

A COMMENTARY ON HOMAGE TO DARWIN DEBATE

By James D. MacAllister

With an Afterword by Professor Denis Noble

PART 1

An unrehearsed program chaired by Oxford University Professor of Physiology, Denis Noble (author of *Music of Life; Biology Beyond Genes [2008]*) was open to students and the public. It was organized at Balliol College, Oxford University UK (May 8, 2009) on the 200th anniversary year of Darwin's birth. A lively discussion by faculty, students and others ensued. Four short presentations by Oxford Professors constitute Part 1 (43 minutes): new Oxford Professor of Microbiology, Stephen Bell described the archaeobacterial legacy of eukaryotes; Professor of Paleobiology, geologist Martin Brasier showed complexification in forams, the "*fruitflies of geology*", their appearances and extinctions in the fossil record; Prof. Richard Dawkins presented his "gene's-eye view of evolution"; and Prof. Denis Noble commented on cooperating genes. A review of the previous presentations by Eastman Professor Lynn Margulis, University of Massachusetts-Amherst, an introduction to her film "*Eukaryosis, origin of nucleated cell*" and the presentation of the 14-minute film with her live narration constitute Part 2 (51 minutes). Part 3, a less formal continuation of the discussion took place later in the evening at the same venue and was documented with digital audio but not videotaped.

I have included sequentially numbered "markers." These are for navigation when the DVD or web streaming video is viewed and correspond to the transcript and this commentary. Scenes can be randomly accessed using the "chapter" function found on most DVD players and computers. There are also running times given in brackets [e.g., 23:16] that closely match the running time to match the transcription to video or the mp3 audio CD.

Professor Lynn Margulis, since the late 1960's, has proposed that symbiogenesis, acquisition of genomes by cyclical or permanent fusion of organisms, is the principle way in which novelty in evolution is produced. Her ideas about the origin of mitochondria and chloroplasts as once free-living bacteria that became incorporated into nucleated cells as organelles was initially dismissed, ridiculed or ignored. When electron microscopic (EM) and DNA evidence of the bacterial nature of these classes of cellular organelles became indisputable, the neo-darwinian evolutionary biologists who opposed symbiogenesis accepted the idea as self-evident but conceded that genomic fusions of distantly related whole organisms happened only rarely in the distant past.

The neo-darwinian explanation for novelty, the so-called Modern Synthesis attributes inherited variation to the accumulation of random beneficial mutations of genes that exclusively determine differences in phenotype coupled with natural selection that favors certain phenotypes. Neo-darwinian theory has filled biological textbooks for more than six decades.

Lynn Margulis accepted an invitation to be the Eastman Professor at Balliol College, Oxford University in 2009. She had just received one of the Linnean Society of London's Darwin-Wallace medals for her Serial Endosymbiosis Theory (SET). It was the bicentennial of Charles Darwin's birth and the 150th anniversary of his publication of *The Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life*. Margulis was particularly interested in the work of two Oxford Professors: the physiologist, Denis Noble; and the biogeologist and paleontologist, Martin Brasier. Noble questioned the validity of gene-only-determined inheritance in his book, *The Music of Life*. Brasier had reconstructed a fossil history of symbioses of photobionts in tropical marine foraminifera that extended back to "the Cambrian explosion". Richard Dawkins, the author of at least 4 neo-darwinist best sellers, including *The Selfish Gene*, is Oxford's Charles Simonyi Professor of the Public Understanding of Science. Dawkins is the public face of neo-Darwinism and the person sought out by the media when evolution is in the news. The time and circumstance would never be more opportune for a debate on the sources of novelty in evolution. Lynn Margulis relished the chance to challenge neo-Darwinism and demand evidence.

Marker 1 - Introduction to the Debate

Lynn Margulis and Denis Noble introduce the plan for the evening. The debate is open to the discussion of any subject related to evolution. Margulis lists some ideas for possible discussion:

- Group selection
- Neo-Darwinism and the source(s) of evolutionary novelty
- Fleckian thought styles [(sic)Fleck 1936]
- Survival of Charles Darwin

Marker 2 - Stephen Bell "Archaeobacterial Legacy in Eukaryotes"

The first casualty of the *Homage to Darwin* debate may well have been Woese's Three Domains, a taxonomy claimed to be representative of all of life's history, past and present. The 3-Domain concept is based on complete measurement of several hundred linear sequences of nucleotides, in the small subunit ribosomal RNA, a long chain required for protein synthesis and transfer universally present in all living cells at all times. This measureable nucleotide base-pair RNA sequence is taken as representative of any whole organism. Partial phylogenies are intrinsically limited. The study of evolution must consider full phylogenies that consider the full range of available data of physiology, development, life history and genetics. Stephen Bell, Oxford Professor of Microbiology and a biochemist, describes the Domain of the so-called Archaea as composed of two unique groups of bacteria, the Crenarchaea (mostly high-temperature dwelling sulfoacidophils) and the Euryarchaea (aerobic halophils and methanogens). Some references divide the Archaea include more subdomains (e.g., Korarchaeota) (Garrity 2005).

These Crenarchaea and Euryarchaea are not monophyletic with respect to ESCRT (endosomal sorting complex required for transport) “machinery” for DNA replication. The ESCRT “machinery” of the Crenarchaea thermosulfoacidophils is more closely related to that of eukaryotes than to Euryarchaea.

A second casualty of Bell’s presentation was the neo-darwinist belief that evolution maps exclusively to bifurcating trees. Bell and his group along with many others in the scientific literature conclude that the “tree of life” is the incorrect topology. Bell’s discoveries are better explained by James Lake’s “ring of life” model that recognizes symbiogenetic mergers of organisms rather than bifurcation of branches from a single common ancestor. Bell endorsed the idea that the novel DNA replication system of the Crenarchaea resulted from another merger. He hypothesizes that a prokaryotic microbe dubbed the Last Universal Common Ancestor (LUCA) had a virus integrate into its DNA at the origin of replication. With its own “replication machinery” impaired, LUCA used the viral genes and proteins for its DNA replication. This cell became the first of the Crenarchaeal lineage. Bell thinks this scenario is “sweet” and goes on to say that there is even some evidence for the idea. Mitochondria incorporated the genes of a bacteriophage, a virus that replicates inside a bacterium, for its replication. Bell describes that the common bacterium, *Bacillus cereus* contains a bacteriophage as a component of its own genes that codes for Archaeal and Eukaryotic proteins. Bell’s examples signal the occurrence of widespread genetic transfer between very distantly related taxa. Archaeal genomes have been shown to contain integrated viral nucleic acid sequences that define the start sets for cell DNA replication. Bell’s conclusion is that viral mergers may well have “sculpted” the replication machinery of life. These mergers show that genes move across taxa. This makes the topology of life a net or web, not a tree. **Marker 3 - Martin Brasier “ The Fruitfly of Paleontology”**

Martin Brasier’s presentation begins with the observation from his book, *Darwin’s Lost World: The Hidden History of Animal Life*, that Darwin was unaware of the fossil record of the 85% of “deep time” before the “Cambrian explosion.” The geological record of life is documented by microfossils and geochemical evidence not detected until the mid 20th century. That “most of the really important things that have taken place in evolution, the irreversible transformations ” occurred during the Precambrian was unknown to Darwin. Brasier summarizes the vast studies of the fossil record of single-celled protists known as foraminifera (forams for short). The foram fossil record begins 542 million years ago in the Cambrian Period at the base of the Paleozoic Era. The forams, Brasier claims are the paleontological equivalent of “fruit flies” (*Drosophila*). The evolutionary path of forams, reconstructed from the study of the distribution of their tests (shells) in sediments, follows cycles that last from 20 to 30 million years. Each cycle begins with forams as solitary predators. As the cycle progresses through time, forams acquire photosynthetic symbionts (e.g., dinomastigotes, red algae, diatoms, chlorophyte green algae, etc.) and begin “body farming” by retention and subsequent utilization of their symbionts’ photosynthate (food). Succeeding generations of the symbiotic forams evolve new genera and species. Larger and more specialized shells appear in the fossil record that house and illuminate the photosynthetic symbionts until the foram tests are both highly

specialized and gigantic (some disk-shaped forams reach diameters up to 15cm). These gigantic symbiotic forams become progressively more widespread in sediments. However, this specialization leaves them more vulnerable to smaller and smaller perturbations of their environment over time. There is no free lunch: the cycle ends when environmental change occurs that is intolerable to the overspecialized population of forams and the lineages go extinct, The more generalized smaller forams survive. As generations of the surviving forams persist, symbiotic genera and species evolve again by convergence. Larger and more specialized forams evolve convergently. Extinctions in these cycles correlate with mass extinctions. Brasier concludes that the ecosystem in which gigantism occurs contains within its “connectedness” the source of its vulnerability.

Marker 4 - Richard Dawkins “The Gene’s Eye View”

Richard Dawkins begins, “I thought I would talk to you about neo-Dawinism, which sometimes comes in for some stick [criticism], and in particular the gene’s eye view which is one way of looking at neo-Dawinism.”

Both Bell and Brasier explicitly spoke of symbiosis and symbiogenesis in evolution. The all-important role of gene in the neo-darwinist worldview was not mentioned prior to Dawkins talk.

Dawkins states that genes are “potentially immortal in the form of copies.” Dawkins claims that the condition of potential immortality sets up a competition for survival between variations in phenotype.

Dawkins, “Natural selection is the differential survival of coded pieces of information that exert some phenotypic power over [their] success in being replicated. This is control over the embryological processes, the building of bodies, or, if I can generalize, any power that a gene can exert over the world that improves the possibility of it replicating itself into the potentially eternal future will be favored by natural selection.”

The “vehicles” of genes most familiar to Dawkins are “great big multicellular entities” [animals]. Dawkins admits that this zoocentric view of evolution is peculiar to neo-Dawinism. He offers a more general way to think of the gene’s eye view: “that any kind of phenotypic power that a gene can exert, will be.”

Dawkins repudiates criticism of the gene’s eye view as determinist, “as if we are saying that genes exert an influence on bodies that is deterministic, which is irreversible and inevitable and simplistic.” He “yields to no one in his admiration of the “ complexity, of the feedback loops, ...the immensely complex details whereby genes actually do influence phenotypes.” To Dawkins it does not matter that genes are parts of a system (feedback loops) or that their “vehicle” may have a symbiotic relationship or be the product of symbiogenesis.

Dawkins, “The only thing that singles out the gene in the hierarchy of life as being important in the gene’s eye view... is not that they exert a more causal influence on bodies, the only thing that matters is that they are potentially immortal and that differences in individuals are reflected in differences in survival.”

Several of Dawkins's points appear contradictory. Genes determine phenotypic difference, yet they do not exert an influence on bodies that is deterministic. Genes never separate from their "vehicle" or the complex protein making system within the "vehicle" in which they are expressed. Yet, the genes alone are "potentially immortal." Genes with their phenotypic power are the sole determinant of survival of the "vehicle". This is inconsistent with a "vehicle" that relies on a symbiotic relationship with another "vehicle" to survive (e.g., lichen), a "vehicle" that survives due to necessary symbionts (e.g., mitochondria in an oxygen atmosphere) or a "vehicle" that is a symbiogenetic composite of more than one "vehicle" and genome (e.g., alga that live off the photosynthate of its chloroplasts).

Dawkins gene's eye view rests on the following propositions:

- Only genes are "coded pieces of information".
- The potential for immortality is exclusive to genes.
- Only differences in genes are reflected in differences in phenotypes.
- Differences in phenotype alone determine survival.
- Evolution is hierarchical and genes are exclusively "in charge."

Dawkins concludes with some surprising rhetoric and obfuscation that seem to endorse the adage that "the best defense is a good offense." Lynn Margulis, in Dawkins's words, "is the great apostle of symbiogenesis". Given that Dawkins is the author of the polemic, *The God Delusion*, the choice to label Margulis an "apostle" is rhetorically loaded. Then Dawkins takes a surprising tack.

Dawkins, "I don't think she goes far enough. We can regard the entire gene pool [collection of genes in a single population] of any species as a symbiotic collection of self-replicating pieces of information."

Can the gene pools be considered symbiotic? Symbiosis is defined by scientists who study it, as organisms of different taxa that live in physical contact for most of the life of at least one of the partners. Genes are not organisms. Genes within the same species gene pool are not from different taxa. How is Dawkins using "symbiosis"?

Dawkins concludes, "Every gene in the gene pool is surviving against a background not only of the external environment, ...but also the other genes in the gene pool. Therefore, the gene pool of the lion species is one particular collection of symbiotic genes that are cooperating to make lions, and similarly the buffalo gene pool, and the kangaroo gene pool. They are all symbiotic collections of genes in just the same way as Lynn has taught us with respect to symbiotic organisms."

If Dawkins is using symbiosis as a metaphor or analogy, it is a badly mixed metaphor or a tortured analogy. In one breath, genes are competing with each other and in the next; they are cooperating to make lions. Margulis never talks of competition or cooperation because to her these terms are misleading, anthropocentric, unscientific and unmeasurable. Genes do not form symbioses. Nothing in Margulis's work applies to genes "in just the same way" as the relationships between members of different taxa of organisms. Dawkins's argument seems to be empty rhetoric, perhaps meant to appeal to the audience and give the

impression that he is ahead of Margulis in her own field. Or maybe his argument is sincere and he just does not understand symbiosis or symbiogenesis.

Marker 5 - Denis Noble “Cooperating Genes” [in the relative shortness of deep time]

Denis Noble begins his presentation with the explanation that as a physiologist, he studies the interaction of gene products that produce function (e.g., heartbeat or pancreatic secretion). How many interactions he asks are possible given the human genome? The human genome is currently estimated to comprise 25,000 genes. We humans have neither the largest nor the smallest number of genes in our genome. Noble states that the number of possible interactions is calculated to be $10^{70,000}$. Noble provides a frame of reference for this astounding number. The total of atoms in the Universe as determined by the Hubble telescope is 10^{80} . The actual number of working gene interactions is far fewer than the total number of possible interactions, but even if we considered only $1/1000^{\text{th}}$ of Noble’s number, it would still be astounding.

Dawkins states that “any power that a gene can exert over the world that improves the possibility of it replicating itself into the potentially eternal future will be favored by natural selection.” However, even considering $1/1000^{\text{th}}$ of working gene interactions to be tested and the relative shortness of deep time, a different explanation of the serendipitous favorable combinations that do exist is warranted.

Add to this that most random gene mutations studied have no or very little effect on phenotype. When a random mutation does affect phenotype, it is most often deleterious and even fatal. Therefore, the odds that a random beneficial mutation (or any accumulation of beneficial random mutations) will affect phenotype positively in terms of survival is exceedingly long.

Marker 6 - Questions and Comments on Part 1

Edinburgh Professor of Developmental Biology, Jonathan Bard, makes this precise point, “It’s just not terribly helpful to take the gene’s eye view. It’s not so much that it’s wrong, but it isn’t much use, because selection doesn’t act on the gene. It acts on phenotypes too complicated [to be affected by a single gene]. We know one of the most distressing experiments anybody can do is to knock out a gene and see that it has not even a subtle phenotypic effect.”

Dawkins reply is rhetorical. “Of course, we don’t disagree on that.¹ You do need to actually look at phenotypes. However, when you do look at phenotypes... and ask the question, as a field biologist does, ‘What is the adaptive advantage of...a certain phenotype?’ You do need to ask at what level are you asking that question. If you go out to the Serengeti, if you go to the Antarctic, wherever field biologists are now working on adaptive questions, that’s the question they’re asking.”

¹ [Noble] Neo-darwinists here are really talking about phenotypes, not DNA. If they stopped talking about genes, as though the meaning of the word had not changed, and made it clear that they mean phenotypes misunderstandings and contentiousness would be greatly diminished.

What the field biologist asks according to Dawkins is “What’s in it for the gene?” Dawkins claims that the results from this question are “enormously fruitful.” No one asks for specific examples of the fruitfulness.

Robert Siegel, an Associate Professor (Teaching) in the Department of Microbiology & Immunology and the Program in Human Biology at Stanford University, remarks “I wanted to address this to the first speaker [Bell]. As a virologist, my heart beat faster, to hear your theory of the role of the virus. But doesn't that really just push the question backwards? Because, you have to actually explain where the virus got it [the DNA enzyme complex], and presumably, ...there's only one origin for the enzyme [complex] in history...”

Bell, “One answer, I guess, is the number of generations the viruses go through to scramble the coding sequence will increase the chance of diversity occurring. What we also need to recall, though, is that we're currently looking at three domains of life. Those are the ones that are still existing on the planet today. There are probably two billion years prior to the divergence at LUCA [the Last Universal Common Ancestor] where other lineages have emerged that tried various combinations [DNA enzyme complexes] out. They've become extinct. It's possible that viruses may actually reflect ancient fossils of those ancestral merged lineages. And so, we're just pushing the question back further.”

Siegel: “Yeah, the real question is do you think that it [DNA enzyme complex] evolved independently more than once or have you just spread it out in time, so that you could get more diversity?”

Bell, “What we can do is take it back to the point where the genome itself wasn't DNA, but rather, it was RNA. In which case, we then have a takeover point where, possibly distinct lineages evolve different mechanisms for generating DNA and replicating it. Why hasn't that simply happened in LUCA? Why hasn't LUCA an RNA genome? Firmly possible that it could, but we note that bacteria, archaea and eukaryotes all share a common mechanism for repairing DNA. The homologous recombination machinery is the same in those three lineages suggesting that that was present in LUCA, which, in turn, suggests that LUCA was repairing DNA. Therefore, LUCA itself had a DNA genome. So, the RNA-based genome, we will see, was earlier in time.”

Michael Leiserach, an audience participant, asks Dawkins and the panel if they can give an account of the huge volume of non-coding DNA [referred to as “junk DNA”] in the human genome that hasn't been selected out. He finds it hard to believe that it is doing nothing.

Noble, “I'm quite sure it is not doing nothing.”

