the prehensions in nature, that is to say, the events in nature" [9]. Indeed, theories of life resembled theories of color in which the "qualitative is really a bump that can be shifted around under the worn rug of materialism" [10].

In time, life scientists also began questioning life's "redness". They appreciated the difference between the real and the realizable and confronted the vital conundrum: If life's qualities are entirely subjective how can they lead to an understanding of life? Indeed, these biologists realized that life's properties were being seen through a corrupted mirror that would have to be shattered in order to see life clearly.

The triumph of endosymbiosis

How then do biologists escape the dogma of life's linearity to approach life's fundamental properties? One pathway opened when some biologists/ philosophers noticed that symbiosis "as a source of evolutionary innovation occurs at many levels of scale" [11].

Symbiosis is universal among living things from the microbiota of archaea, bacteria, and fungi residing on every surface of animals, nitrogen-fixing microbes in root-nodules of legume plants, associations of fungi and photobionts in lichens, bioluminescent bacteria in marine animals, and planktonic and benthic microbial communities each displaying constant competition of virulence and fitness traits over long periods of coevolution. Symbiosis would seem to have no limits. Indeed, the "ancestor of the nucleus probably started as an accumulation of prophages and plasmids integrated in the growing 'chromosome' of the outer symbiont of the first eukaryotes" [12], and the continuation of life is undoubtedly tied to the continued success of symbiosis.

Ultimately, biologists/philosophers investigating symbiosis escaped the "royal science". They did not bow to the monocracies of either objective physical properties or subjective human references and perceptions - to the human construction of reality or "misplaced concreteness" [9]. Instead of adopting the concept of species and looking for sets of shared fundamental properties, these investigators set out to discover life's differences and took the revolutionary path working upwards from the ground of difference.

How are new connections and pathways of thought postulated? For the philosopher Gilles Deleuze, the answer comes from a "rhizome" that traces uncharted channels directly through its matter and mutates to "create new concepts" [13].

For biologists, endosymbiotic theory was a new pathway [14], and its triumph kicked off a "true Kuhnian minirevolution" crowned by two major colloquia published in the *Annals of the New York Academy of Sciences* [15, 16]. Contributors traced endosymbiosis to its roots in the 19th Century [17] while acknowledging the singular contributions of the late Lynn Margulis whose theory of serial endosymbiosis [18, 19; aka serial endosymbiotic theory (SET)] was widely credited, if sometimes grudgingly, with turning the theory into a doctrine [20]. Nowadays "there appears to be little reason to doubt that" [17] chloroplasts and mitochondria are self-replicating semiautonomous organelles (cytobionts; endocytobionts [21]) evolved from prokaryotes through the "process of the 'assembly' of a complex system from largely 'prefabricated parts'" [22].

Abundant evidence now supports major roles for symbiosis in the origins of life's major evolutionary lineages. Indeed, the argument for the symbiogenic origins of mitochondria and chloroplasts rests on the retention of ancestral prokaryotic specificities recognizable as unique features of modern prokaryotes [23]. For example, branches "representing the mitochondrial and chloroplast compartments of eukaryotic cells converge on different parts of the multi-kingdom tree. The mitochondrial SSU rRNAs affiliate with the purple bacterium *A. tumefaciens*, and chloroplast rRNAs affiliate with the cyanobacterium *'A.' niculans*. If [taxonomic] trees constructed from rRNA sequence comparisons have any validity, the eukaryotic cell must be a chimera" [6].

Probably the most common criticism of symbiogenesis is its alleged lack of parsimony, and probably the evidence cited most often is systematic difference (e.g., in mitochondria's small subunit ribosomal RNA). For example, why don't the mitochondria of different organisms have more or less the same rRNA if they originated symbiotically from a single source? The answer is that the respective cell organelles did not originate from a single source!

Indeed, historical "'imperfections and oddities' ought not be ignored as exceptions… [when] they would be comprehended as products of opportunistic… evolution" [24]. Evidence for multiple types of mitochondria and chloroplasts (plastids) may thus strengthen the argument for symbiogenesis, assuming that symbiogenic origins were common rather than rare. In fact, the acquisition of symbiotic partners is hardly confined to the rare and ancient. Symbionts are frequently acquired during the lifetime of organisms. For example, reef-building corals hosting dinoflagellate algae (e.g., *Aiptasia* sp. hosting *Symbiodinium*) reproduce with non-symbiotic larvae that acquire their symbionts by phagocytosis [25].

Endosymbiosis would provide a spectrum of varieties of mitochondria and plastids had they been adopted from different sources [26]. Hence, "apparently unicellular populations of *Cyanidium* actually contain three related but different algae" [27]. Likewise, difference among chloroplasts (and nucleomorphs) "supports the hypothesis that the chloroplasts of some algal groups were acquired through eukaryotic endosymbionts" [28]. Thus, differences among *analogous* organelles are perfectly compatible with the co-descent of symbionts.

On the other hand, only one mutualistic microorganism colonizes ciliates at a time (with rare exceptions in which two microorganisms are present in the same population of ciliates and rarer still exceptions in which two endosymbionts are present within the same host). The explanation is not that endosymbiosis is rare; it is not. Rather, symbiogenesis does not exclude separation or the ability of hosts to limit coexistence with additional endocytobionts in the presence of one well-adapted endosymbiont [29].

Symbiogenesis: novelty and the rhizome

Understanding symbiogenesis requires deconstruction. Symbiogenesis has played its role in evolution by creating biological novelty and not through teleological narratives.

For both Whitehead and Deleuze, novelty is the highest criterion for thought: “even truth depends on novelty and creativity, rather than the reverse” [30]. Whitehead was first to contextualize novelty in theory: “If you have had your attention directed to the novelties in thought in your own lifetime, you will have observed that almost all really new ideas have a certain aspect of foolishness when they are first produced” [9]. Whitehead went on to place novelty in practice: “It is for this reason that the meaning of the phrase ‘the actual world’ is relative to the becoming of a definite actual entity which is both novel and actual” [31]. Indeed, the “universe is thus a creative advance into novelty. The alternative to this doctrine is a static morphological universe” [31].

As for life, novelty is of the essence. Whitehead explains that the very “doctrine of ‘life’… [its] primary meaning… is the origination of conceptual novelty… Thus a society is only to be termed ‘living’ in a derivative sense” [31]. As for life science, “novelty may promote or destroy order; it may be good or bad. But it is new, a new type of individual, and not merely a new intensity or individual feeling. That member of the locus has introduced a new form into the actual world; or, at least, an old form in a new function” [9].

At the same time, order “is not sufficient. What is required is something much more complex. It is order entering upon novelty; so that the massiveness of order does not degenerate into mere sameness; and so that the novelty is always reflected upon a background of systems” [31].

Building on Whitehead, in addition to concepts from biology, geology, and philosophy, Gilles Deleuze and Félix Guattari developed their views on repetition and difference epitomized by the rhizome [32]. The rhizome challenges dualistic thinking by means of a multiplicity of organic, economic, and political codes. Thus, the rhizome dismantles the reductive linear unity of knowledge epitomized by arborescence [33].

Deleuze and Guattari’s rhizomatic form evoked a new concept of unity based on fragmentation and the making of the “multiple that *must be made,* not by always adding a higher dimension, but rather in the simplest of ways, by dint of sobriety, with the number of dimensions one already has available — always n – 1 (the only way the one belongs to multiple: always subtracted). Subtract the unique from the multiplicity to be constituted, write n – 1 dimensions. A system of this kind could be called a rhizome” [8].

The rhizome is different from roots and radicles, plant life, and pack forms. The singular characteristic of the rhizome is that it can be connected to anything other, and must be. In contrast to a tree within the tree world, the rhizome has no singular position in a root world.

Citing the Nobelist developmental biologist François Jacob, Deleuze and Guattari illustrate the rhizomatic with connections between two different animals; for example, the baboon and the cat. These animals are not copies or models of each other. In their aparallel evolution, nevertheless, viruses have formed rhizomes between them and it is this “communication” that exists between different lines, scrambling their genealogical trees [34]. It is in the molecular or sub-molecular particle where the alliance occurs. Indeed, a Deleuzian way of describing the common or collective dimensions of plants in human cells is a collective assemblage, the mingling of bodies reacting to one another. Nevertheless, the rhizomatic process has room for individuals. In fact, the rhizome relies on individuation — when individuals open up to pervading multiplicities. The key is intermingling as articulated in symbiogenic relationships that have constituted a means of becoming.