Dawkins, “I think it might well be doing nothing.” [Laughter]

Noble, “Well, OK. [Laughter] You think it may well be doing nothing. [Laughter]

Dawkins, “I mean, it's very easy on the gene's eye view to explain. It is simply the ultimate parasite, as [Francis] Crick and [Leslie] Orgel said: it's got the perfect way of replicating itself, it doesn't affect anything so, it's not selected against.”

Dawkins ignores the alternative: that this “non-coding” DNA does do something, that something is useful, so it is selected for. This is one of the first instances where Dawkins answers from authority by the invocation of the names of Francis Crick and Leslie Orgel. Dawkins considers DNA at the top of the control hierarchy in animals, so this explanation that “junk DNA” is the “ultimate parasite” is strangely akin to the religious answer to questions about nature, “God did it.” This is not science since neither God nor “junk DNA” can be investigated. To quote Dawkins from later in the debate (see page 49), “It could be true, but you need evidence for it...”

Noble provides a different answer, “When, as a physiologist, I look at the way in which a protein functions, I have to focus on the active sites of the protein, the bits that really make it be the receptor for this, the channel for that, or whatever its function is. ... We [physiologists] say that [all the protein that is not an active site, receptor, channel, etc.] takes part in forming the three-dimensional structure within which the sites are to be found. That has a very big effect on the speeds of interactions, and therefore it does have a function. Now, my suggestion would be simply that the genome has to be folded up... the DNA is wound around histones and all the protein machinery that the nucleus has. We know, also, that many genes, particularly in the higher animals, are broken up, into many introns and exons. ... When you look at the way in which the whole thing is folded, and which exon comes close to which other exon, we may be able to start to say why it is that particular splice variants appear, rather than others, or in higher frequency than others. So, I don't think it's too difficult, using the analogy with proteins to give some sort of functionality, particularly in the folding mechanisms that may determine which genes are expressed and to what extent they're expressed. Now, this is just an idea. I don't think anybody can prove this.”

Dawkins, “There are related species of salamander, which have orders of magnitude difference in genome size. Any kind of functional explanation is pretty improbable. It's far more likely [parsimonious] that this is just rubbish that's left lying around on the hard disk, and just hasn't been cleaned off.

Brasier, “So, they're fossilized in effect?”

Dawkins, “Yeah.”

Noble, “These are basically fossils? Our instincts, obviously, disagree, on this.”

Dawkins, “Well, how would you explain the salamanders, then?”

Noble, “I don't work on the salamander, Richard. [Laughter] What I do work on is the fact that the, taking, for example DSCAM [Down Syndrome Cell Adhesion Molecule], one of the genes in the fruit fly, that has something like 35,000 different ways in which its own spread of exons can be expressed. And what we know is that those are expressed at different times during the development of drosophila. So, something is interacting to determine that. Whether it is the “junk DNA,” as we call it, that is helping to form the structure or not, I can't say. I'm only putting an idea out. We have to explain that, though, because it's clear that something else is determining the order in which the expressions are occurring, in addition to what is in the DNA sequence in the exons, themselves. That's, I think, the essential point that I would want to make.”

Dawkins makes the first of many assertions about what is parsimonious and what is not. Related species may exhibit orders of magnitude differences in the size of the total genome. Variation depends on the stage of growth and development, cyclical stages or the condition of the environment. Speculative agreement by Crick and Orgel does not support or negate Noble's functional explanation.

Bell, "Just to agree with you [Noble] that a lot of the DNA probably plays an architectural role.² But we also have to recall that, until recently, we didn't know about the existence of small, non-coding RNAs, that are actually involved in the control of a great number of genes. That was previously thought to be DNA that had no coding function. Now, we know it actually plays pivotal roles in regulation. So, a lot of ["noncoding"] DNA, I think, will have as yet undiscovered roles, the sort of micro RNA type families and genes being one example."

Bell, open to explanation for noncoding DNA, does not dismiss it as "junk".³ William Ashland, a geology student at Oxford, asks, "Professor Brasier, you mentioned following the PT [Permian-Triassic 251.4 mya] and KT [Cretaceous-Tertiary 65.5 mya] extinctions, the gigantism in the Foraminifera. Does anybody know of any possible explanations for that? If so, could we use those explanations to explain the causes of the extinctions? I think in the case of the KT extinction, they're pretty controversial."

Brasier, "Yes, we've done isotope work and it looks like ... some of these foraminifera [-symbioses] lived tens to possibly as much as a hundred years. So, they were probably optimizing their moments in reproduction. That's just what I'm guessing anyway. And probably living fairly low down in the photic zone waiting for the right moment in a way that corals do: they reproduce about once a year or thereabouts. As you know, mass extinctions tend to hit very large things [organisms] with rather slow rates of reproduction and recruitment. So it [K strategy by giant forams] probably explains the sorts of things [extinctions] that are going on. More than that, I wouldn't want to interject, at this point. I'm not sure that it throws too much light on the discussion."

HOMAGE TO DARWIN DEBATE, PART 2

Marker 7 - Lynn Margulis Comments On Part 1

Margulis points out the assumption that underlies Bell's work: Darwin's brilliant insight that all life on Earth has common ancestry. However, the idea that the topology of evolution is a tree, "even Woese's tree," is "very wrong" according to Margulis. Since Bell showed that genetic sequences from viruses

² [Noble] Shapiro's recent book, *Evolution. A view from the 21st century*, brings out some of the functions of the non-protein-coding DNA. Much more of the difference between mouse and human genomes is found in the non-coding regions. Over 2 million transpositions reflect the difference. These observations point to functionality of the highest order; to refer to 'junk DNA' as if this were an explanation inhibits investigation.

³ [Noble] The Encyclopedia of DNA Elements (ENCODE) analysis has revealed that 80% of the human genome serves some purpose, much of what was considered "junk DNA" is involved in a complex network that controls how cells interpret genetic instructions. (Nature, Sept. 2012).

transferred to members of bacterial domains (Crenarchaeal and Euryarchaeal), the assumption of ever-bifurcating branches of the tree of life is erroneous as it omits mergers that show a web or net topology.

Margulis clarifies a point made in Brasier's presentation: natural selection works at the level of community: the heterotrophic foram with its photosynthetic algal symbionts. Different taxa living in the same place at the same time is the definition of *community* (Whitaker 1975). Foram cells include algal symbionts therefore the cell unit has genome contributions from eubacteria (perhaps spirochetes and certainly mitochondria from proteobacteria in both the foram and alga), archaeobacteria and plastids, former cyanobacteria. Single-celled photosynthetic forams are composites, communities and not single *individuals*.

Margulis, "Clearly the unit of selection isn't a single gene or a single genome. I love Richard's metaphor of the 'selfish gene' because it focuses attention on the science behind natural history. But of course, it's just a metaphor because a gene doesn't have a self. A gene is not a self. How can something be selfish when it has no self? The self...is the cell. All cells have self and the self has been forgotten."

Margulis claims that many of the assumptions of evolutionary biology are unwarranted. "The topology that is taught [branching trees] is not right. That the accumulation of random mutations is the way that species change from one species to another has very little evidence for it. That *junk DNA* is just another way of saying 'We don't know what the DNA is doing.' ... The idea that there is *junk DNA* is just not a useful idea. ... You seek the answers."

Margulis takes a contextual or systems approach to life. Two kinds of cells are recognized: bacteria studied in microbiology and the other kind studied in biology classes, protists, animals, plants and fungi. A bacterial cell is the minimal unit of life because it shows all the properties of life all of the time. The later, nucleated cells, evolved from one or more fusions of bacteria and viruses. Archaeobacteria undoubtedly contributed to eukaryotes as Stephen Bell explained. The eubacterial contribution to nucleated cells is evident in oxygen-respiring mitochondriate eukaryotes. The film *Eukaryosis: The origin of Nucleated Cells* shows live organisms that represent every hypothesized ancestral step in symbiogenesis that resulted in the evolution of the earliest nucleated organism.

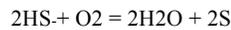
Marker 8 – *Eukaryosis*, the movie

"Eukaryosis" refers to the evolutionary process that resulted in the earliest nucleated cell (eukaryote). Serial Endosymbiosis Theory (SET), the concept named by Taylor (1974) was based on Searcy's argument that *Thermoplasma acidophilum* best represents the extant descendent of the original archaeobacterial ancestor of eukaryotes. The earliest eukaryote originated by symbiogenesis of motile sulfur-oxidizing spirochetes eubacteria with sulfidogenic archaeobacteria (e.g., *Thermoplasma*, *Sulfolobus*).

Stephen Bell disagrees with Margulis's choice of *Thermoplasma* because unlike *Sulfolobus*, Searcy's *T. acidophilum* lacks a typical crenarchaea 16sRNA sequence and ESCRT "machinery". *Thermoplasma acidophilum* is classified as a euryarchaea by some while other studies raise questions about where in Archaeobacteria (Archaea) *Thermoplasmatales* belong (Sapp 2005).

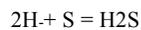
Spirochetes are helically-shaped eubacteria with flagella inside their periplasm, located between their plasma inner membranes and the outer Gram negative membrane. Heterotrophs, they tend to inhabit organic viscous gel-like habitats in which their corkscrew rotation provides efficient penetrating locomotion. Populations of spirochetes synchronize movements when they are crowded and/or attached. In addition to this mechanical sensitivity, they are chemosensitive, attracted to phototrophic bacteria that leak photosynthate. Spirochetes absorb and feed on leaked photosynthate and other exudate. One large spirochete, *Spirosymlakos deltaeberi*, demonstrates phototropism by changing the direction of its movement to stay in the light. Many kinds of spirochetes are also pleomorphic. Their outer membranes swell, the rest of their bodies pull inside to form “round bodies” under conditions unfavorable to growth (Brorson et al 2009). Some round bodies, resistant to unfavorable chemical concentrations and desiccation, remain viable for at least five years.

The spirochete in the original eukaryotic fusion by hypothesis, scrubbed oxygen from its environment by oxidizing HS-ion (H₂S gas), as detected in the extant *Spirochaeta perfilievi*.



Such spirochetes require proximity to a sulfide source (e.g., sulfidogens) These form stable associations called “thiodendron,” described first as a single bacterium with a developmental cycle by Boris Perfiliev (Dubinina 2010).

The archaeobacterial contribution by hypothesis came from an extremophile prokaryote tolerant of high temperature and acidity similar to the extant *Thermoplasma acidophilum* that uses elemental sulfur as a terminal electron acceptor and produces hydrogen sulfide.



Eukaryosis occurred in fluctuating anoxic/microoxic environments beginning to be “contaminated” by oxygen. Atmospheric O₂ is the waste product of oxygenic photosynthesis by cyanobacteria. Toxic O₂ contamination threatened anaerobic life on Earth and selected for the consortium: a sulfur syntrophy formed by a *Spirochaeta perfilievi*-like spirochete and *Thermoplasma*-like archaeobacterium. The metabolic association stabilized the consortium and accelerated its locomotion toward food.

The *karyomastigont* is an organellar system in single-celled protists named by Janicki (1915). It was not understood and therefore ignored (Chapman and Alliegro 2012.) The karyomastigont includes the undulipodium (a generic term that covers the “eukaryotic flagellum” of protists, the sperm tail, oviduct and other cilia), the centriole/kinetosome (“basal body”), and a varying proteinaceous “nuclear connector”. The karyomastigont is a *seme*, a novel morphological, metabolic or behavioral character of evolutionary advantage (Margulis 2007). All semes require a number of interacting genes to be produced and inherited. A seme, once evolved, is retained over generations. Although, it may be altered, it is not lost without a trace. Study reveals clues to its changing form and selective advantage (Margulis 1993).

The karyomastigont of *Caduceia versatilis* rotates thanks to a *shear zone*, a ring of viscous liquid cellular membrane (Tamm 1982). The rotating karyomastigont of *C. versatilis* easily separates as a unit from

the cell (Dolan 2002). The karyomastigont by hypothesis is the evolutionary residuum of the attachment site of the eubacterial ancestral spirochete to the *Thermoplasma*-like archaeobacteria. Another seme is the kinosome-associated DNA of *Chlamydomonas* that is positioned just inside the nuclear membrane (Hall 1984).

Dramatically different in eukaryotes is their ubiquitous intracellular motility based on their microtubular cytoskeleton. The varieties of intracellular motility include eukaryotic membranes that open and close (e.g., phagocytosis, cyclosis, exocytosis, pinocytosis, karyokinesis, mitosis, cytokinesis, meiosis, axonemal transport, among others). Alternate hypotheses to SET for the origins of eukaryosis, fail to explain how, without cytoskeletal-based phagocytosis, prokaryotic ancestors internalized (ate) the prokaryotes that would become mitochondria (the origin of the nucleus in an alternate hypothesis to SET), hydrogenosome and chloroplast ancestors (Dolan 2002).

Margulis introduces her “poster child” for eukaryosis, *Mixotricha paradoxa*, a hypertrophied trichomonad that lives in the anoxic hindgut of an Australian wood-feeding termite. Harvard protozoologist, L.R. Cleveland traveled to the Australian continent when it was reported that *Mixotricha* had both eukaryotic flagella and cilia on its cell. What Cleveland found was that *Mixotricha paradoxa* did have typical undulipodia (“eukaryotic flagella”) of trichomonads, one forward and three trailing. But the hundreds of thousands of shorter beating hairs that emerged from its cortex, responsible for the slow forward swimming, are not cilia at all. Rather they are a type of small spirochete morphologically indistinguishable from *Treponema pallidum*. *Treponema pallidum* is the bacterium associated with the symptoms of syphilis. A second spirochete morphologically similar to *Borrelia burgdorferi*, the spirochete associated with the symptoms of Lyme disease, and a third 25-27 μm long named *Canaleparolina* also are attached to the cortex. In addition to the spirochetes, *Mixotricha* also has at least two other rod-shaped bacteria (“bacilli”), one associated with each *Treponema*-like spirochete at an attachment site and a second type that covers the cell’s posterior protrusion where pieces of wood are phagocytosed. What was published and named a single-celled protozoan turns out to be a community of one protoctist and “hundreds of thousands of bacteria” of at least 5 kinds. The cortex of *Mixotricha* is composed of aligned protrusions: “attachment sites” studded with spirochetes and rod-shaped bacterial symbionts attached by fuzz (Margulis 1993).

In one electron micrograph (EM), a streptomycete bacterium simultaneously conjugates (receives or donates genetic material) with five other *E. coli* rod bacteria. This bacterial “promiscuity” when survival is at stake is one of the reasons that resistance to antibiotics spreads so rapidly among bacteria.

In another termite hindgut protist, *Deltatrichonympha*, undulipodia cover the front half of the body and spirochetes cover the back half. Even in the scanning electron micrograph (SEM), it is difficult to distinguish undulipodia from attached surface spirochetes. Margulis asserts that cytoplasmic tubules originated in spirochetes. A number of EMs of spirochetes with tiny tubules in their cytoplasm are shown.

Tubules emerge from a *cytoplasmic tubules associated center* (CTAC) in one EM. In another, a transmission electronmicrograph (TEM), cytoplasmic tubules connect inside the membrane with the rotary motor of the bacterial flagellum.

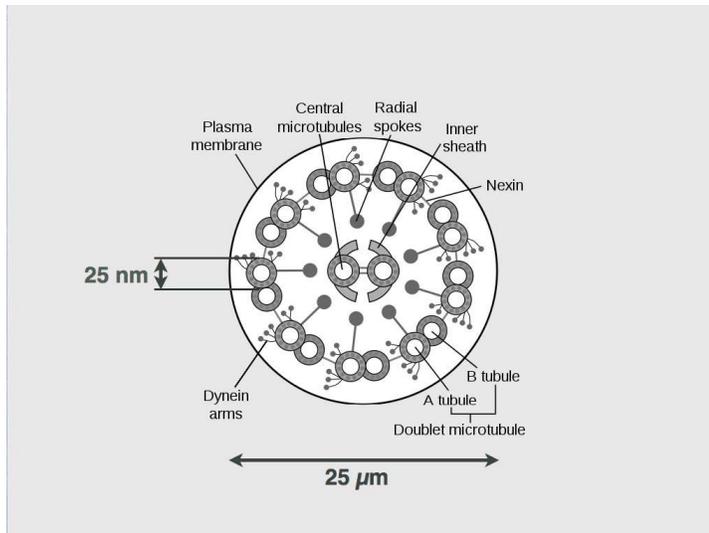


Figure 6. Cross section of undulipodium (cilium) [9(2)+2] organization

Microtubules are present in the undulipodium. Undulipodia (Figure 6) are of uniform size, 25 μm, throughout eukayotes. In cross section, the undulipodia is contains nine sets of doublet tubules in a circular array around one central pair of microtubules [9(2)+2]. The microtubules are uniformly 25 nm. Margulis interprets the uniformity of undulipodia as a seme that traces back to the last eukaryotic common ancestor (LECA).



Figure 7. cross section of kinetosome-centriole [9(3)+0] organization

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Footage of swimming detached sperm tails without their nuclei (DNA), mitochondria or membranes, demonstrates that the swimming motion of the undulipodia is an ability that resides in the [9(2)+2] structure that contain >350 to 1000 different axonemal proteins. When their protein bonds are weakened with a protease enzyme (trypsin), the sets of doubled microtubules show their intrinsic motility, they shoot out of the undulipodia extending their length 9 times.

Mitosis involves microtubules and in single-celled protists, the base of the undulipodia, the *kinetosome* the circular pattern are triplets with no tubules in the center [9(3)+0], becomes a *centriole* [9(3)+0], a *microtubule organizing center* (MTOC) at a pole of the mitotic spindle (Figure 7). A protist, *Acronema sippewissettensis*, in mitotic division substantiates Margulis's point that motility or locomotion (in this case, swimming ability) is forfeited when kinetosomes are employed as mitotic centrioles.

As Margulis sees it, natural selection favored the sulfur syntrophy because it cycled the necessary element sulfur and it also protected the consortium against fluctuating atmospheric oxygen concentrations in anoxic/micro-oxic sulfurous muds. The symbiosis became obligate as increasingly specialized attachment sites evolved into permanence. Eukaryosis, the permanent fusion of a sulfidogenic archaeobacterium and a sulfur-oxidizing spirochete eubacterium evolved as motility proteins: ATPases, cytoplasmic tubules and actin-like microfilaments of the prokaryote were redeployed and generated the intracellular motility of eukaryotic cells (e.g., the ubiquitous cytoskeleton). The conjugation of spirochete and archaeobacterium DNA became irreversible. The genomes combined in the form of a membrane-bounded unit comparable to the nucleoid of *Gemmatata obscuriglobus* (Fuerst and Webb 1991). The organellar system recognized by Janichi's *karyomastigont* (composed of the nucleus, nuclear connector and undulipodium) connected the nuclear genetic, motility apparatus and sulfur-cycling system in the earliest protist, the composite swimming eukaryote (LECA).

Beyond the karyomastigont, the microtubule system evolved into the complex cytoskeleton (the network of microtubules responsible for the intracellular motility) of eukaryotic cells. The cytoskeleton underlies changing shape including the opening and closing of cell membranes (e.g., phagocytosis, fertilization). Unlike heterotrophic bacteria that only absorb small molecules (feed osmotically), the LECA eukaryote ingested particles (bacteria), water, protein molecules, other eukaryotes, etc. for food.

One type of bacteria ingested by LECA, but not digested, was the oxygen-respiring ancestor of mitochondria (theorized to be proteobacteria). These endosymbionts that become mitochondria utilize O₂ and produce energy in the form of adenosine triphosphate (ATP). They provide eukaryotes with the ability to thrive in rising concentrations of oxygen. Oxygen respiration of 1 molecule of glucose produces 36 molecules of ATP in contrast to fermentation, which (depending on the type of fermentation) yields much less, approximately 4 molecules of ATP. This boost in energy use was prerequisite for protoctist-, animal-, fungi- and plant-types of multicellularity. Over time, many of the mitochondrial genes migrated to the nucleus (Margulis 1993).

Margulis follows Darwin's admonition to study the oddities and peculiarities of nature to use clues (semes) to reconstruct evolutionary history. The animation *Eukaryosis* sets the examples from extant oddities and peculiarities into a chronology in deep (geological) time. A more recently acquired symbiogenetic organelle is the *chloroplast*, the photosynthesizing green body in algae, plants, and green animal cells. Chloroplasts as once free living cyanobacteria, in Margulis's estimation, are the "greatest" or "highest" kind of organism on Earth with oxygenic photosynthesis they make their organic bodies with only sunlight, water, CO₂ and salts. Cyanobacteria are *primary producers*: they form the foundation of food chains. With the exception of other autotrophic prokaryotes, all life on Earth depend on cyanobacteria or chloroplasts for energy and food.

The film ends with two amitochondriate eukaryotes, archaeoprotists *Mastigamoeba* sp. and *Dimorpha mutans*. Many claim that the acquisition of mitochondria was the symbiogenetic event that gave rise to the nucleus, and therefore no truly amitochondriate eukaryotes ever existed. Their assumption is that mitosomes, hydrogenosomes, and other intracellular bodies are the remnants of once O₂-respiring mitochondria. In Margulis's scenario, this can not be true as LECA is amitochondriate. Growing evidence, some based on mitochondrial proteins is that eukaryosis must have preceded mitochondrial acquisition (Hall 2011).

Marker 9 - Comments and Questions for Lynn Margulis

Denis Noble asks if Margulis meant "inheritance is not just DNA?"

"Certainly" Margulis replies.

Noble, "In effect, molecular biology has redefined the gene as a piece of DNA"

Margulis adds, "It used to be a 'Mendelian factor'."

Noble asks if the molecular biological definition was useful given what is known of introns, exons and the role of epigenetics in development? He suggests that the term gene be given to the molecular biologists and that a new name be given to what is important in inheritance. Margulis sees no need to abandon "genes as pieces of DNA", but "what is totally crucial is that the minimal unit of life is a cell so it is always a gene in a context of protein synthesis and energy transfer and so on... that is the unit of heredity. The gene is the blueprint, but it's not the building."

Robert Siegel, Associated Professor (teaching) in the Department of Microbiology & Immunology and faculty in the Program in Human Biology at Stanford University, is a visiting faculty in the Stanford-Oxford program. He asks, "I have a couple of fundamental questions. You paint this view that the big organism is in charge and one of the principals of microbiology is that the smaller organism is almost always in charge..."

Margulis objects, "No, I don't speak about 'in charge', or cooperation or competition."

"You said the cell takes up the other one," Siegel responds.

Margulis, "I mean by phagocytosis, a property only found in eukaryotes."

“It’s actually not true,” objected Siegel, “because what happens is that there are microorganisms that actually have the ability to go inside cells and actually force it...”

“But that is not phagocytosis,” Margulis is well aware of bacteria that penetrate and eat other bacteria. “Are you talking about *Bdellovibrio*?”

Siegel, “No. That’s how lots and lots, all viruses have the ability to force the cell to take them up.”

“Viruses aren’t organisms. Let’s start there,” counters Margulis.

“That’s the second point I want to make,” continues Siegel, “viruses are clearly a unit of selection, a much more rapid unit of selection, and in fact, cells take up their genes and pass them back and forth all the time so just in the basic form you can’t actually argue that cells are the basic unit of selection because there are smaller units.”

“I didn’t [say cells are units of selection]. I said communities are,” Margulis corrects Siegel. “I said cells were the basic unit of *life*.”

“That’s a definitional thing,” Siegel complains.

Margulis “It’s all definitional. There is nothing short of a cell that displays all the properties of life. Viruses only show some when they are inside living cells.”

Science is in essence about definitions and distinctions. Let us consider Siegel’s two contentions: viruses are microorganisms; and viruses are *units of natural selection*. An organism, by definition alive, is an autopoietic system. Autopoiesis requires 3 factors: the first is identity; second, is self-making and self-maintaining; and third, is self-bounded. To be autopoietic, entities must have metabolism (appropriate rates of material and energy flow from their environment). Neither viruses nor genes are autopoietic. By themselves, they are lifeless, unable to self-maintain, metabolize, grow, or transduce energy. By themselves, they are not self-bounded, cannot reproduce, evolve or be selected. Viruses and genes require a cell’s system.

The second comment comes from Jacob O’Neil. “It seems like an alternate explanation for the shared nine microtubules $[9(2)+2]$ in the pairs of those is that it evolved beforehand and then was passed to the spirochete and then to the sperm.”

Margulis, “The evidence is the other way: that the single tubules are present from much smaller to some standard size in spirochetes, but the nine-plus-two organization is only found, as far as I know, in eukaryotic cells and probably it coevolved with eukaryotes... If we had a nine-plus-two spirochete then we could argue the other way.”

Margulis points out that the $[9(2)+2]$ organization of 25 μm microtubules in undulipodia (sperm tails, cilia, etc. see pages 72-73) of eukaryotes is homologous. The pattern originated in an early common eukaryotic ancestor (i.e., LECA).

The next comment comes from Chas Salmen, a student of medical anthropology. “When we start to look at the relationships between these organisms that develop, the suggestion that [Noble] made was that inheritance may not be at the level of DNA. [Margulis] gave the analogy of the gene being the blueprint and

the organism being the building. Doesn't the notion of symbiogenesis suggest that the blueprint is in the relationship between these two organisms and the level of inheritance is this relationship that's passed on and not the composite genes, or composite pieces of DNA, and what we might redefine as the gene is that relationship?"

Salmen's suggestion of "relationship" is another way of saying context. Genes require the context of a cell, or in the case of symbiogenesis, require the context of two or more types of integrated cells (organisms). The need for the context of a cell is also true of viral genes or any small replicon.

Margulis, "Genes by themselves can be flushed down the toilet with no struggle. That is, they have no self, for in order to show the properties of life—and we can talk about what those are, but they are always materials and energy flow—you have to have more than the gene. You have to have the system that the gene expresses itself in... and in my view that is a cell minimally. It's also something much larger than a cell often."

Margulis states that she disagrees with the ideas of evolution she was taught. "Evolution was 'entities that replicate, mutate and replicate their mutations'." Evolution is much more than evolutionary biologists teach because the biota respond reciprocally to the incessantly changing environments. Earth is a system and life exists only in the context of the biosphere. It's the definition that's the problem. The unit that shows absolutely every aspect of life is an autopoietic one, which means it has a boundary. That boundary is at least a lipoprotein membrane, sometimes it's more. That body can maintain itself always with energy flow. The energy is chemical or light. It's also by itself able to build up matter. It's not programmed from the outside at all. It's from the inside that these properties, this autopoiesis exists... Of course, it also has to be in an environment that permits this... The minimal autopoietic entity is a bacterial cell. Most of the diversity of life is in the bacteria to begin with, bacteria *sensu lato* ... I would say the unit of heredity is that [a bacterial cell] and whether you call it a gene or a cell can be discussed, but at least, we should be talking about the same thing."

Marker 10 General Discussion

Dawkins comments, "I think we are getting quite unnecessarily confused here. The cell is the minimal unit of living function. Of course it is. But that is not the unit of heredity."⁴

Dawkins, a reductionist, sees genes at the top of a hierarchy called "heredity", without genes there is no heredity. Margulis looks at genes as inextricable parts of a biological system (minimally, the cell) where

⁴ [Noble] I say that the cell IS most certainly the unit. Living beings cannot survive by inheritance of genes alone. Moreover, the neo-darwinist view of genes as 'genes for' this and that, brings the cell (and organism) back in by defining genes in terms of the phenotype. This is linguistic confusion that pretends that "gene inferred by phenotype" means the same as the "gene" the molecule: the molecular biologist's "gene as a DNA sequence". These are two very different definitions of "gene" and the differences are critical to answering questions like 'what do genes do?'. As surrogates of phenotypes *genes* are defined to be the cause of the phenotype. As stretches of DNA *genes* may or may not contribute to the phenotype. The distinction becomes an empirical question: the empirical fact is that many gene "knock-out genes" (KOs) make no phenotypic change. See my article on 'Genes and Causation' (Noble D. 2008. Genes and Causation. *Philosophical Transactions of the Royal Society A* **366**, 3001-3015).

all components are required for the emergent properties of life through time. Margulis is aware that inheritance other than DNA or RNA (genes) has been demonstrated.

Dawkins, "The unit of heredity is DNA, or RNA under some circumstances."

"That's what I'm not sure about." Noble's comment gets a laugh from the audience. "If I were to want to send life to one of those Goldilock's planets that the astronomers think they've found. The information they would need to reconstruct life here on Earth, it would obviously make no sense for me to put on a CD the whole of the human genome."

Dawkins, "That's right."

Noble, "That's obvious. I'd have to send the whole of, at least, a fertilized egg cell information on that CD for them to even begin. Let's forget about the complexity. You need a womb and all the rest of it." Noble changes tack, "Part of our difficulties here is what do we mean by *heredity* because what that means to me is that we inherit the whole fertilized egg cell. We inherit more because we inherit the maternal and paternal influences on that egg cell as it develops. So is this a matter of defining what we mean by *inheritance* and ... are we prescribing that 'it shall only be DNA?'"

Dawkins, "When you send your seed life to that Goldilocks planet, you'll have to send the information, the DNA, plus the water and all the other things that are necessary."

Nobel, "That's right."

Dawkins, "Now the key point that makes the difference between hereditary substance code and all the other stuff is this: If you mutate the non-hereditary part, for example, if you make some kind of manipulation to the cell, not the hereditary part, but the cell, that will not be transmitted to the next generation. If you mutate the DNA part, it will ... If you cut a cell or make a blemish in it in some way, a blemish in an organism, it will not be passed on to future generations. If you make a blemish in the DNA, it will. That is the key point, certainly from a [neo-] Darwinian point-of-view, that is an absolutely water-tight operational definition of the distinction between the true hereditary part of the entire enterprise. The entire enterprise you need to send to the planet, that's not in doubt. You need the entire shooting match, but if you change a bit of it, and the change is inherited, that's heredity."

One obvious leak in Dawkins "water-tight *operational* definition" of heredity is that if you make a mutation to DNA, that "blemish" in all likelihood will not be inherited. Single gene mutations overwhelmingly result in no heritable change as Professor Jonathan Bard pointed out (see page 65). A second *operational* leak is that, as Dawkins himself states, "you need the entire shooting match," that is, the organism in a suitable environment.

Noble points out that implanting the nucleus of one species in an egg cell from another species will only develop so far before failing. "There are extremely few cases of cross species cloning that lead to a living organism. What that tells me is that the genetic "program" --if we can use that metaphor--lies as much in the cell as in the genome."

DNA is often compared to software, a digital computer application. Noble in his book, *The Music of Life*, suggests that the most apt analogy is to a database. This, in essence, is Dawkins reductionist view, and there is no doubt that data is encoded in genes. The systems approach, or contextual view, that Noble and Margulis advocate recognizes that a computer database requires at least computer hardware, firmware, software and the flow of electrons to function. Data is important, but no more important than the many other components of the computer system if some form of function is to emerge.

“To the question of whether cellular inheritance can occur, and whether inheritance over and above the transmission of DNA can occur,” continues Noble, “I think the development of epigenetics has thrown a cart and horses through that.”

Epigenetics is the study of inherited features, processes, functions or gene expression that do not involve changes in the genome. An example of epigenetics is the process of mammalian cell differentiation where a specific function or tissue type changes with time but the cells’ nuclear DNA remains constant. Many phenotypic changes result from response to the internal or external environment during embryo, postpartum growth and development (Blumberg 2010).

Dawkins, “[Epigenetics] is coming close to a difficult, borderline case. The reason that it doesn’t drive a coach and horses through [my definition of heredity] is the epigenetic pseudo-inheritance dies away after 3 or 4 generations.”

“Well that’s what we’re not sure about. Who’s proven that?” asks Noble.

Dawkins, “If it doesn’t. If it goes on forever than it’s a fully paid up, pukka [*English slang for the genuine article*] form of genetics.”

“But then we have to redefine what we mean by gene because it’s clearly not then the sequence of DNA is it?” asks Noble.

“Yes we do,” Dawkins agrees, “The key question is ‘Does it go on forever or does it fade away?’”

Noble, “Yes, that’s the question that I think is an empirical question open to discovery.”⁵

Next is a question from the audience, Alexis Gallagher asks if there is a definition of *unit of selection* on which the presenters can agree? Brasier and Bell decline. Margulis says it is a profound question. Everyone agrees that the minimal autopoietic unit is the cell. Margulis returns to Noble’s statement

⁵ [Noble] This is a key question, very different from different perspectives, as both Dawkins and I recognize, Dawkins suggests that if the inherited effect dies away after a few generations then it is not a factor in evolution. I suggest that how “the inherited epigenetic change is produced” is crucial. If it is produced in response to a serious environmental challenge then there is no reason why selection should not act on it immediately and favor those with the change. If a substantial proportion of the population is affected (by contrast with the lone possessor of a new mutation) and if the environmental pressure is great enough, there is no reason why, in a Waddingtonian fashion, the change could not become assimilated and inherited in subsequent generations. Once the Weismann barrier is broken, and any environmentally influenced new trait is inherited, the possibilities are open. Weismann’s barrier is one of the dogmas I believe needs revisiting. The barrier has been broken: Some epigenetic effects are transmitted through germ-lines (i.e., sperm and egg).

about the failure of animals to hybridize [cross species clones] in order to mention the example of *Geosiphon pyriforme*, an organism formed by a fertilization-like event between members of two kingdoms! “They aren’t animals!” Margulis chuckles because she is aware that the kingdom Animalia is much more limited in every way than the older, extremely diverse kingdom Protocista. Extrapolating to all of life from a zoological (basically an anthropocentric, medical) frame of reference distorts conclusions.

Margulis, “It is clear that the identity is given by the naturalists, a name and that one is *Geosiphon [pyriforme]*... That’s identity and what is heredity? It’s the inheritance of that entity in nature. To me, it has to be in nature. Is that an individual? It is certainly not a virus. It’s cellular. I would say that when you have this identity and you have these parents produce a living organism, you have a heritable system and its going to last as long as that identity persists. But that’s *group selection!*”

Margulis returns to use Brasier’s large symbiotic forams to emphasize that they too are selected as groups. “It’s a group, in the sense that they are cells from different origins. The unit that is persisting, that has identity, persists, has offspring, has a heritable unit and it’s a minimal heritable unit, it’s a lot more than a piece of DNA.”

Dawkins responds, “There are two different meanings of the phrase unit of selection: *replicator* and *vehicle*. *Replicator* is that which persist through time and that is DNA or RNA or something like it, that is to say, coded information that is copied exactly subject to occasional mutation just like computer data is copied, just like Xeroxing is copied. The *vehicle* is quite different. The *vehicle* might be a cell. It might be an individual. It is the unit that we observe in nature--to survive or not survive, to reproduce or not reproduce... The long-term evolutionary consequence is the differential survival of *replicators*, DNA mostly, which exist inside those *vehicles*. You can talk about natural selection at either of those two levels. You can even talk about group selection, if you must [draws chuckles from the audience], in which case the group you are talking about will be a *vehicle*: it will be some kind of joint unity of *vehicles* or bodies or something like that which has some kind of coherence to it. I don’t think it is helpful to talk about group selection. But I do think it is helpful to make the distinction between *replicator* selection, which is something very, very precise. It’s the differential survival of alternative pieces of coded information, and *vehicle* selection, which means different things to botanists and zoologists—and it’s a mess, but there are times when you do need to talk about it.”⁶

Dawkins proposes two distinct meanings for unit of selection, however his two distinctions lack an evolutionary difference. Replicators (DNA/RNA) are precise and last through many generations. The suggestion here is that replicators remain unchanged while vehicles lack “potential immortality.” Evolution

⁶ [Noble]This seems to me to have missed the point about cross-species clones, both interspecific fused cells in culture and transplanted eggs. Overwhelmingly, they don't form adults. Products of fusion, they don't survive. The cell therefore does evolve. Not all the differences between species lie in the genome. Moreover the only clear case of a cross-species clone that survives (the goldfish-carp cross) known to me shows that cytoplasmic effects THAT DETERMINE THE PHENOTYPE are inherited. (Sun YH, Chen SP, Wang YP, Hu W & Zhu ZY (2005). Cytoplasmic impact on cross-genus cloned fish derived from transgenic common carp (*Cyprinus carpio*) nuclei and goldfish (*Carassius auratus*) enucleated eggs. Biol Reprod 72, 510–515.). Yes, it’s a mess. It is not “very, very precise.”

is about change through time. If replicators control phenotype and are impervious and immortal, it would follow that there would be no variation (novelty) within populations. Natural selection would still work. Survival might be reduced to the pure chance that a lucky vehicle (and its replicator) happen to occupy a better place at the opportune time relative to climate and the necessities of life. The unlucky vehicles (and their replicators) would perish. Extinction would be possible, but not necessarily inevitable.