A major distinction between the arborescent and rhizomatic, is that a tree, the quintessential arborescent structure, comes ready made — the tree hierarchizes its tracing — whereas the rhizome is a map that is oriented toward experimentation. The rhizome has no beginning and no end, but it has a middle “from which it grows and overspills” [8].

At the middle is a plateau made of plateaus, the site of an inter-being, and relations of mutuality, a union of repetition and difference characteristic of the rhizomatic.

The case of the orchid and wasp illustrates the difference between the characters of becoming in the rhizomatic as opposed to linearity in the arborescent [35]. “One does not break with the arborescent schema, one does not reach becoming or the molecular, as long as a line is connected to two distant points, or is composed of two contiguous points. A line of becoming is not defined by points it connects, or by points that compose it… If becoming is a block (a line-block), it is because it constitutes a zone of proximity and indiscernibility… The line or block of becoming that unites the wasp and the orchid produces a shared deterritorialization: of the wasp, in that it becomes a liberated piece of the orchid’s reproductive system, but also of the orchid, in that it becomes the object of an orgasm in the wasp, also liberated from its own reproduction” [8].

This relation between the orchid and the wasp is critical for rethinking Deleuzian repetition and difference: The orchid territorializes while forming an image, a tracing of the wasp; but the wasp is re-territorialized on that image. The wasp is nevertheless de-territorialized, becoming part of the orchid’s reproductive process, but it re-territorializes the orchid by transporting its pollen. Wasp and orchid, as heterogeneous elements, form a rhizome. It could be said that the orchid imitates the wasp, reproducing its image in a signifying fashion (mimesis, mimicry, lure, etc.). But for Deleuze and Guattari this is only true on the level of strata — a parallelism between two strata — a plant organization on one imitates an animal organization on the other.

“At the same time, something entirely different is also going on: not imitation at all but a capture of a code, surplus value of a code, an increase in valence, a veritable becoming, a becoming-wasp of the orchid and a becoming-orchid of the wasp. Each of these becomings brings about the deterritorialization of one term and the reterritorialization of the other: the two becomings interlink and form relays in a circulation of intensities pushing the deterritorialization even further” [8].

Another major characteristic of the rhizomatic emerges from necessary distinctions between the molar and the molecular. Deleuze and Guattari characterize all molar functionalism as false, “since the organic or social machines are not formed in the same way they function, and the technical machines are not assembled in the same way they are used, but imply precisely the specific conditions that separate their own production from their distinct product. Only what is not produced in the same way it functions has a meaning, a purpose, an intention” [36].

Deleuze and Guattari’s molecular rhizomatic thinking is, however, categorically not teleological. It is not linear; it decenters disciplinary formations so as to allow for thinking difference differently. Furthermore, their methodological practices downplay the arborescent and decenter disciplinarity bringing science creatively into communication with philosophy (epitomized by the work of Lynn Margulis).

As a consequence, evolutionary schemas have to account for other modes of movement: the tree and lines of decent have to succumb to an “aparallel evolution” with beings that have “absolutely nothing to do with each other” [36]. Rhizomatic movement, as with a virus, entails flight into cells of an entirely different species; for instance, bringing genetic information via type C virus to baboon and cat. In short, citing Jacob, Deleuze and Guattari illustrate how “transversal communications between different lines scramble the genealogical trees… Always look for the molecular, or even sub-molecular particle with which we are allied. We evolve and die more from our polymorphous and rhizomatic flus, than from our hereditary diseases, or diseases that have their own lines of descent. The rhizome is an anti-genealogy” [36].

From the biologist’s point of view, microscopic cybernetics has given molecular evolution a practically limitless field of exploration and experimentation to elaborate the high network of cybernetic interactions. In *Chance and Necessity,* Jacques Monod claims that with “the globular protein we already have, at the molecular level, a veritable machine — a machine in its functional properties, but not, we now see, in its functional structure, where nothing but the play of blind combinations can be discerned. Randomness caught on the wing, preserved, reproduced by the machinery of invariance and thus converted into order, rule, necessity. A *totally* blind process can by definition lead to anything" [37].