According to neo-Dawinism, differences in phenotype result from mutations to the genome. Therefore, evolution requires variation (novelty) that is only possible in mutated genes. Genes that have mutated have failed to “last forever” (remain unchanged). There is then only one evolutionarily functional difference between replicators and vehicles: vehicles can reproduce, replicate and evolve; replicators without a vehicle cannot. Dawkins makes a distinction, but only the vehicle, of the two units of selection he proposes, is capable of evolving.

“To Richard’s point, it brings up an interesting point,” observes Bell, “Any given gene on a chromosome, you tend to view it as a sequence in isolation, that’s a gene and a heritable unit, but of course that gene in isolation is nothing without the ability of that DNA to be replicated and, in many cases, the sequences that define the replication and duplication can be a considerable distance away from that particular gene. So then, we have this duality or bifurcation of the definition because we have to have the sequences that govern the replication of that gene. So, is that the actual unit would you [Dawkins] say?”

“From a field point-of-view, it would be that which makes the difference between individuals,” Dawkins replies and offers no more.

What is this “field point-of-view” to which he refers? Earlier in the debate, Dawkins referred to research biologists who study animals in nature (see page 6). Dawkins does not claim to be a field biologist. I question if he speaks with authority about questions to which biologists seek answers. If his question is “What is in it for the gene?” Can it be answered?

“Now, if I understand what you’ve been saying,” Noble addresses Bell and Margulis, “Cells must have developed early on. So early on, there had to be cellular inheritance, right? So far, so good. Why should that have disappeared, or to put it in Richard’s terminology, aren’t cells very good replicators right from the beginning?”

Noble points out that through his germ line he is related all the way back to the original cells. “So in one sense, cells are also immortal replicators.”

Bell answers, “I think we would have to view LUCA as without a doubt as a cellular organism and we are the descendants of that cellular organism. Although the continuity, if you like, is the DNA sequence. All our components have been changed and renewed. Where I take issue with some of Lynn’s suggestions are in the nature of the fusion event that gave rise to eukaryotes. We had there the example of *Thermoplasma* think you use. That is probably the wrong Archeon to pick. I mentioned in my talk the Crenarchaea and the Euryarchaea, the two lineages, *Thermoplasma* is a Euryarchaea that lacks all of these

features that Crenarchaea have that are clearly eukaryote-like in nature. I would suggest that—although the fusion idea I would agree with totally—your choice of partner is possibly wrong.”

Margulis, “And the sulfur, hot temperature?”

Bell, “Yeah.”

Margulis, “You’d say we don’t have [the correct partner] yet?”

Bell answers, “There are plenty of hyperthermic Crenarchaea that are sulfur utilizing, so you can use one of those instead and then you would have the multiple origins [of replication], ESCRT machinery, then you would have “replication licensing”, all the various components that are eukaryotic-like.”

Bell’s research has concentrated on *Sulfolobus*, Crenarchaea where these eukaryotic-like features were discovered. Dennis Searcy, Margulis’s colleague at the University of Massachusetts Amherst, who proposes *Thermoplasma* as the extant descendant of the original partner, does so because of these attributes not necessarily found in one strain of *Sulfolobus*.

1. Histone-like proteins that protect DNA from acid hydrolysis (high temperature in acidic solution is how DNA is broken down into its nucleotide base-pair components).
2. Viscometry measurements that indicate that *Thermoplasma acidophila* has a rudimentary "cytoskeleton" and slow motility based on actin-like protein.
3. *Thermoplasma acidophila* is microaerophilic: it uses oxygen (in the presence of minute-5% oxygen) as terminal electron acceptor in an environment where O₂respiring mitochondrion ancestors could co-exist. Only under complete anoxic conditions must it cling to elemental sulfur globules and use sulfur as its terminal electron acceptor to produce H₂S.
4. *T. acidophila* is pleiomorphic: it takes on different shapes unimpeded by the typical rigid bacterial cell wall.
5. *T. acidophila* is an archaebacterium based on RNA polymerase and other enzymes involved in "informational" (nucleic acid replication) rather than "operational" (metabolic) pathways. Margulis adds the sulfidogenic metabolism of *T. acidophila* to Searcy’s list. He thinks the fusion of *T. acidophila* and the protomitochondrion suffice to explain the origin of the cytoskeleton and motility in eukaryotes.

Eric Werner comes from a background in computer science, specifically multi-agent systems (MAS). MAS use numbers of autonomous interacting intelligent agents working in parallel to solve problems that defy an individual approach. An intelligent agent can be a person, but is more often a form of artificial intelligence (AI), such as a functional, procedural, methodic or algorithmic search, sort, find or process routine. Multi-agents are used to model or simulate various scenarios, such as very simplified in silico models of evolution. The following comment by Werner is abridged here and in the edited Homage to Darwin DVD.

Eric Werner, “There is evidence, first of all, that you can do modifications to cells—there have been papers I think where you modify a cell—it will inherit that independent of the genome. So in effect, the cell

in that sense is also a replicator. The key thing is about the interactions, since the cell is in effect an interpreter of the genome, that means that if you modify [the cell] in a particular way, then you get a radically different interpretation of the genome, which results in a totally different phenotype. So, you could have inheritance by slow modification of the interpreting “mechanism”, the cell, as well, right? So, you can have evolution-by-way-of-interpretation.”

Noble requests that each participant give her or his concluding remarks for the formal session [Parts 1 & 2 of the DVD].

Martin Brasier, “I’d just like to say that geologists look fondly on biology as one of their more successful products through Darwin. [Laughter] We’re learning in geology, after decades of reductionist thinking, that where we have to look for things like mass extinctions with a big bolide or some single driving “mechanism”, we have to think in a systems way. Everything is a matter of connections of various sorts, so this connectedness is what I’ve tried to just hint at in this work we’re doing. It also shows that the fossil record is a test bed for ideas of how symbiosis and symbiogenesis could work. It’s not just a theoretical concept. There is something we can turn to.”

Bell concludes, “I think we’ve certainly seen the theme of symbiosis and the way in which the fusion of cellular organisms has undoubtedly led to the development of more complex lineages. Where we should think more about is the issue of viruses. That maybe we should not view as living, but ‘conditionally living’ within the host, not just as ‘parasites’, but as forces that are shaping content, ‘mechanism’ and the overall complexity of genomes.”

“I want to say that a cell is not a replicator,” Dawkins begins. “A cell is a reproducer, just as an organism is a reproducer. An asexual [uniparental] organism such as an aphid or a female stick insect appears to be a replicator because it appears to give rise by parthenogenesis to an identical daughter—and indeed, it does. It is not, however, a replicator for the very reason I was mentioning to Denis before. If you cut off the leg of an aphid and the aphid then reproduces, as you know, the daughter will not have a missing leg. If you cut off the equivalent of the leg of the germ line DNA of the aphid, then it will have a change. That is absolutely a straightforward operational definition.”⁷

All Dawkins’s examples are animals. These are the organisms he knows best as he stated earlier (see page 4). Evolutionary biology grew out of zoology, but that presents a conundrum: it reverses the chronology of evolution. Animals are late arrivals in evolution. They appear in the final one-sixth of evolutionary time. The fossil record of organisms with hard parts, mostly animals, begins with the “Cambrian explosion” 542 million years ago. For many decades, the fossil record was believed to be the

⁷ [Noble] The problem I see with the cut-off leg example is that this does not answer the question, which is whether CELLS are replicators. Cells replicated themselves even before they acquired DNA. Furthermore, the accuracy of DNA replication, without which ‘immortality’ would be a pipe-dream, is a cell property. The accuracy of DNA replication depends on a whole army of proteins organized as a SYSTEM that responds to physiological, behavior and environmental signals to correct mistakes. I may be alone in this, but I find the distinction between replication and reproduction hard to define. Not surprising; they are synonyms. I prefer to define the difference between DNA inheritance and non-DNA inheritance in terms of whether the representation is digital or analog. The paramecium example is inheritance of analog information (the structure itself) but it is just as good at replicating itself.

entire record of life on Earth. Most recently evolved members of the Animal Kingdom tend to be the most constrained metabolically, chemically, energetically, genetically, and their mode of reproduction (egg fertilized by sperm) arbitrarily requires biparental sex either directly or by modification.

Far older and with more diverse members is the kingdom Protoctista that evolved 1800 million years ago. However, the most varied metabolically, chemically, and energetically are the prokaryotes (eubacteria and archaeobacteria) that have existed in something like their current forms for 3500 million years. Modeling the process of evolution on the earliest and most diverse life forms and then taking note of limitations and innovations that have resulted from natural selection in chronological order is the logical, but not the historical approach.

Dawkins continues, "[Eric Werner] was saying that there are examples where you can alter a cell in a non-DNA kind of way and that will be inherited. I don't know what you're thinking of there. One example you might have meant is Sonneborn's *Paramecium* where you cut a bit of the pellicle [ciliate cortex] and twist it 'round. Well, if that's true, and is indeed a non-DNA form of heredity, that's absolutely fine. I would embrace that gladly as a new "honorary" gene. That's fine. [Groans from the audience] Why not, why not?"⁸

Margulis, "No. I have to answer that because we know what that is."

Dawkins, "Well, good. I'm delighted to hear that."

Margulis, "Yeah [Chuckles]."

Dawkins, "But even if we didn't know, if you could find a piece of genuine heredity which is non-DNA-based—and by genuine heredity, I mean once that the mutation has happened it potentially goes on forever. Of course it may not go on forever because it may be disadvantageous, but nevertheless, if it has this quality that it doesn't fade away over generations, that's the key point. That's the key point that DNA has, cells do not have. DNA does have, organisms don't have.... I'm not wedded to DNA, I am wedded to this operational criterion that alterations in it go on forever potentially.⁹ The reason that matters is that the ones that don't go on forever are the ones that are selected against. But in order for that to be evolutionarily interesting there's got to be a difference between the ones that do go on forever and the ones that don't. That's got to be heredity in the broad sense. DNA may not be the only kind of heredity, but its got to be something that is truly inherited in that sense."

⁸ [Noble] The groans surely indicate something slippery here. I'd call it 'having it both ways'. The whole point of the discussion is whether inheritance is determined by genes alone as Dawkins implies. Sure, we can go on redefining 'gene' until we have exhausted all the possibilities. But a statement that says everything also says nothing.

⁹ [Noble] Cells do not fade away over generations. They persist, maintain, reproduce and evolve; even tiny bacterial cells in nature tend to have several thousand genes. All are far more than a sequence of nucleotides in DNA. The cell, the minimal unit of reproduction to me is the minimal unit of heredity as well.

Noble asks, "That would be an empirical question, wouldn't it?"

Dawkins, "That would be an empirical question and if somebody discovers a new kind of heredity, I'd be delighted."

Noble, "One obvious conclusion here is that the field of epigenetics has to look very carefully at these possibilities."

Dawkins, "To see if it fades away."

Noble, "That's right, exactly"

Let us consider a thought experiment: a world without any gene mutation. Would natural selection still occur? Biotic potential would still produce more offspring than could be supported by any environment. Excess offspring whose continuity (survival and reproduction) is limited by environmental constraints on population growth (what Darwin called "checks") would still exist. Natural selection by definition, the differential survival of over-abundant offspring, does not require mutations in DNA.

Identical human twins have identical genes. However, as identical twins grow and develop, they become measurably different. Such identical live "cloned" complex dynamic systems (in this case human monozygotic twins) are exquisitely sensitive to initial conditions and myriad relationships. In this case, I refer to physiological, developmental and social internal conditions in the supportive habitat and, in general environmental conditions through the entire life history of the person. Identical genes, in twins or any other clones do not generate identical phenotypes.

If heredity were governed strictly by genes, survival and evolutionary "fitness" (success in reproduction) would depend on geographical location, contingency, compatibility within the community or learned behaviors useful for survival. Groups of organisms would still live in communities. Ecological relationships among community members would strongly affect survival. Prototaxis would occur among organisms. Depending on selection pressures (e.g., food and water needs, protection, desiccation resistance and utilization of light wavelengths, etc.) members of different taxa would tend to form successful symbioses. Physical associations that eventually lead to the acquisition of a foreign metabolism and genome begin and are sustained by specific selective advantages. Symbioses are documented to lead to symbiogenesis, a succession of changes from behavioral to metabolic to gene product to genetic. Genetic change would be in the form of *semes*, sets of genes that underlie a function, structure or characteristic recognized by evolutionists, rather than individual point mutations in DNA. Semes (e.g., photosynthesis, oxygen respiration, feathers, eyes, swim bladders, lungs, amniotic eggs, flowers, seeds, etc.) are inherited.

Margulis does not say gene mutation plays no part in evolution, however, she contends that symbiogenesis is more important in the generation of novelty because semes are by definition genetic determinants of traits or characteristics of clear selective advantage (i.e., they are functional). Our thought experiment shows Darwin-Wallace natural selection is inevitable and that genetic inheritance is in the form of semes rather than point mutations in DNA. I argue that given the very long odds against the accumulation of beneficial random point mutations and problems, such as Muller's ratchet, seme acquisition, in the world

as we know it, is the more parsimonious explanation of the limited sets of genes and gene products observed in living beings.

DNA and cells do, in fact, share the *potential* to go on forever, however, DNA polymers by themselves do not function; they cannot perpetuate alone in nature.

Contrary to what Dawkins states, the potential of DNA to “go on forever” only holds true for DNA within cells. Noble is the product, as are we all, of an unbroken lineage of live cells each with its complement of intact dynamically produced and repairable DNA that trace our ancestry back to Last Universal Common Ancestor (LUCA). The *Homage to Darwin* debate accentuates a genuine, not rhetorical, difference, which is not between cells and DNA, but between two *denkencollectifs* (schools of thought, belief systems): the Neodarwinist-exclusivist (hierarchical/reductionist) one for which Dawkins is the famous spokesman, and an inclusive contextual alternative. The second view, evolutionist and far more empirically demonstrable, holoarchitectural/contextual is represented by Noble, the other speakers and many in the audience.

Lynn Margulis concludes the formal debate. “Let me just answer one thing about the *Paramecium* experiment which is what got me into this to begin with. You saw the *Mixotricha* and you saw the organisms making up the cortex and that’s what they call it, the cilia cortex... Janine Beisson, who did the experiment, Beisson and Sonneborn. What they did was they took a piece of cortex, that really was grafted in the opposite direction and it [the reversed fragment of the cortex] lasted [was reproduced in the reversed position] for two years at a [uniparental] reproductive rate of one cell per day, so it [the genetic change] was indefinite. They never got a different result.”

Here is an example of an induced-by-the-investigators inheritance. It is an indisputable Lemarkian inherited “acquired characteristic.” Margulis says the way to think about the inheritance of the reversed patch of ciliate cortex is that the former “bacterial community” (comparable to the motility symbiosis of spirochetes and bacilli that comprise the *Mixotricha paradoxa* cortex) has been surgically inverted. Here is inheritance that is not so much the “DNA of an organism” as it is the physically associated DNA, RNA, protein synthetic-coupled activities, the pattern of a reversed-position “microbial community” within the context of its system.

HOMAGE TO DARWIN DEBATE, Part 3 (mp3 audio CD)

The final open discussion starts with Martin Brasier who expands on his remarks about the role of connectedness, how specialization increases the vulnerability of communities to collapse, and what the cycles of extinctions in foraminifera through geologic time suggest.

Brasier, “This is the parable I tell and it’s a little story of a happy couple called Albert and Emily who are in their 40s or whatever, and they live in a little block of flats. And Albert’s taken to smoking cigars and Emily gets tired of him smoking cigars in bed and asking him to go out on the balcony to smoke his cigar. And eventually she gets tired even of this because it stinks the flat out and she gives him a little push. A very slight push. He’s on the edge of the balcony. Over he goes and he falls down into the flowerbed. It stubs his cigar out but Albert gets up and climbs back up because they’re on the first floor. But she repeats

exactly the same operation after she's had them relocated to the 12th floor. She pushes with exactly the same force, but because of the energy built up in the system of course his fall is fatal not only to the cigar but to him. So you have to ask the question there what caused the push? And my point there is it's not the meteorite, it's the nature of the system that the meteorite or anything else perturbed. And what we're showing with this forum work is often systems which experience mass extinctions seem to have tuned themselves right to the edge of efficiency so they've got enormously large, very complicated structures, protozoans [protocists] and other things. And they are of course set up for the kill in some kind of a way. The answer to that then is that mass extinctions are caused by what happened in the 5 or 10 million years beforehand. It's a little bit like the economic situation we find ourselves in now [the financial crisis of 2007–2010]. We're in a fix now because we've had 10 golden years. That's the worst possible thing that could really happen to an economy because its fitness must be constantly tested in order to prepare it for big and small ups and downs. Lots and lots of little shakes and re-tunings [are] a really good thing for an ecosystem. Stability tends to push it more and more towards one particular kind of r/K strategy or whatever you'd like to call it at the very edge of its peak and then of course the thing will collapse.”

In r/K selection theory, **r** represents generally smaller organisms, quantity of offspring and rapid reproduction in unstable environments; **K** strategy organisms are larger, emphasize quality: fewer offspring and less frequent reproduction in stable environments. The answer to that is that mass extinctions then require us to look at the connections within a system and understand those connections and the degree, the way in which they feed through the system.

Brasier continues, “And if that matters [how stable environments affect organisms], if connections are important to extinction, and presumably connections are important to speciation and specialization too because you could argue that mass extinctions and speciation are part of the process, part of a systems process, which we ought to see in this bigger way.

Dawkins responds, “Well I suppose mass extinctions are very likely selective, but a very different kind of selection from the ordinary selection that goes on between mass extinctions. So a mass extinction is more like a one-off [occurring once and not repeated] event. In the Permian extinction, most of the brachiopods went extinct and mollusks didn't ...but it's a totally different kind of selective event from the one that produces individual level adaptations within brachiopods or within mollusks.”

Brasier: “Well, there is an argument slightly against that which is the parallel pattern of distribution of extinctions, which suggests that mass extinctions are part of a parallel spread so that there is a sort of continuum from small extinctions through medium to very large. Which to me suggests that the nature of the causes as with the explanations for avalanches, big ones and small ones are not caused by different things. So it does raise the possibility then that we don't have to look outside the system. What I'm arguing is we need to look inside the system and start to analyze system structure and to extrapolate that back through time.” [4:17]

Brasier hypothesizes that extinctions result from specialization often in communities that live in habitats that have remained stable over millions of years. Organisms complexify (e.g., grow large, lines of communication are streamlined and shortened, etc.) and in so doing a lethal fragility develops that may not survive even modest changes to their environmental. Like an avalanche, the potential energy is present. It may be triggered by a metaphorical pebble (e.g., volcanism, climate change, an anoxic event), rather than a huge boulder (a large meteorite impact).

Jonathan Antcliff, Departmental Staff Lecturer in Evolution and Paleobiology, Department of Earth Sciences, University of Oxford, points out that of the 20 largest craters on earth, only the Chixulub crater is known to come within a million years of an extinction event, the 65-million year old Cretaceous–Paleogene (K–Pg) extinction boundary (formerly called the K-T, Cretaceous-Tertiary). The fact that extinctions occur without sizeable triggers, such as a large external bolide impact or Deccan Traps-sized volcanic eruption, suggests that the cause may be within the system that collapses.

Brasier adds, “I often ask geologists what would have happened if a 10 or even 15 kilometer meteorite had appeared 2 to 5 million years after the Cretaceous–Tertiary boundary, would there have been a mass extinction? Most will say probably not. That sort of emphasizes the fact that the size of the meteorite may not be that relevant. What we’re arguing ... is the size of the foraminifera is telling you something about the way the systems are connected at that time. It’s really rather vulnerable. You could have hit it with something quite small ... It’s actually bringing the whole thing back into biology ... we’ve got to understand the nature of connections and model them and try to find how we get that out of the record in deep time.” [5:33]

An unidentified audience member asks, “Mass extinctions do raise the problem of how you define success in evolution. These organisms obviously have been fantastically successful, but only for a period in some cases 2 and 3 million years or 20 million years. Then they’ve been completely wiped out. Is that success or failure?”[6:20]

Brasier agrees, “It obviously shows that “success” is not a word that a biologist would normally use ... I’ve been trying to convince Lynn that actually getting towards true symbiogenesis in which organelles come together is quite a difficult thing and that symbioses clearly gets smashed apart within the scales of tens of millions of years and it might take a lot more than that actually to drive a whole series of organisms together to create new kinds of organisms. That may not be an easy thing to do. ... It might take a 100 million years or more. Sorts of periods we worry about in geology, but you biologists don’t have to think about too much.”

Margulis, an “evolutionist” who refuses to call herself an “evolutionary biologist”, defines symbioses as ecological phenomena that generally occur over short time periods. Symbiogenesis, by contrast, is an evolutionary process that happens at geological time scales. One case of symbiogenesis was documented to occur in a laboratory experiment in only five years. Kwang Jeon, a cell biologist at the University of Tennessee in the 1960s and 1970s used large free-living amoebae, *Amoeba discoides*, as

model cells that divide to reproduce once per day to study biological phenomena. Jeon investigated and published on cell motility, nucleocytoplasmic interactions and membrane function for years. When he acquired a new batch of amoeba from a colleague, his own amoebae became ill and began dying. His electron micrographs showed populations of 150,000 unidentified Gram-negative rod bacteria, he designated “x-bacteria,” inside each sick amoeba. Most infected amoebae reproduce more and more slowly and died. Some that still harbored x-bacteria survived albeit with slower rates of reproduction. After 5 years, the carefully tended, still infected survivors (now with 43,000 x-bacteria inside) returned to health. Their reproduction rates had returned to once per day. Jeon showed that the nucleus of an infected amoeba would not survive when surgically transplanted into the cytoplasm of the naïve *Amoeba discoides*, but would regain healthy functioning if the amoeba was inoculated with the x-bacteria (Margulis 1993). This result also confirmed use of the antibiotic chloramphenicol. Amoebae treated the antibiotic would survive if their population of x-bacteria was reduced by 90%. If the x-bacteria were eliminated with the antibiotic, the amoebae would die. Jeon had demonstrated that symbiogenetic bacterial acquisition in amoebae can happen naturally over a span of five years in modern cells (Jeon and Hah 1977).

Eric Werner (see page 22), “I’m in the multi-agent area ... and one of the simulations that was quite impressive was assembly language programs that had this cycle of mass extinctions simply because of the social inter-connections of the programs and ... if we resurrect some of these things [agents], it might be very successful later again. So I mean you do have this cyclic social behavior because one little element changes, it [one agent] then gains a tremendous advantage and kills off all the other ones [agents].”

Daisyworld, the computer simulation created by James Lovelock and Andrew Watson demonstrated that a biosphere could self-organize the regulation of planetary temperature over geological time despite increasing solar insolation. Daisyworld is an example of a multi-agent system where the agents were the planet, a sun, white and black daisies. In later versions of the model, the ecology (number of agents) was expanded (Lovelock 1995).

Brasier, “I agree with you that it is like those social connections. It’s very much like the argument that all great civilizations have collapsed. All of them have and ours will presumably by definition. They collapsed because they’re complex structures that tend to become top heavy or whatever.”

Werner suggests that survival of agents is not necessarily connected with the physical environment of the model, but has more to do with the social environment. Which agent survived had little to do with its individual properties. Agents that had died off in the model could be resurrected later and survive. It was the constellation [context] that agents were in that led to their survival or their destruction. [9:04]

Noble wonders if the evolutionary process is so historic that a scientific analysis of it at this point in time was impossible. He commented to Brasier, “You ... disagreed with Gould on how chancy evolution was.” [9:38]

Brasier, “Yes, I think you can point to short term winners and losers, ... I would agree with Gould in the sense that I think that *initial conditions* [emphasis added] are rather important in setting what happens

later. If you reran the tape of the Cambrian explosion etc. etc. the outcome could have been different. I would sort of follow him in that way.”

Dawkins feels this has already been demonstrated, “I mean the tape was rerun in Australia, in South America, in the Old World, with really remarkably similar results. So there does seem to be a set of lawfulness.”

Margulis is quick to qualify the “rerunning of the tape”, “Convergent results, not homologous.” Dawkins agrees that Australian versus Paleoarctic (Eurasia and North American) mammals evolved from separate lineages (convergence). The marsupials and placentals are not from the same lineage (homologous). In complexity theory, the space in which the function of dynamic systems is plotted is known as “phase space”. In applying complexity theory to the real world, there are many different and often exclusive spaces. When considering space, one must be careful to not confuse “apples with oranges.” Here the space of phenotype and metabolism is known as “morphospace.” Morphospace is determined by natural selection working in the context of community and the laws of physics. For example, organisms of a similar size living in similar contexts (e.g., communities, sources of energy, electrons, carbon sources, cycles, climate and threats) tend to resemble each other in phenotype even when not homologous. In Australia and South America (prior to the Great American Interchange), convergent evolution produced marsupials to occupy the variety of morphospaces occupied by placentals in Eurasia and North America.

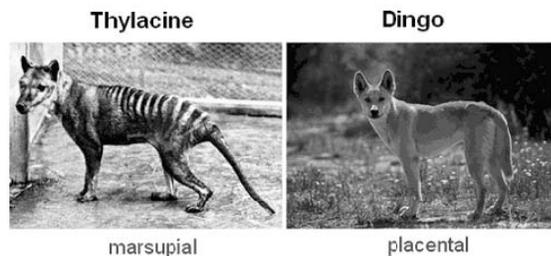


Figure 8. convergent evolution in morphospace (body plan)

Brasier, “Yes, it does come down to that convergence, I suppose. I would suspect that the further back you go, the more difference those possible outcomes can be. I’m not absolutely convinced that there are just a few *strange attractors* [emphasis added] in morphospace like Simon Conway-Morris or others believe. I think it’s much more varied and interesting, possibly beyond our imagining. Some of the possible outcomes could have happened if there was a massive meteorite bombardment in the middle of Earth history, which there wasn’t. What we have here now might look very different.”

Dawkins, “But if there was a massive meteorite extinction now, I think I would predict that you’d get something pretty similar within 10 million years.”

Brasier, “I think that’s right, yes. Because we’ve reached a certain stage in the laws of development.”

Antcliffé (see page 28), “What’s interesting about convergence is: it never actually converges things that are particularly that far apart. I mean in terms of the tree of life, it can work on certain dolphins and fish [both aquatic animals] that aren’t that diverse.

Brasier, “Well, you have the ... squid’s eye, for example.”

Antcliffé, “But I mean there’s no giant purple bacteria that do the same thing ... convergence only happens when you’ve got things that are already relatively closed related. I don’t think ... that you could say given bacteria, then humans, as some would.”

Brasier, “I mean the little diagram I showed which shows these forams keep coming back to this pattern. It shows how *iterative* [emphasis added] and how there’s a *strange attractor* [emphasis added] that keeps drawing them to these particular shapes, the spindles and this and so on.”

Werner, “I don’t know about using the word *attractor* [emphasis added] because that comes from dynamic systems theory which I assume is a lot about mathematics and actually these systems aren’t, they have their *internal control* [emphasis added]. That’s one of the things I think where Richard [Dawkins] is strong because you really do have some kind of internal information that in part is responsible for the ontogeny [growth and development] of the organism. So this notion of *attractor* [emphasis added] has a tendency to externalize that concept perhaps unnecessarily.”

Brasier, “It’s just a metaphor.”

Werner, “Yeah, I know it’s a metaphor but it can be misleading. In the sense that if we’re looking at an explanation, we have to also combine ontogeny with phylogeny and these *external attractors* [emphasis added] may confuse that issue.”

Brasier, “Perhaps you’d like to suggest another name?”

Werner, “Well, one thing would be that you look at punctuated at equilibrium, let’s say. You can look at how particular homeotic mutations [mutations of genes that control the *where, when, what and how* of differentiation of the body] can lead to rapid morphological changes. You can look at that kind of thing. That would be a way of looking at an *attractor* as ... within a constrained ... developmental space.”

Brasier, “Let’s use *attractors* in inverted commas.”

Brasier is amused by Werner’s objection to borrowing the term, *strange attractor* from complex systems theory. To Brasier his use of *strange attractor* is metaphorical. However, Werner argues that *strange attractor* would be confusing because it comes from mathematical modeling and relies on *external controls* or limits, rather than the Dawkins idea of the internal control by DNA or RNA. I would argue that evolution in general, and *convergent evolution*, in particular, are not exclusively directed internally as Werner suggests. Werner and Dawkins believe a hierarchy of control exists, DNA and RNA are at the top. However, if growth, differentiation and development receive cues, environmental or epigenetic feedback signals to which they respond, then the system is not a hierarchy. In a system, no part can be privileged because all parts are necessary for the system as a whole to function.

Werner suggests that an example of a *strange attractor* is a homeotic mutation that causes rapid morphological changes (e.g., adaptive radiations) observed as punctuated equilibrium. Such change would be confined to “developmental space”. This would be a *strange attractor* working on divergence of phenotypes entering new eco-spaces. Any animal that occupies a given eco-space (similar scale, habitat, climate, ecological relationships, carbon source, trophy, and respiration) will share a good many features and behaviors (ecotype) dictated by that eco-space. The organism is singularly suited to its eco-space, if it is “good enough” to compete successfully with other would-be residents of its eco-space, or if it succeeds in being difficult or impossible to evict. Form follows function in any particular eco-space; the better survival strategies (ecotypes) survive and tend to converge toward certain criteria and limits (*strange attractors*) in morphospace.

Chas Salmen describes two events: the radiation and extinction of *Haplochromis* cichlids (teleost fish) in Lake Victoria in Africa. Both radiation of species and extinction are remarkable for the short time spans in which they occurred. *Haplochromis* cichlids radiated into 500 species from a common ancestor in fewer than 14,000 years. Then in the 1950’s, Nile perch were introduced into Lake Victoria, Lake Tanganyika Lake Malawi and eradicated the cichlids.

Margulis asks, “What is considered the basis for the extraordinary rapid speciation in those fish [cichlids]?”

Dawkins responds, “Just ordinary evolution by natural selection.” [16:02]

Margulis, “Yes, but that's not ordinary. You've got to ask what the environment is that's correlated.”

Dawkins, “I suppose it was a virgin environment with nothing there.”

Margulis “I mean, the idea is that niches were just vacant, is that the best [explanation]?”

Dawkins, “Yes and it's convergent with Lake Tanganyika and Lake Malawi as well.”

Salmen, “It seems like ...an example where morphological evolution outpaces molecular evolution at least on the timeframe that we would suggest [for] the accumulation of random mutations.” [16:33]

Antcliffe points out that the Cambrian Explosion might be similar. The genetic diversity at the start of the Cambrian may have been lower than previously thought because different phenotypes interpreted as different organisms may be different ontogenetic states (juvenile or adult) of the same organism.

Werner suggests that such rapid speciation might be due to epigenetic control of the genes because “genes don't evolve.” In comparison to the genes, Werner offers that the epigenetic control system could evolve rapidly to provide new morphologies while keeping a relatively unchanged set of genes. Some light has been shed on extremely rapid radiations in work on stickleback fish of the Pacific Northwest. Sticklebacks radiated into many varieties and 50 “species” in marine and fresh water lakes created after the melting of the glaciers at the end of the last ice age, 10,000–20,000 years ago (Taylor and McPhail 1999). The work on sticklebacks has resurrected Goldschmidt’s long reviled idea of the “hopeful monster” because it has been discovered that mutations in a single control gene have large effects in sticklebacks (Chouard 2010). However, single mutations are not the whole stickleback story.

“Speciation may arise largely as a by-product of ecological differences and divergent selection on a small number of phenotypic traits” (McKinnon 2004). In light of the work on sticklebacks, “evolutionary theory in the 21st century needs to become more ‘inclusive’ than the so-called modern synthesis of the 20th century, in which development did not feature nearly enough” (Arthur 2004).

Brasier agrees with Antcliff that the rate of evolution or new forms during the Cambrian Explosion was very fast, perhaps comparable to the Lake Victoria rate of new fish species. [17:56] Both Dawkins and Margulis caution that the 20 million years of the Cambrian explosion was far longer than the 10,000 – 14,000 years of Lake Victoria.

Brasier, “Yes, but the disparities are huge, too, so we've got to scale it up. But it's geological scales, that's considered a pretty short period of time. That 20-30 [million years] is probably an outside estimate. It might be less than that.”

Noble then challenges Margulis to answer whether symbiotic change is frequent or rare. Noble further frames the question with a description of two “remarkable discoveries” of genetics: one is the extent of genetic buffering that prevents changes in the genome from affecting the phenotype, and second, the observation that cross-species clones don't work. Stem cells are made and the embryo may develop to the eight-cell stage or a bit beyond, but no further. The only reported successful cross species clone, a wild ox with a banteng inside a cow, is not open to science investigation [private proprietary corporate research].¹⁰ [19:54]

Margulis pointedly reminds Denis Noble that what he has described about cross-species clones is true *in mammals* [her emphasis]. Mammals represent a tiny, evolutionarily recent and physiologically limited fraction of life on Earth, yet many biologists and medical researchers reveal a disturbing mammalocentric bias in their mental models of evolution.

Noble, “Now, you're already beginning to answer my question, ...but it seems to me to be quite reasonable that cells should go on evolving just as genomes go on evolving. Therefore, it's not too difficult to see why you might end up with this species having an egg cell that can't accept the genome of that species, and form an organism. But if that is [generally true], then symbiosis, at least in certain parts of the kingdoms, will be really very rare indeed, won't it?”

Margulis, “Well, I'm a mammalian idiot, ...but there's a couple of mammal cases that are really fabulous, though. We don't see symbiogenesis when there's a disparateness in size. We see it always with lichens. 100% of the people who study lichens are Schwendenerists.”

A treatise by Simon Schwendener (1829 - 1919) proved the composite nature of lichens. All lichens are now known to be symbiogenetic associations of fungi with photobionts (Honegger 2000).

¹⁰ [Noble] As I noted previously, we now do have another example, the goldfish-carp clone. And that one clearly demonstrates cytoplasmic inheritance.

Margulis, “No, lichens are not plants in any way, because the partners are very equal in size and you cannot study the mycobiont, the fungus, without the phycobiont [algae, cyanobacteria, or purple bacteria]. But let's take the cow. All right? That's one of my favorite examples. The Bovidae in general ...the point is that these animals are 40gallon fermentation tanks on four legs. And when you look at the speciation that's gone on, in fact higher taxa levels, *isotrichid* ciliates and *Entodiniomorphid* ciliates, yeast, bacteria, and of course, they're studied because of milk, so we really know. We have fistulated cows we can study. They [Bovidae] are dependent upon Miocene grasses to eat, and cellulose is a hell of a thing to eat, as you know...if you don't have a cellulolytic ...hypertrophied esophagus. And this is the basis of the taxonomy of all of these animals. And the placenta is ...licked because the ciliates all encyst and if you don't get the ciliates, you're dead in two weeks with starvation. Now, we don't talk about that as symbiogenesis.”