Deleuze and Guattari's thinking elevates tracing and mapping to central roles in design; however, tracing and mapping are not regarded as being reinserted into *reproducing* the tracing or the map. That is not rhizomatic. Understanding tracing and its relationship to mapping is a question of method: It "is inaccurate to say that a tracing reproduces the map. It is instead like a photograph or X ray that begins by isolating and selecting, by artificial means such as colorations to other restrictive procedures, what it intends to reproduce… The tracing has already translated the map into an image; it has already transformed the rhizome into roots and radicals. It has organized, stabilized, and neutralized the multiplicities according to the axes of significance and subjectification belonging to it… [I]t injects redundancies and propagates them" [8].

In contrast, the rhizomatic system is acentered. It is composed of "finite networks of automata in which communication runs from any neighbor to any other, the stems or channels do not preexist and all individuals are interchangeable, defined only by their *state* at a given moment — the coordination of local operations and the final, global result synchronized without a central agency" [8]. However, following the work of Pierre Rosenstiehl and Jean Petitot, Deleuze and Guattari emphasize that the opposition between the centered and acentered is "valid less as a distinction for things than as a mode of calculation applied to things. Trees may correspond to the rhizome or they may burgeon into a rhizome. It is true that the same thing is generally susceptible to both modes of calculation or to both types of regulation, but not without undergoing a change in state" [8].

In sum, rhizomatic thinking escapes from the linear unity of knowledge. The rhizomatic evokes a different concept of unity based on the "multiple, not by always adding a higher dimension, but rather in the simplest way by subtracting the unique from the multiplicity" [8]. Deleuze's rhizome can be connected to anything other, and must be. In contrast to a tree with its roots, the image of the tree world, the rhizome has no points or positions. A rhizome, exemplified by a tuber, is a multiplicity and multiplicities are defined by their line of flight, the diverse forms and ruptures that can start on old lines or on new ones.

Like the rhizomatic, the symbiogenic circulates in different orbits that do not touch each other so much as cross each other's paths. A Deleuzian way of describing the common or collective dimensions of plants in human cells is as a collective assemblage, the mingling of bodies reacting to one another much as a symbiogenic way falls back on common cellular organelles.

Probably the most seductive aspect of the linkage of the rhizomatic and symbiogenic is the potential for innovation. Indeed, "those interactions culminating in mechanisms for the integration of today's semiautonomous organelles were even indispensable for the evolution of the eukaryotic cell out of an endocytobiotic organization" [38], specifically, endogenous clocks and calcium signaling both playing pivotal roles in development, growth and differentiation of multicellular eukaryotic organization.

Heirs of symbiogenesis

Symbiogenesis has a long if not hidden (repressed) history. Russian and Soviet era scientists worked for many years on organisms consisting of two or more simple entities that continued to live independently if separated but could live a common life again when brought together through a change in their environment [22]. Lynn Margulis, whose own work was ignored by Western biologists, finally brought attention to the Russian work through her study on symbiogenesis [39]. She also brought attention to the work on "symbionticism" by the American, I. E. Wallin and on symbioses in evolution by the Frenchman, Paul Portier [40].

After Margulis and others demonstrated endosymbiosis satisfactorily, the late Donald Williamson took the bold step of expanding the concept to fusion at the organismic level. He extended symbiotic thinking toward metazoan forms with his radical hybridization hypothesis for the "horizontal transfer of larval form": On "occasion during evolutionary history, larval and embryonic forms that originally evolved in one lineage have later appeared in another, as if they had jumped from one branch of the phylogenetic tree to a distinct and sometimes distant one. The implied transfers of large amounts of genetic material are attributed to successful hybridizations between animals that are not closely related. This assumes that the genes specifying larval form act largely independently of those specifying adult form, but most animals keep their larval and adult morphologies quite separate, irrespective of how the larvae evolved" [41].

Hybridization with the retention of ancestral genes in coherent packages (chromosomes) was thus proposed as the instrument of larval transfer, resulting in the fusion of one biological form as a larva with another biological form as an adult. Developmentally, the transition between larva and adult was accomplished through the otherwise well known if obscure process of metamorphosis [42] now dubbed the "mid-developmental transition" [43].