Dawkins, “No, we do. I mean, there's no question that the Bovidae are incredibly reliant upon their symbionts. But you've suggested that speciation within mammals, with the invertebrates...”

Margulis, “No, not mammals. I never say anything about mammals, let's take insects.”

Dawkins, “Vertebrates, let's just take animals. You suggested that speciation in animals is nothing to do with mutation and selection and ordinary...”

Margulis, “No, not nothing to do. I'm saying ...I have no cases where just simply the gradual accumulation of mutation has led to a new species. The touted case was Dobzhansky with a wonderful experiment. But we now have great insight into that experiment. That was the cold and hot drosophila cages that after two years they couldn't mate again, you know, this is the famous case. ... Of course mutations are accumulated. They are not sufficient in any case to make speciation, in my opinion. Let me give you what's the most beautiful case of all. It's ...a neo-darwinist from way back, population geneticist named Werren [John Werren of the University of Rochester] who has studied...”

Dawkins, “It's a wasp.”

Margulis, “I think it is, parasitoid wasp. ...The story of the inordinate fondness of beetles is missing the last line, the inordinate fondness of beetles and their *Wolbachia* symbionts. What do I mean? They've found spectacular cases where differences in *Wolbachia*, which you don't see, they all look like beetles. You don't see them because you don't see those bacteria. Nitrogen metabolism differs in the *Wolbachia*. Hormone production that changes gender [of the insect] differs in these *Wolbachia*. But the coup d'état was when the entire *Wolbachia* ...genome was sequenced, and it's not even the size of typical bacteria, it's smaller. The genome was labeled by hybridization DNA and the *whole damn genome* of the *Wolbachia* is on one of the autosomal chromosomes the fact that the entire genome of that bacterium has been incorporated into the chromosomes of the [insect] nucleus, how much more intimate can you get? ...so it's genome acquisition. It's not gene mutation.”

Dawkins, “You're not seriously suggesting that, I mean, that's a lovely example, it's one-off example...”

Margulis, “No, it's multiple.”

Here again Dawkins used loaded language. He implies that Margulis ideas cannot be taken seriously. He patronizes Margulis's example as "lovely" and dismisses it as a "one-off" or one-of-a-kind. He cannot fail to recognize that *Wolbachia* interactions may affect 450,000 species of beetles, some 40% of all insects. J.B.S. Haldane famously remarked when he was asked what science revealed about God Almighty that "He had an extraordinary fondness for stars and beetles."

Dawkins, "You don't really think that if you look at the entire family tree of animals..."

Margulis, "No, beetles. Let's just stick with beetles. Well, I don't know animals, I don't know mammals."

Dawkins, "I mean but no, you've suggested in your book that speciation events are matters of symbiotic..."

Margulis, "Symbiogenesis. I have, and I stand up for it."

Dawkins, "I don't believe you can. I mean, you cannot be serious..."

Margulis, "Yeah, well, you give me, please, this is wonderful, you give me *any* example--I asked Niles Eldridge, I asked everybody-- just give me the "poster child" for simply documentation in the fossil record, in laboratory cages, or in the field, *any* case where it's documented from the beginning to the end, this is one species, these are the events that are "accumulation of random mutation", and that has transformed [from one species] to another species."

Dawkins, "You don't have the documentation for symbiogenesis, either."¹¹

Margulis, "Oh, no, that's not true. I can show it to you right now."

Dawkins, "You have it for Werren's wasps, I mean."

Margulis, "No, no, no, Werren's wasps solves the beetle aspect. My cases are really clear. They're much clearer because they're green. ... What you have is *Convoluta roscoffensis* which was described by Keeble (1910) in his little book called, *Plant Animals*, because he'd see them every summer ... Roscoff is a marine station in France and so it's very well known that people go there in the summer. Well, *Convoluta roscoffensis* covers the entire beach in these Channel islands [southeast Atlantic] and Spain, and you think it's green algae. It looks just like green algae. But when the tide comes in ... the green disappears. It's because *Convoluta* itself is a flatworm. And *Convoluta convoluta* lives right around there, so they know, and that eats algae and it's got totally worm-like behavior. *Convoluta roscoffensis* has eaten *Platymonas* [a marine green alga], and we know that that's three different genomes there [in the alga], because it's nucleocytoplasmic, chloroplast and undulipodium. And the eggs hatch and they just are regular *Convoluta* eggs. But the animal eats the seawater and it keeps, of all the things that come in with the seawater, it keeps one, it's a "parafertilization" event. It keeps this green algae, and every member of the population is 100% green. They all photosynthesize, and Sir David Smith [Muscatine et al 1974] has shown that the carbon dioxide is incorporated into photosynthate, and their mouths are no longer doing anything as far as feeding.

¹¹ [Noble] I find it remarkable here that Margulis' question is not addressed. This is why I was prompted later to issue the challenge at 54:07. The debate was threatening to disintegrate into assertions: a whole set of unproved assumptions.

Now, and they grow in huge patches, whereas the other ones [non-symbiotic *Convoluta convoluta* worms] are not lying in the sunlight, they're not phototropic, in other words, the ones that don't have the algae. So, we have *Convoluta convoluta*, no algae, standard flatworm. And I don't make the names up, *Convoluta roscoffensis*, which is the green one that we're just talking about, and then there's *Convoluta paradoxa*, again, I don't make the names up, the naturalists make up the names. *Convoluta paradoxa* does not grow in large groups, it's solitary and it doesn't have any green algae symbionts, it has diatom symbionts, and therefore it's a brownish color. So the naturalists have gone in there and said, here we have one genus and three different species, and it's very clear that speciation is totally correlated with the presence of no symbionts, green algal *Platymonas* symbionts and the diatom symbionts.”

Werner, “But you know, I think though you're missing the point though, because I mean what Richard was talking about is in a particular instance where something gobbles up something, OK, then incorporates its genome, that doesn't mean it, that's the way evolution works in general.

Margulis, “No, I'm saying that's the way evolution works in general.”

Werner, “Yeah, exactly that's what you're claiming.”

Margulis, “Yes.”

Werner, “So you're claiming from a particular [to the general].”

Margulis, “I've just given you one example.”

Werner, “Yeah, exactly but if a particular instance...”

Margulis, “Let me say something very clearly, too, first...”

Werner, “And what we also have to explain with evolution is not just the gobbling up and utilizing the genome for catching whatever light rays, we have to explain the morphological evolution. What you have to do, in order to make a case, is actually have some kind of symbiotic effect that then affects the ultimate structure of a multicellular organism [mammalian multicellularity] that gives Denis [Noble] two heads instead of one head, for example. ...And your theory doesn't explain that. I mean, I agree with you in a sense that you can have rapid evolution with genome incorporation, right? Where you have the bacteria incorporate...” [31:42]

Dawkins, “Happens once-in-a-blue-moon, and is very important when it does.”

Margulis's position is that symbiogenesis is a more important source of novelty in evolution than the accumulation of random mutations. She was challenged to provide evidence and did so with examples of the incorporation of *Wolbachia* bacteria in insects (e.g., parasitoid wasps and beetles). When that example was challenged as a “one-off” example, she described speciation in *Convoluta* flatworms that have differing phenotypes, behaviors, metabolism, gene products, genomes and life histories correlated with the presence of symbionts and a non-symbiotic *Convoluta* as a control (Nozawa 1972, Muscatine 1974, Meyer 1979). Werner asked for an example of a phenotypic effect in a multicellular organism (i.e., mammals), such as giving a Denis Noble two heads. Here again we see a specious, no pun intended, mammalocentric model of evolution. Also demonstrated is the widespread ignorance that multicellularity abounds in all five

Kingdoms, including bacteria. In neo-Darwinism “multicellularity,” means animals and fails to recognize the idiosyncratic obligatory multicellularity of animals (Margulis and Chapman 2010). In fact, *Convoluta roscoffensis*, has animal multicellularity, but no longer uses its mouth to feed; it farms photosynthetic symbionts in its parenchyma (tissue between the body wall and the organs). Here are the examples of a morphologic effects Werner requested. Equally important in this symbiogenesis, its *Platymonas convolutae* algal symbionts also undergo phenotypic change: they lose their undulipodia and cell walls and they assume new shapes (Boyle and Smith 1975). Dawkins assertion that symbiogenesis occurs “once-in-a-blue-moon, and is very important when it does.” is wrong on both counts. There is ample evidence that symbiogenesis happens frequently and while symbiosis and symbiogenesis are undoubtedly of more significance in evolution than neo-darwinists would allow, not every occurrence of a symbiosis or every symbiogenetic event has to be “very important”. How would someone measure the importance of symbiogenesis in *Convoluta* flat worms?

Bell, “That's the point I was going to make as well, is that there's a fundamental problem with that as well on the biochemical level, which is that the machinery that the bacteria used to express their genes is different from the host organism. The host's replication and transcription machinery will not recognize the appropriate signals in the bacterial genome, so that genetic material becomes junk DNA, becomes simply a passive component of the host genome, it's not actually going to contribute because it can't be expressed.”

If the earliest eukaryotes were amitochondriate, as SET postulates, then there is a very long history of the acquisition and utilization of bacterial genes (e.g., mitochondria, chloroplasts, *Wolbachia*) by eukaryotes.

Margulis, “Well my answer to you is that you don't know this until the detailed examples are studied, and I would maintain that in all the good cases, now you see the symbiosis that you can study are the ones that are very recent and new and one is green and one is, one is green and it's an algae and the other one's a worm. The ones that are really well known and best are in the insects and symbiosis literature because in all these cases that are really studied you have an insect, which is a eukaryote with all of its features, and you have a bacterium, and when each partner is very similar, that set of partners, like all beetles, are very similar to each other, and each of the other symbionts are very similar to each other, like all the *Wolbachia*. Then the changes are subtle and they're very hard to see as dramatic changes. But I would say something that I haven't said at all, and that is, in my opinion, prokaryotes are very distinguishable. They are differentiable. But I do not believe that speciation as a word is appropriate for prokaryotes. That's my opinion.” [33:20]

Dawkins, “Well that's probably right, but if you take the standard story for ordinary animals, and what's wrong with it? You've got a distribution of animals. You've got a promontory or an island or something and so you end up with two distributions there.

Margulis: “This is a geographical diagram?”

Dawkins, “Just geographical. And then on either side of this promontory, you get different selection pressures and so this one starts to evolve that way, this one starts to evolve that way, and what's wrong with that? It's highly plausible, it's economical, it's parsimonious, why on earth would you want to drag in symbiogenesis when it's such an unparsimonious, uneconomical?” [34:01]

Margulis, “Because it's there.”

The most obvious flaw with the “standard story for ordinary animals” (i.e., mammals) is its inappropriateness as a model for the evolution of all life on Earth (overwhelmingly not mammal or animal) over 4000 million years. Dawkins admits that the neo-darwinist explanation, evolutionary novelty arises by the accumulation of random mutations or genetic drift due to geographic isolation, is a “story.” The Modern Synthesis is based on questionable assumptions with mathematical proofs and statistical models. Symbiogenesis is based on observation or direct documentation from nature. Neo-Dawinism offers few examples, if any, of speciation by the accumulation of random favorable mutations.¹² The reader should note that Dawkins’s position here that symbiogenesis is unparsimonious and uneconomical contrasts sharply with his position at the start of the debate that Margulis did not go far enough. Dawkins said, “We can regard the entire gene pool of any species as a symbiotic collection of self-replicating pieces of information...They are all symbiotic collections of genes in just the same way as Lynn has taught us with respect to symbiotic organisms” (see page 5). Dawkins rhetoric makes the logical fallacy of *argument by assertion* when he states the accumulation of random mutations or genetic drift are highly plausible, economical, and parsimonious. He uses repetition (*argumentum ad nauseam*), not evidence to support his assertions.

Margulis, “Let me say something about this. I don't want to get into a big fight about this, but in addition to the standard symbiosis events that I'm talking about, there's also, in mammals, a wonderful history and literature on karyotypic fissioning, which is not directly symbiogenesis. It is indirectly, I can show you it's ultimately symbiogenesis that's a chromosomal level phenomenon comparable to polyploidy in plants. I would never argue that polyploidy is not involved in speciation in plants. So when you get to eukaryotes, there are chromosomal phenomena that are unique and so on. But I want you to answer my question, which is give me any case in the fossil record, in the laboratory, in the field or anywhere else where simply the accumulation of random mutations has led to a step from one species to another where it's the naturalists that are changing the names of the species. And not like Daphne Island [in the Galapagos] where they [the Grants, a research couple who received Darwin-Wallace medals in 2009] have wonderful stuff, but no one has changed the name of any of those [finches] because they are the same species.”

¹² [Noble] Are there any? This is important. Jonathan Bard, in a recent talk, quoted the Greenish Warblers as an example of a ring. Around the ring each subspecies can breed with the next, but when the ring meets on the other side of the Himalayas, they can't interbreed. Have the genomes been studied?

Karyotypic (chromosomal) fissioning results in closely related animals having chromosome numbers that reflect an original number and multiples (sex chromosomes are not duplicated). Chromosomal fissioning has the potential to isolate the affected population from the ancestral population. Neo-centromere formation is a related literature in medicine that is generally not considered in discussions of speciation of animals.

Antcliff, "Might I actually comment directly on that question, actually?"

Margulis, "Do you have an answer?"

Antcliff, "Well, I mean, the allopatric speciation mechanism [geographic isolation] you've just drawn up is not necessarily about the accumulation of mutations, it's about the movement and selecting of variety that already exists." [35:30]

Noble, "Even within the same genome."

Antcliff, "That's already there. And so you don't actually have to have the mutation to do that. So that's one point just to throw that back. The second thing is something in *Nature* or *Science* ...some report of the snail that had its gonads on the left side of the body. There was one gene that coded for the chirality [right or left handedness] of the shell, and because the shell came out so far that if you changed the direction of the chirality they couldn't get the gonads together between a left- and right-coiled snails. So you've got this mutation, ...the left-coiled child had to go and join a different species to its parents because it couldn't actually interbreed with the right."

Margulis, "And that changed the name of the species?"

Antcliff, "Well they gave them subspecies names. I guess the question here is whether there was a backward mutation that allowed the lefts to go back to rights, and maybe there was, which over multiple generations would mean that there wasn't actually speciation, but I do think it was interesting that this case exists. I mean, it's quite close to being the sort of hopeful monster situation. [36:50]

Antcliff's example of speciation in the Japanese land snail *Euhadra* describes reproductive isolation in one species of snail due to shell chirality (Ueshima and Asami 2003) exemplifies Dawkins's "one-off" status. A later study of *Euhadra* concluded, "We have shown that reproductive isolation between chiral morphs is possible, but unstable, and will lead almost inevitably to gene flow. While chiral morphs may be a step towards distinct species, complete reproductive isolation must require other factors, such as divergent selection for habitat use or geographic separation of populations (Davison et al 2005). [36:57]

Siegel, "I actually have a string of arguments, so feel free to jump on all of them, but the first thing is that you [Margulis] criticized that they [neo-darwinists] haven't seen a speciation event, and you haven't either, you've just seen three different species that have three different properties and humans have a different group of symbiotic flora [microbiota, not plants] in their gut ...So if you were to look at humans and gorillas and orangutans, you would find that they had different symbionts. So, I could conclude based on your logic that the symbionts are the reason that there's a difference between orangutans and humans. And that is just completely illogical."

Siegel is so heated in his remarks to Margulis that Antcliff will characterize Siegel's remark as an "attack" (see page 41). Margulis had already stated earlier in the debate that she believed speciation in mammals is due to multiple factors, including some mutations, some geographic isolation, but in her opinion, the phenomenon of karyotypic fissioning was quite likely to be the most important factor (see page 38). Even if Margulis's statement about karyotypic fissioning were absent, Siegel's comparison is fallacious because humans, gorillas and orangutans relationships with their microbiomes are not comparable to translucent flatworms and their photobionts.

Siegel, "The second thing that's illogical is, you can't argue a generality from an example because both things might be true."

In math and formal logic, Siegel's argument is true because philosophers and mathematicians have shown that deductive logic is rigorous while inductive logic is not. However, what experimental scientists do is to make an educated guess at the answer they seek, a hypothesis, by use of inductive and deductive logic and results. They then gather specific data from specific observations, measurements and experiments designed to either support or falsify their hypothesis. This is known as hypothetico-deductive method (Pagels, 1988). Margulis hypothesis is that much of evolutionary novelty is produced via symbiosis and symbiogenetics. At the macro-scale, her collaboration with James Lovelock is based in the Gaia hypothesis.

Siegel, "So nobody's arguing that symbionts aren't important in terms of the biological environment that creatures live in that cause their evolution. Nobody's actually saying that. If you want to look for a speciation event that involves DNA, all you have to look for is polyploidy plants. That's an example where something actually speciates and it's all based on DNA, it has nothing to do with symbionts."

Siegel goes on to say that the fossil record shows no evidence of changing symbionts, instead the *entire* fossil record demonstrates gradual changes to organisms over time. Margulis had already mentioned polyploidy in plants which is a chromosomal level phenomena, rather than DNA, in the sense that there is no accumulation of random mutations or "genetic drift" (see page 38). Few researchers seek direct evidence for microbial symbionts; it must be inferred (Bermudes and Back 1989). Brasier's work on symbioses in fossil foraminifera is a groundbreaking example. He concludes from a data set of 30,000 fossil foram tests that changes over time in large foraminifera are attributable to the acquisition of photobionts and an increasing specialization over time that accommodate larger populations of farmed algae or diatoms per foram. Siegel's generalization about the *entire* fossil record's gradual change is at odds with punctuated equilibrium. "The intense controversies that surrounded the youth of punctuated equilibrium have helped it mature to a useful extension of evolutionary theory. As a complement to phyletic gradualism, its most important implications remain the recognition of stasis as a meaningful and predominant pattern within the history of species, and in the recasting of macroevolution as the differential success of certain species (and their descendants) within clades" (Gould and Eldridge 1993).

Siegel, "And as far as the question about speciation is concerned, yes the definition of species is problematic. If you actually look at the data from the Grants, the Grants actually believe that a true speciation event in birds takes about 30 million years. There are no species in the Galapagos finches, they're actually all capable of interbreeding. But it doesn't mean that you don't have distinct groups of birds that do distinct things that have different species names to them. [39:16]

In his description of the Grant's work, it is Siegel who argues from a particular to the general. Galapagos finches are one example of varieties that have been incorrectly classified as different species, but it does not follow that naturalists generally misclassify varieties as species, or that species are based entirely on distinct phenotypes and behaviors (e.g., *Canis lupis familiaris*).

Antcliff, "I do think it's [the debate] in danger of becoming slightly unfair on Lynn, in the sense that we're now accusing her of arguing from a particular to the general when she made a perfectly general statement about what the role she thinks symbiogenesis has in evolution and then was asked to provide examples of that. ... It may be that she believes that there are many, many examples, but we can't sit here and quote all of them. [39:55]

Dawkins, "Symbiogenesis is terribly important in evolution, but not in every speciation event." Dawkins "straw man" statement is invalid. Margulis does not claim symbiogenesis is the cause of *every* speciation event.

Antcliff, "All I'm saying is that we can argue over the particulars of any example that she's given, I think that's perfectly reasonable, but I don't think it's fair to attack [her] just because an example was given, and that she's arguing from a particular to the general because she may not be." [40:18]

Siegel, "Well, you can argue that she gave an example of speciation that wasn't an example of speciation. We didn't see something go from one species to another after accumulating a symbiont. All we saw is that there's a correlation between the presence of a symbiont and the difference in a species. That's not a speciation event."

The challenge was to present a "poster child" for speciation resulting from symbiogenesis, not to witness a speciation event in real time [see page 35]. Siegel argues that speciation in Galapagos finches is estimated to take 30 million years. Margulis gave the example of three flatworm species with different phenotypes, metabolism modes and behavioral patterns. One species that lacks photosymbionts as a control. The presence of different photobionts in each of the other two flatworms is not only correlated with species named differently, but with metabolism, patterns, colors, (e.g., green platymonads or brown diatoms), phenotype and behavior. What is Siegel's alternative explanation for the differences between these three species, members of the same genus *Convoluta*, in similar geographical area? Are the three colored flatworms misidentified varieties, the results of "genetic drift" or "the accumulation of random beneficial mutations" independent of their photobionts?

Salmen, "I think it does come down to the level of our definitions. It depends on what we define as an organism. I mean, the difference between an organism and an ecosystem is not really an arbitrary

distinction when we're talking about something like speciation. Because the suggestion is that by incorporating a symbiont, this relationship actually forms a new organism, and then it's actually the composite. I've read it in one of your [Margulis] papers where you say that individuality is relative. And it seems like that suggestion is that [in] any speciation event, the way that we define our organism has a lot to do with the way we would define what that species is. Is that two separate species that are working together or ...can we say that this ecosystem or this community has become a new species?" [41:24]

Siegel, "Well, the lichen is a perfectly good example, because according to the argument that you [Margulis] make, if one particular fungus picked up one algae, then it would be one organism, but if it went and picked up a different one it would be a different species and we should give it a different name. But, that's not actually what happens. What happens is they've actually evolved so that the particular lichen actually is a combination of one particular species of algae and one particular species of fungus. So they've actually evolved together in a co-evolutionary way.

Co-evolution is the effect of reciprocal selection pressures within a community. It is a looser relationship than symbiosis. Symbiosis adds the requirement that differently named organisms be in physical contact with one another for most of the life of at least one partner. The relationship of the fungi and its photosynthetic partner in lichens is more than co-evolution, it is a symbiogenetic relationship where symbiosis over time has led to new behaviors, traits, metabolism, tissues, organelles, gene products, or integration of genomes. Co-evolution would accurately describe other ecological relationships such as the selection pressure of bees on flowering plant pollination details and vice versa, or the reciprocal selection pressures of predator and prey.

Margulis: Well, first of all, there are lots of lichens that have the same fungus and on one side of that lichen it's lichenized with a cyanobacterium and the other side of that lichen is lichenized with a green algae. On the side with the cyanobacterium, the carbon that flows is glucose. On the side of the green algae, it's a sugar alcohol like mannitol or ribitol, and the morphology is completely correlated with one or the other of the symbionts. You could cut it in half and just show this one, and that will have a name, its lichen name to a lichenologist, and you could show that one, and it [will have another lichen name] so the same organism is changing its name as a function of its symbiont. [42:53]

Siegel, "In fungi, many of the species have a sexual phase that's identified, the sexual phase has one name, and the asexual phase has another name, and they look completely different, but they're not different species. Giving them a name doesn't mean a thing."

Margulis, "Ooohhh, so we are not to trust the naturalists on the names, either?"

Siegel, "No, because if you find they have identical DNA, then I'd call them the same species."

Margulis, "Oh, they do have identical DNA [within a specific symbiosis] ...they have different DNA depending on the partnerships. There's a very fundamental kind of investigative aspect here. If the organisms are very different from each other, that is, the partners are very different from each other, and they are cyclical like [some] lichens, that is, they can be separated, then it's very clear they're two different

organisms. But when the integration is, first of all, permanent, it's not temporal, it's permanent, and the partners are very similar to begin with, then nothing is left but the Cheshire Cat's smile. In other words, you can't have it both ways. When we trace the good cases, then you have to have differences.”

Siegel is a great foil for Margulis in the debate. He states many of the standard neo-Darwinian arguments, but unlike Dawkins who makes assertions from authority, Siegel attempts to provide examples for his positions, albeit that lichens do not match his description of them. I would agree with Siegel's earlier statement that “the definition of species is problematic” (see page 41). Recognition of species universally for all forms of life is difficult or impossible (e.g., in bacteria). Nonetheless, the key useful condition is the acceptance of the species designation by naturalist experts.

Margulis, “I have with me a case which is an answer your question [Siegel's desire to witness a speciation event] ...an organism that was put in a herbarium called *Geosiphon pyriformis* in the 19th century, and it was put in as an algae, they didn't know what it was. An algae. It turns out that not only is it not an algae, there's nothing about it that's an algae. In its form, the organism itself looks like a moss, and I can show it to you. You can see it form yourself. It is formed by a fertilization, that is a fusion, a breakdown of cell walls, and the complete fusion of organisms not of different, very close relatives, not of different species, not of different genera, not of different families, not of different orders, not of different phyla, different kingdoms. And one of them is a cyanobacterium and whatever, however you, it's a prokaryote. Absolutely, 100% *Nostoc*. And the other one is a fungus, and to make this organism, every six weeks you have to have a para-fertilization. Now, that's not allowed by [neo-Darwinist] biology, but there it is in nature. [45:19]

Dawkins, “Of course it's allowed, why shouldn't it be allowed? It's a perfectly interesting natural phenomenon.”

Margulis, “Because you can only have fertile offspring with your own relatives of the same species.”

Dawkins, “No, rubbish.”

Dawkins first claims throughout this debate that symbiogenesis is very rare and happened long ago. Later, Dawkins defines speciation as “the separation of a previously interbreeding population into two new populations which can't interbreed” (see page 49). If fertilization can occur only between members of the same species, then *Geosiphon pyriformis* is by definition impossible, but there it is: a dazzling modern example of symbiogenesis: a merger of organisms from *different kingdoms*; a fusion of *prokaryote and eukaryote*. Dawkins employs a rhetorical strategy here in the face of evidence that contradicts his statements: first, he dismisses his own definition of species as “rubbish,” then he trivializes *Geosiphon pyriformis* by judging it as little more than “a perfectly interesting natural phenomenon.”

Werner, “I think the generalization maybe that you're [Margulis] giving is that you think that evolution proceeds more by the combination of the genomes, which may be from disparate organisms...”

Margulis, “Heterogenomes.”

Dawkins, “Occasional major events [by symbiogenesis], yes.”

Werner, “Whereas Richard is saying, evolution proceeds by mutations of a given genome, and I can...”

Noble, “Or even without mutations.”

Werner, “Yeah, I mean, you [Margulis] bring some beautiful examples of, you know, I come from a multi-agent area [computer simulations] where you have these cooperating agents [programs] with different strategic abilities. The kind of thing you're talking about fits beautifully with that sort of view of things. So, you can no longer really define an individual because they're cooperating so much they tend to become an individual. So, those examples are quite striking. I like it, so maybe...” [46:27]

Margulis, “It's individuality on a more complex level of an organization [integrated community].”

Relationships among different organisms are subject to natural selection. Relationships start with proximity that leads to *prototaxis*, a predictable habituated behavior between unlike organisms (Wallin 1927). Prototaxis within a community may lead through reciprocal selection pressures to *co-evolution*. Selection pressures may lead from co-evolution to *symbiosis*, an ecological relationship where different organisms live in physical contact either as epi- or endo-symbionts for the most of the life of at least one partner. Finally, *symbiogenesis* is the evolutionary integration of the symbionts. The integration of the symbionts may evolve from facultative to obligate metabolically and from cyclical to permanent temporally. Symbiogenesis evolves new behaviors, traits, tissues, metabolism, organelles, organs, gene products or composite genomes. The symbiogenetically composite organism may expand its habitat or occupy a habitat unlike that previously occupied by its partners, as recognized in 1927 by Kozol-Polyanski (Fet 2010).

Noble's comment that evolution may proceed “even without mutations” refers to the phenomenon of *assimilation* pioneered by the founder of epigenetics, Conrad Waddington (1905–1975). Waddington discovered that environmental stress could favor unusual development. Natural selection acts to combine and improve the new stress-induced phenotypes, and after a number of generations the phenotype is inherited even in the absence of the original environmental stress (Noble 2010).

Werner, “Maybe evolution proceeds both ways. I mean, obviously you have to have mutations to get your original genome that combines with the other genomes. So you do have mutations that actually develop a species at some level, right? Whereas you could have rapid evolution by the kinds of “mechanisms” you suggest. It's just very hard to see how that happens with multi-cellular organisms. [46.49]

Multicellularity is found in all of the kingdoms of life including bacteria (eubacteria and archaeobacteria). The prevalence of dichotomous thinking throughout this debate; ideas are right or wrong, an effect has only one cause is notable. Margulis claims that evolutionary phenomena result from many factors in addition to symbiogenesis. Her insistence is not that symbiogenesis is the exclusive producer of evolutionary innovation.

Margulis, “You mean with animals [animal multicellularity].”

Werner, “Well, big things with lots of cells and they're different [differentiated].”

Noble, “Martin, you wanted to come in.” [46:57]

Brasier, “We have raised this question of whether symbiogenesis is important, and I just want to give a geobiologist's view of what is important compared to what might be an evolutionary biologist's. We tend to view a creature according to a spectrum of their impact on the planet. OK? So it's not like looking at the enormous diversity in the rainforest, but what is their impact on the carbon cycle and the biogeochemical cycles? These are the things we focus on.”

Brasier takes the discussion into geology and Earth systems, disciplines that are critical to a broad understanding of evolution: what has the effect of life been on the physical Earth and how has a changing Earth affected life? This is the complete story of natural selection, not just the environment limiting survival, but how organisms survive change, diversify, produce new environments and selection pressures related to the enlarging biosphere. Brasier recognizes the continuous reciprocal effects of Earth and life through at least 3500+ million years of planet-level evolution.

Brasier, “So, I'm going to bring the discussion a little bit back to foraminifera. Back in 1856, when they were trying to lay the first transatlantic Morse code cable across the Atlantic, they had to learn what the bottom of the Atlantic was like, because they had no idea how deep it was, if there was any life down there. And Captain Berryman of the US Navy started with a series of deep sea trolls. He took 12 across the Atlantic. And they went down, of course, to three or four thousand meters, or whatever it was, and they discovered the sea floor was absolutely covered in foraminifera. There's nothing but this enormous, great deposit of chalk that Huxley so evocatively wrote about. Nearly all of that is foraminifera, and nearly all of those are symbiogenetic foraminifera. The vast bulk of the calcium carbonate that ends up in the deep sea is the product of symbiogenetic evolution between particular forams, in this case, and dinoflagellate [dinomastigote] symbionts. So although it [symbiogenesis] may not be quantitatively important, there's only about 40 species of planktonic foraminifera, in terms of geobiological importance, it's really rather a significant thing for us to look at. And like both the coral reefs and everything that Darwin was so fascinated by, the corals themselves, where *Hexactinians* cultivate dinoflagellates [dinomastigotes] and most of that wonderful star sand that accumulates around them is foraminiferal symbiogenesis. So importance in a geobiological sense shouldn't be dismissed here. [49:00]

Dawkins, “I bet it's vastly important, but it's got nothing to do with speciation. I mean, all these animals are symbiotic, we're all symbiotic. We're all, I mean, joining up of different things and all, but as we speciate, our symbionts speciate with us. I mean, they go with us. It's not that symbiogenesis causes the bifurcation between, at least animals.

In describing evolution, neo-darwinists seem to me to display a form of “tunnel vision.” Evolution is not all about speciation. Evolution is not all about animals. Evolution is not all about biota. Evolution is not encompassed by evolutionary biology or all of biology. Evolution is an emergent property of Gaia, the Earth system. Evolution is the history of the Earth and its solar system. Evolution, the changes to planet Earth through geological time, encompasses far more science than zoology.

Dawkins uses the logical fallacy of an *appeal to ignorance* with his assertion that symbiogenesis “has nothing to do with speciation” in animals. His statement would not necessarily be true even if there were no evidence that it is false. His statement is a false dichotomy because the possibility also exists that there is so little known that there is no way to prove the proposition true or false. However, in this case, an example of speciation by symbiogenesis, *Wolabachia* bacteria in Werren’s wasps, has already been discussed to which Dawkins did not take exception (see pages 34-35). Furthermore, the concept that one cause alone accounts for all speciation events, even when limited to the kingdom Animalia, is dogma, not science.

Dawkins, “I mean nobody is saying that symbiogenesis isn't important.”[49:30]

Margulis, “Oh yes they are. In the Oxford museum... they're going to have an exhibit ...and I was told when somebody asked what are you going to do about symbiogenesis when you have this big Darwin evolution exhibit, a zoologist professor said, well nothing, that's only relevant to protists.”

Dawkins, “Well, look, it's very important. Let's say it's fantastically important.”

Margulis, “(Cheers) YEAH!”

Dawkins, “But it's not, it's nothing to do with speciation, that's the only thing I'm going to say, I mean, you were trying to imply...”

Margulis, “No I'm not trying, I'm saying it.”

Siegel, “I emphasize, you know, from the microbiological standpoint, I emphasize the importance of our relationship with microorganisms by saying the following thing: first of all, if you count the number of bacteria in the human body, it outnumbers the number of human cells ten to one. So we're much more bacteria than human. If you count the number of mitochondria in every cell, they greatly outnumber the number of human cells.

Dawkins, “No question...”

Siegel, “So we're much more bacteria than we are, and if you count the number of genes that are devoted to retroviruses, it outnumbers the number of genes that are devoted to humans, but it doesn't mean that humans evolved because of that.”

Dawkins, “That's the point, that's the point. Exactly right.”

Siegel, “That's all part of our, that's part of our biological endowment. We are way more microorganisms than human, but that's not what created humans. And if you look through mammalian evolution...”

Dawkins, “That's not what split us off from chimps.”

Siegel, “Exactly. And you can't really make that argument for any mammalian evolution or most different organisms.”

Dawkins, “Or animals generally.”

Siegel, “Animals, yes.”

It is true that “we're much more bacteria than human,” but it is condescending to recite such a bromide as if this were news from microbiologists to the rest of science. Perhaps Siegel is unaware that it was Margulis (1967), who fought long and hard to convince biologists that cell organelles (mitochondria and chloroplasts) descend from bacteria. She was ridiculed for her ideas about symbiogenesis then as well. Siegel does make a good *prima facie* case that even we humans are a community of symbionts, but then fails to define what “our biological endowment” means. He does not explain how it has been proved that with all these symbionts and viral genes, we humans have managed to avoid all symbiogenetic effects. The same would be true for animals or “most different organisms.”

Evolution is the 4000+ million year history of Gaia, the self-organized, complex, nonlinear, far-from-equilibrium Earth system. Gaia displays homeorhetic tendencies (regulation around set points that move over time). Gaia operates within physical limits (Lovelock 1993). Siegel (a medical virologist and microbiologist) and Dawkins (an evolutionary biologist and zoologist) choose to argue one example (a particular), the bifurcation of chimps from humans, as proof of their general model of evolution and speciation of all lineages of all life throughout deep time on Earth. Common ancestry of chimpanzees (*Pan troglodytes*) and humans (*Homo sapiens*) is well documented; they share 99% of their genomes. They both should be in the genus *Pan*, but the modern human lineage did not bifurcate directly from modern chimps as Dawkins and Siegel imply. Millions of years of evolution within a distinct lineage of proto-chimpanzees with their changing symbionts separate *Pan troglodytes* from the lineage of hominids and their changing cast of symbionts leading to *Homo sapiens* (Morrison 1999).

Molecular biologists run computer programs on database profiles based on the sequence of the small unit of ribosomal RNA from a tiny sampling of an extant population of organisms that contain multiple genotypes. Then computer programs compare, sort and align patterns of nucleotides to derive a preconceived bifurcating tree model of ancestral relationships with “bootstrap” probability values. There are anomalies (e.g., long branch attraction and assumed “horizontal gene transfers”). In fact, some have argued that the amount of “horizontal gene transfer” has all but erased traceable evidence of relationships (Doolittle 1999). Then there is the conspicuous use of Occam’s broom, which places integrated communities, such as the composite organism *Zea mays* (corn) in the Woesean Domain of Eukarya (eukaryotes) by ignoring its mitochondria (protobacterial) and chloroplast (cyanobacterial) genes. Siegel does not acknowledge that his argument against symbiogenesis applies equally well to exclusively genetic neo-Dawinism. The differences detected in genes do not distinguish which evolutionary processes (e.g., mutagen, macromutation, horizontal gene transfer, genome acquisition, transcription errors, epigenetic effects of the environment, or Lamarckian acquired characteristics) led to observations seen in extant organisms.