Another and equally bold step was taken by the late Eric Davidson [44]. Working on the developmental biology of sea urchins, Davidson discovered that the well-known regulative development (i.e., pluripotency) of early sea urchin blastomeres was an artifact of cell isolation, and that the fate of blastomeres, or course of differentiation, was already established (i.e., determined) *in situ* [45, 46]. Consequently, Davidson proposed a concept of adult-forming "set-aside cells" sequestered in embryos and larvae. These cells resembled the well-known imaginal disk cells in holometabolic insect larvae that proliferate between molts and differentiate into adult organs at metamorphosis. Thus, normally, set-aside cells are not unrestricted embryonic stem cells but more nearly adult stem cells able to divide and exercise limited developmental potency [47]. In other words, set-aside cells are sequestered in larvae and only play their roles in differentiation post-metamorphically (i.e.,Williamson-like).

The set-aside pattern may not be universal, however. Vertebrates seem to follow a different pattern of embryonic development. The behavior of vertebrate embryonic stem cells may even run counter to that of invertebrate set-aside cells inasmuch as embryonic stem cells in vertebrates are credited with making the embryo and fetus as well as the adult in contrast to set-aside cells in invertebrates credited with only making the adult. The hiatus may be breached, however, if vertebrates sequester their set-aside cells as adult stem cells late in development [48, 49]. A theory of adult stem/set-aside cells in human beings has obvious (latent) implications for health, regeneration, and transplantation therapy as well as for notions of cancer stem cells in adults [50].

The set-aside pattern would seem to be quite ancient. After examining pre-Cambrian fossil embryos [51], Davidson suggested that fossils from the lower Doushantuo phosphites from China's Yangtze Gorges, especially from Weng'an, Guizhou Province China (~580 Mya) [52] were early embryos up to the 16-cell stage (i.e., "diapause egg cysts, or hulls") with "polar lobes" reminiscent of those in contemporary spiralian embryos. The content of their polar lobes would, presumably have been funneled into their D quadrant and ultimately into the 4d micromere of embryos, the source of the majority of adult mesoderm (endomesoderm) and probably the germ line (e.g., in *Crepidula fornicata*) [53]. Thus, the segregation of determinants for set-aside cells would predate the Cambrian explosion of metazoans.

The complexity of rhizomatic thinking might offer inroads into the myriad mysteries surrounding the origins of metazoan tissues. Thus, much as Margulis' endosymbiotic theory liberated chimeric individuals (eukaryotic symbiogens) from the confines of linear temporal succession, symbiogeny may replace exclusive points of evolutionary rupture with possibilities for reconnection and carry symbiosis beyond the cellular level to the tissue and organ levels.

Symbiogeny proposes a fusion of biological films (pre-epithelia) and individual cells (pre-connective tissue) [54]. The two primordial tissues would then have become "integrated symbiotically in a primitive organism(s) and evolved by competition within the organism(s) into present tissues" [55]. Competition would have promoted the evolution of somatic tissues (including their embryonic and adult stem or set-aside cells) and germ cells (hence sexual reproduction). In vertebrates, epithelia, muscles, nerves, and eggs would have been derived from epithelial-like ancestors, while blood, lymph, connective tissues, and sperm would have been derived from ameba-like ancestors.

Margulis came close to suggesting the essence of this symbiogeny hypothesis of tissue origin when she proposed that varieties of eukaryotic cells were in place a billion years ago. Not only were “some sort of protoctists” present (e.g., amoeba) but so were traces of “distinctive globular fossils as much as a millimeter in diameter” (e.g., films or pre-epithelia [40]). The Cambrian eruption thus may have followed the origins of tissues by symbiogeny in different forms of eukaryotes. Indeed, according to Margulis “the modern era was in full swing prior to the appearance of the hypertrophied familiars we hold so dear: most invertebrates, vertebrates, and plants. Their absence is the main distinction between the upper Proterozoic and the lower Phanerozoic” [40].

One can only speculate at this time on the possibility that understanding the sources and evolution of tissues will have practical implications. Such understanding may provide solutions to problems in stem-cell therapies and suggest ways to promote the survival of normal tissue at the expense of cancers [55].

In the case of Cnidaria

The peculiarly sharp border between cnidarian epithelia and amoeboid cells would seem consistent with the separate origin of these tissues. Original epithelial-like and amoeba-like symbiotic partners in pre-Ediacaran cnidarians might have evolved into the tissues of polyps and medusas: epithelial-like cells into epithelia, muscle, nerve, and female sex cells and amoeba-like cells into the stem cells of cnidocytes, glands, and male sex cells [56]. Indeed, in polyps, such as Hydra, muscle fibers are extensions of epithelial cells [54, 55], and female and male sex cells arise from different stem cells [57, 58].

Another feature of the Cnidaria reminiscent of the rhizomatic and symbiogenic is re-separation. Indeed, the highly multicellular organisms comprising the standard polyps and medusas of the phylum have branched off the virtually unicellular class, the Myxosporidia, one of the two classes of Myxozoa.

Initially, accumulated molecular evidence required the relocation of Myxozoa from the protoctistans (unicellular eukaryotes) to the metazoans (Animalia: multicellular eukaryotes [59-63]). Confusion prevailed, however, about whether the myxozoans were bilaterians [64] or cnidarians [65-70], but Cnidaria won out [71], in part, due to repositioning cnidarians among bilaterians [72, 73]. Indeed, the phylogenetic placement of Myxozoa within the Cnidaria is now supported by “strong evidence” [74].

This consensus view not only coincided with the symbiogeny hypothesis for the evolution of metazoan tissues [56] but put an end of the monopoly of animal germ cells over meiosis (reduction division) and fertilization (conjugation). Henceforth, meiosis and fertilization also belong to the repertoire of cellular activities available to somatic animal cells.

In myxozoans, fertilization occurs either before or after the emergence of the sporoplasm through “the fusion of chromosomes of haploid nuclei of the sporoplasm” [75]. In *Myxobolus pfeifferi,* micro- and macrogametes formed by reduction division inside the plasmatic mass of large plasmodia “conjugate and their nuclei fuse to form the synkaryon. The zygote thus formed transforms into a pansporoblast in which spores form” [75]. Other Myxosporidia exhibit variations on this theme. For example, in *Ceratomyxa drepanopsettae,* karyogamy, “i.e., fusion of the nuclei into a synkaryon, could take place at different phases of the life cycle and differently in different species and sometimes differently within a single species… [D]evelopment could be polysporic or disporic when large multinucleated vegetative forms have formed, or it could be monosporic. In the first case remnants of vegetative forms with some number of vegatative nuclei are preserved after the formation of the spore. During the monosporic process these remnants may be present or absent” [75].

Sex is thus a mechanism of growth and development and may even expand possibilities for differentiation. Indeed, the role of symbiosis in metazoan evolution [39] may be far grander than one might have anticipated. Segregation and recombination in somatic tissues might even play roles in carcinogenesis [76].

CONCLUSION

Eighteenth Century biology began with efforts to apply Aristotelian requirements and divisions to nature; not an easily accomplished task. “According to Aristotle, the work of natural philosophers is dividing genera into opposing species. This procedure not only lacks ‘reason’ by itself, it lacks a reason in terms of which we could decide whether something falls into one species rather than another” [77].

Whitehead, Deleuze and Guattari would have biologists pursue their mandate by turning the question, “What resemblance is there?” on its head to “What difference is here?” Difference is far more likely to be discovered than resemblance, since difference “carries with itself the genus and all the intermediary differences. The determination of species links difference with difference across the successive levels of division, like a transport of difference… until a final difference… condenses in the chosen direction… becoming itself something unique and indivisible… In this manner, therefore, the determination of species ensures coherence and continuity in the comprehension of the concept” [77]. We encourage biologists, therefore, to take the hard way of looking at life’s resemblances through differences.

Where then does difference leave resemblance? Deleuze answers: At “the price of a more general categorical reversal according to which being is said of becoming, identity of that which is different, the one of the multiple, etc” [77]. Thus, for present purposes, Deleuze has brought us to the edge of synthetic evolution, symbiogeny and the origins of repetition — “the universal matter or continuum from which the essences are finally made” [77]. Deleuze was, of course, aware that structure exists at many levels: Chromosomes “appear as *loci*… not simply as places in space but as complexes of relations of proximity; genes express differential elements which also characterise an organism in a global manner, and play the role of distinctive points in a double process of reciprocal and complete determination… [T]he whole constitutes a virtuality, a potentiality; and this structure is incarnated in actual organisms” [77].

Our discussion of novelty and the rhizome is also intended as a critique of reductionism and teleology in 20th Century biology. Expressions such as “because of” and “in order to” in the literature of biology [78] have rendered a near-death blow to theorizing [79]. Indeed, orthodoxy has blocked innovative ways of thinking and problem solving in biology far too long. For example, biologists have known for centuries that vast numbers of different microbes reside inside and on us, but the consequences of this integration of symbiotes are yet to be adequately considered. The microbiome is not even appreciated for its role in nutrition to say nothing of resistance to infection.

Likewise, data accumulated since the 1970s demonstrate the presence of human fetal cells in mothers and maternal cells in offspring [80]. Our tissues are, therefore, not necessarily entirely of our own making! Our mother’s cells, and even our older siblings’ cells may be “resident aliens”. This phenomenon, namely maternal/fetal hybridization, or microchimerism, is attributed to leaky placentas allowing cellular transfusions to take place in both directions, but biologists are yet to consider adequately the consequences of “cross-fertilization”.

Above all, we have endeavored to place symbiogenesis in the context of life’s origins and the evolution of life’s fundamental forms emphasizing that the notion of the rhizomatic suggests both syntheses toward and away from sources. Indeed, we anticipate and await eagerly the elucidation of symbiotic relationships in the origin of cancer. We might add that miniviruses, mamaviruses, megaviruses and pithoviruses (each with hundreds of genes and an uncanny ability to organize a host’s ribosomes and replicative apparatus) can be parts of the rhizomatic “before” or “after”.

Ignoring novelty and the rhizomatic, common conceptions of life raise the question of whether viruses and phage are alive or not. The differentiated “cork” plugging a hole at one end of the giant pithovirus makes the case for viruses being alive and the “stargate” apparatus seen in miniviruses also make the case for “living” viruses. Indeed, the minivirus’ penta-symmetric, star shaped portal that opens during infection allowing the release of infective viral particles [81] is uncannily similar to bi- and tetra-partite arrangements of suture lines in mature spores of the myxosporean *Kudoa* that rupture and allow the sporoplasm (planont) to creep out and infect a host cell [60].

Viruses may also be thought of as living when parasitizing a cell and organizing ribosomes and proteins around the parameters of reproduction. The development of infectious particles would then be a mere extension of the “living” parasites. Retroviruses in the role of transforming agents would also qualify as “living”. Turning the question “on its head”, however, suggests much more compelling possibilities of separate origins for viruses and cells and their rhizomatic interactions at many levels of symbiogenesis.

Finally, our objective has not been to challenge the massive amount of evidence supporting the evolution of species through competition and selection. We have no quarrel with using differential reproduction as a model for the evolution of species, and we grant that the origin of species may provide a suitable model for the origin of genera and even families. But additional theoretical complexity would seem necessary to explain the origins of orders, classes and phyla to say nothing of subdivisions, branches, domains and kingdoms. For example, symbiogenic processes such as horizontal larval transfer and the sequestration of set-aside, imaginal disk, and adult stem cells may have played diverse and profound roles in creating life's diversity.

We are also critical of the tendency of biologists to extend the notion of arborescence all the way to the origin of life. Hence, we have employed Deleuze and Guattari's philosophical notion of the rhizomatic for probing biology's reliance on arborescence as the sole source of life's origins. We have suggested instead that life's diversity bespeaks diverse origins and its many forms diverse rhizomatic interactions.

Indeed, as Lynn Margulis and Mark McMenamin suggested in their editors' introduction to Liya Khakhina's *Concepts of Symbiogenesis*, "If all animal cells have at least three ancestors and all plant cells at least four, how many heterologous ancestors has a human, a cow, or a weeping willow? Not only will the concept of *individual* be replaced with that of symbiotic complex for all animals, but since all eukaryotes harbor heterologous DNA's from various sources, both the sciences of eukaryotic evolution and of developmental biology… become special cases of applied microbial community ecology" [82].

CONFLICT OF INTEREST STATEMENT

There are no conflicts of interest.

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