Margulis avoids exclusivity when it comes to influences on evolution. She is a fierce proponent for the importance of symbiogenesis, but she has modified her Serial Endosymbiosis Theory (SET) over her career as new evidence appeared. Lovelock and Margulis have similarly modified the original Gaia hypothesis as the result of both evidence and criticism. Margulis is a scientist who is open to surprise. She

does not deny the existence of random mutation with respect to selection, but believes its importance has been overemphasized relative to symbiogenesis and other factors that contribute to evolution.

Brasier, "So your argument is for co-evolution rather than causation."

Siegel, "We have evidence by sequencing that these, you know, that the web of life thing [anastomoses of lineages] happens at intervals. I wouldn't say it happens frequently, but I think it's very important. We find mixing and matching of kingdoms and things like that. So we know it happens. They may be critical events in evolution, but they're not the thing that goes from one species to another."

Partial phylogenies based in the recently developed field of molecular biology are unproven and statistical. It is a science-under-construction with newer papers refuting and evaluating earlier results. I question if a detailed history of relationships of ancient organisms can be reckoned with accuracy and precision from nucleotide sequence studies of small subunit ribosomal RNA of extant organisms while the detailed life histories of these same organisms, the workings of their communities, the fossil record of their kind, the changing geology, biogeochemistry, paleoclimatology, atmospheric chemistry and other important details through deep time are ignored. Zoologist assertions that symbiogenesis does not play a part in evolution of human primate mammals or speciation-in-general is made without evidence to back it up.

Noble, "Well that was part of the reason why I originally posed the question in terms of frequency. Are we talking about events that, while rare, are nevertheless important and importance doesn't necessarily have to go with high frequency." [52:02]

Dawkins, "Very rare and very important."

Noble, "Now, the question that I would like to come to is a sort of, now, I return to my roots as a physiologist for a moment, you see. What astonishes me, I'm going to be a very naïve person just for two minutes. What astonishes me about this debate amongst all the various evolutionary theorists here, is the almost certainty with which they state some of what they state. I don't, this is an accusation against all of you, clearly. Now, that sort of clears me of any partisanship. However, isn't the problem this? Would you, just to be totally naughty, let me imagine the following. Let us imagine that Lamarckian forms of inheritance have been vastly more common than we think at the moment. How would we know?"

Margulis, "We don't study them." [52:59]

Noble, "Just looking back through the record and looking at, you know, each and every one, how would we actually know, either from the genomic record or from the phenotypic record, to the extent that we can measure it, that that was the case or not?"

Margulis, "What kind of Lamarckian..." [53:22]

Noble, "Well, what I have in mind, it's obviously going back to the Waddington idea that you can by canalization lock a genome into a particular direction which then gets selected, so you end up with the evolutionary line going in that direction rather than that direction. But looking back on it, how would you know that was prompted by the environment rather than by some mutations?"

Margulis, "Can you answer?" [53:43]

Noble, “No, I can't. That's the point! That's the whole point! You see, I find the degree of certainty with which people are saying, it's this, it's that, utterly astonishing given my views as a physiologist, you see. I don't know if anybody wants to take up that challenge, this is shaking the boat deep down.” [54:07]

A telling moment of silence follows Noble's challenge. The opportunity to show why their assertions are not “utterly astonishing” is here, yet Dawkins and Siegel, the most dogmatic neo-darwinists, are silent.

Noble, “He's going to take it up.”

Antcliff, “Simpson [George Gaylord Simpson, 1951] wrote about horse evolution, that all trends aren't real. And effectively, you know, when we look back through historical data, the fossil record, you know, you can always see evolutionary trends in whatever way you like, because you can always draw a straight line between those two points, a start and an end. It doesn't make it real. So I guess that's what I'd say to it.”

Noble, “Yes, but it's the problem of “mechanism”, isn't it?” [54:36]

Antcliff, “Sure, but the point is that the “mechanism” presupposes that there's something that warrants the explanation. There's actually a directionality already that has a “mechanism”, whereas in fact, if there is no directionality, then in a sense, it doesn't have to have a “mechanism.” That's what I mean.”

James MacAllister, the author of this commentary and a graduate student in evolution geography works in the Margulis Laboratory at the University of Massachusetts Amherst.

MacAllister, “It seems to me that one of the problems is that we have lots of definitions, and the definitions are all completely arbitrary because the Earth isn't divisible. All these systems aren't divisible. So, we've invented lots of divisions, which are not real. Lynn has a definition of symbiogenesis [symbiosis] and it has to do with the contact of one organism with another for the major part of at least one of their life... But if you go out into nature and you loosen up that definition of symbiogenesis [symbiosis] a little bit, you find that everything lives in some kind of loose symbiotic [co-evolutionary] relationship with other things [a community]. I mean, nothing lives in isolation from anything else. Is there a definition of speciation that anybody here in the room can enunciate that everyone else in the room would agree to? It's a completely artificial...”

Dawkins, “Well, the separation of a previously interbreeding population into two new populations which can't interbreed.”

The Dawkins definition only applies to those life forms in which reproduction is inextricably linked to sex (i.e., obligate sexuality; kingdom Animalia). In most organisms, although reproduction is obligate, sex (formation of new individuals from two or more genetic sources) is not.

MacAllister, “We have Wood ducks in Massachusetts and we have Mallards, and they are completely separate species that do not interbreed [in the wild], but if you put the Wood duck in captivity with the Mallard, they interbreed just fine and have [viable] offspring. They're called two different species.”

Margulis, "But even worse, we have all the protocists we work with have no sexuality at all, so interbreeding is not relevant."

Dawkins, "No, no, no, it doesn't work for, that's absolutely true."

Margulis, "That's an animal definition."

Dawkins, "Yeah, yeah. It doesn't work for..."[56:58]

MacAllister, "I'm curious, Professor Dawkins, this business of these symbiotic [symbiogenetic] events being very, very rare and that's a statement that's made a lot. I just wonder why if you have an event that gave you the use of oxygen, you have an event that gave you the use of photosynthesis in "higher" organisms (the symbiosis events that the incorporated mitochondria and chloroplasts), where nature has had this fabulous success with taking things that are ready-made, off the shelf, just like people did when they built an automobile, they didn't invent all these things, they took things off the shelf and stuck them together and they made an automobile, why with this huge success, would nature abandon that and go for something where the odds are so incredibly long?" [57:53]

Dawkins, "It doesn't abandon it. It's been, it's extremely common in the sense that we all are symbiotic things in which, it's gone on. What's rare is the incorporation of new genomes. Whereas Lynn is suggesting that every speciation event, the separation between humans and chimps, the separation between chimps and gorillas, the separation between chimp, gorillas, and orangutans, every one of those was involved with the incorporation of a new symbiont. I mean, that's an incredibly unparsimonious idea. It could be true, but you need evidence for it, it's not the sort of thing you just..."

Margulis agrees that an insistence that symbiogenesis is involved in *every* speciation event is unparsimonious, but it is a *straw man*, she does not make this claim. Dawkins frames his argument in terms of absolutes and exclusivity, which may be appropriate to physics, chemistry or mathematics, but does not fit the complexity of nature. Dawkins argues from authority or consensus. No evidence is presented to support the gene's eye view as parsimonious. To quote Dawkins to Dawkins, "It [the gene's eye view] could be true, but you need evidence for it."

Is symbiogenesis unparsimonious as Dawkins claimed? Most biologists accept that it is responsible for the origin of the eukaryotic cell, the incorporation of mitochondria (oxygen respiration) and incorporation into eukaryotes of chloroplasts (photosynthesis). These are arguably three of the most qualitatively and quantitatively important events in natural history, each of which led to a new *kingdom* of life. Symbiogenesis is similar to bacterial conjugation, in that sets of functional genes are acquired. Useful functions are the building blocks of symbiogenesis. Direct filiation, by contrast, relies on unparsimoniously long odds of accumulated beneficial mutations to accidentally stumble onto small incrementally useful functions that provide a selection advantage. The accumulation of random beneficial mutations might be parsimonious in bacteria given their reproduction rates and the recombinant power of freely exchanging DNA for 3800+ million years. In eukaryotes, the accumulation of random beneficial mutations producing a new species is like expecting Brownian motion to separate out the cream from your coffee.

MacAllister, "I want to follow up on that. Lynn has asked, can you give an example of a case where you have the accumulation of random mutation causing a speciation event?"

Margulis, "And you have the documentation of it?"

Dawkins, "Well let's not, why concentrate on mutation? It's selection we're talking about, or simply drift. Drift in geographical separation. [58:57]"

No one has argued that natural selection is not required for evolution. The argument concerns "on what does natural selection act?" Antcliff and Noble argued earlier in the debate (see pages 39 and 44) what Dawkins claims here: that genetic drift is separate from mutation. However, neo-Darwinism claims that genotypic diversity in a population results from the accumulation of random beneficial mutations. Therefore, without mutation, there would be no diversity to be reduced through natural selection and geographic isolation.

Margulis, "This is back to what Werner's saying. Natural selection is going on all the time, and geological, geographical separation is going on all the time, and certainly that doesn't preclude, it's, the process of evolution absolutely requires what you're drawing here. Nothing I've said has anything to do with natural selection acting, it's, whether it acts on symbiotic partnerships or individual lineages where mutational change is acted on."

Dawkins, "But do you think a new bacterium was incorporated with every speciation event, for example, the separation between chimps and humans? Did some new symbiont come..."

Margulis, "No, I actually think that in addition to geographical isolation and, in addition to some mutations also, I think that the big event there is karyotypic fissioning anyway. You know about karyotypic fissioning?"

Dawkins, "Yeah."

Margulis, "Yeah, well that's what I think is the best [explanation for speciation] for mammals."

Dawkins, "But that's not a new symbiont."

Margulis, "It's not a new symbiont, no. It is a behavior of the symbiotic residue in the chromatin relative to the rest of the chromatin. It takes a long time to explain it, and it's a derived feature of something that ultimately started as a symbiosis, but no it wasn't a new symbiosis (Todd 2000). The case you guys ought to know about is *Hatena*, thought, do you know about *Hatena*? It's a case. It's a single case."

Dawkins, "We don't want another anecdote. I mean, this is..."

Margulis, "OK. No anecdote." [1:00:40]

Dawkins rhetoric again uses loaded language: Margulis's case of *Hatena* and her previous examples are dismissed as "anecdotes." In science, "anecdotal" means an account based on personal experience that fails to use proper scientific rigor. Anecdotes are unreliable. Dawkins has not provided even one example of the neo-darwinist hypothesis from nature, lab or fossil record. The Modern Synthesis is based on statistical models of hypothesized populations living in isolation with little or no accounting for the influence of a

changing natural environmental and ecological conditions over geologic time. Dawkins own singular anecdote was his “story” of geographic isolation in the debate (see pages 37-38).

Margulis’s example of recent symbiogenesis in a protist, *Hatena*, documents the acquisition of “a genome at a swallow.” *Hatena arenicola*, a single-celled dinomastigote (dinoflagellate), contains a single endosymbiotic green alga, *Nephroselmis*. Only one of the *Hatena* offspring inherits the endosymbiont alga during reproductive mitotic division. The other *Hatena* cell must differentiate a mouth, swim out and ingest a *Nephroselmis* alga to acquire its endosymbiont. Inherited or ingested, once acquired, the alga will continue to be inherited by one of its two offspring cells through many reproductive divisions while the other offspring will ingest a first-generation endosymbiont. A side note: hatena means surprise in Japanese (Okamoto and Inouye 2006).

A unidentified participant brings up these salient points: while the discussion has focused on evolution in terms of mutation, the number of mistakes made by polymerase while copying DNA has been measured and is very low. The participant remarks that the debate has concentrated on evolution in organisms that have animal-style sexual reproduction and by contrast, she draws a parallel between symbiogenesis and bacterial conjugation. The participant points out that thinking of evolution in terms of chimps-to-humans does not consider the very low numbers of mammals on the planet in comparison to all the bacteria. [1:01:40]

Dawkins, “Oh, that’s true.”

Participant, “It seems to be important because we are humans, so we care about humans a lot.”

Dawkins, “That’s true.”

Participant, “Technically speaking, it’s a very weird [unusual] phenomenon where you have a mutation which really gives real change. It’s not changing the code, basically, the big important mutations are in transcription of factors, wherein you change the way the code is read. So I think incorporating a piece of a genome could really give you a large amount of new information that you can interpret into new forms.” [1:02:11]

Dawkins, “That’s hugely important in prokaryotes, no question. But Lynn was suggesting it’s important in eukaryotes and in animals, and that’s just overstating the case.” [1:02:18]

The participant makes the point that “a piece of genome” if acquired by a eukaryote provides new possibilities in the way “the code is read.” She is not talking about prokaryotes. She makes an analogy between symbiogenesis in eukaryotes and bacterial conjugation because both provide “a large amount of new functional information that you can interpret into new forms.” This is demonstrated in the examples given by Margulis. Dawkins suggests that Margulis is overstating the role of symbiogenesis in eukaryotes, however, his own statement earlier that symbiogenesis has *nothing* to do with speciation in animals (see pages 45 and 46) is pure dogma since there is ample evidence which contradicts it.

Siegel, “Actually, this is a really interesting example that has to do with mutations. It turns out that if you were to graph the size of the genome and the number of mistakes that the polymerase makes, you get

almost a linear relationship. So, that we make approximately one to ten mistakes every time we replicate, based on the accuracy of our genome. HIV and flu make about one to ten mistakes every time they replicate their genome. And you can do it through, and basically that mutation rate is actually optimized in evolution so that you have a certain rate of evolution, not too fast, not too slow, and the critical experiment..."

Margulis, "The rate of mutation or evolution?" [1:03:02]

Siegel [ignoring the point of clarification from Margulis], "The critical experiment is this, I was working with *E. coli* and there are mutations that you can make in *E. coli* that either increase the accuracy of the polymerase or decrease the accuracy of the polymerase. If you let them [*E. coli*] free run, in every single case, they mutate back to the optimal rate of mutation. That actually shows that there's some advantage to mutating at a certain rate, not too high and not too slow. It's not because that helps them incorporate symbionts, it's because it allows them to undergo a progressive change to the environment."

The "law of the hammer" states, "if all you have is a hammer, everything looks like a nail." Margulis caricatures the biological/medical research community referring to them as the "*E. coli*/rat liver axis." *E. coli* represent all prokaryotes and a rat liver cell all eukaryotes. Margulis takes exception to such narrow scientific views of life's diversity. She has spent most of her professional career studying protocists, the kingdom that includes those organisms that Darwin describes as the odd and peculiar. He advised naturalists to study the "oddities and peculiarities" when seeking history, otherwise one is led to conclude that how things are now is like they have always been.

Siegel states that errors in transcription do not facilitate the incorporation of symbionts, but provides no explanation or proof.

Noble, "How would that [organisms] know? I'm puzzled about the "mechanism" there. How would the system, whatever you define the system there to be, know what is the correct rate? Because this looks like a backwards explanation to me. [1:03:48]

Siegel, "It does, the system does know because it actually mutates back to the..."

Noble, "Well that's right, but I think without an explanation of how that happens."

Siegel, "Well, explanations are human, phenomenon are nature."

Noble, "Oh dear! [Laughter]

Siegel, "The human explanation is that if you mutate it at too high a rate, that you make so many mistakes that you can't actually function. If you make too low a rate, then you're not flexible enough to the changing environment, so you actually don't outcompete your competitors.

Dawkins, "Now, who are you, though?"

Siegel, "The bacteria."

Dawkins, "Oh, if it's bacteria that's fine. It'll work. OK."

What is the "it" to which Dawkins refers with "It'll work?" Bacteria exchange ready-made functional genes with other bacteria by conjugation. This acquisition of functional sets of genes in prokaryotes is analogous to the acquisition of genomes in eukaryotes. The concept of non-interbreeding

species does not apply to prokaryotes whose behavior across strains is anthropomorphized as “promiscuous” and “miscegenation.” It is by this ancient “biotechnology” that bacteria spread capabilities (e.g., antibiotic resistance).

Werner, “Are you suggesting, though, that it also works for eukaryotes, right? And the fact that you have some...”

Siegel, “Our mutation rate is in that...”

Dawkins, “The optimum mutation rate in eukaryotes, I would suggest, is zero.”

Dawkins appears to agree that bacteria would optimize their mutation rates, but not so eukaryotes. If the mutation rate in eukaryotes were zero (genes immutable), according to neo-darwinists there would have been no evolution for the past 1800 million years. Why would this be the optimal situation?

Siegel, “But we could easily make a polymerase that's more mutational but we don't.”

Antcliffé, “I think the point of having a mutation rate is to maintain some variety in the gene pool.”

[1:04:45]

Dawkins, “That's the group selection explanation, yeah.” [1:04:48]

Margulis, “That's bad.”

Margulis points out that *group selection* is discouraged, even disallowed, by neo-darwinists. According to Catherine Peichel (2001), an expert on stickleback evolution, “Having a lot of genetic variation in the population means that if the environment changes, there may be some gene variant that does better in that new environment than in the previous one, and so nature selects for it. Genetic variation increases the chance of overall survival of the species.” Severe drought, famine, epidemic, etc. that might kill individuals or entire populations would have ramifications for communities and ecosystems.” This is obvious, yet neo-darwinists denigrate all forms of *group selection*.

Siegel, “The mutation rate in mice, because mice basically have about the same number of cancers, they have the same number of mutations approximately we do. They live for about one twentieth as long and they have about 100th as many cells. So, they actually have a higher mutation rate than humans do. Why don't mice have exact, I mean, they're eukaryotic polymerases, why don't they just have the most optimal low, low mutation rate polymerase possible? But they don't. [1:05:16]

Participant, “The problem with mutation is also, you can mutate all the time, but you get cancer or illness or whatever. The mutation must be in the germinal line, which is even more weird [rarely beneficial] event. So it's very low, low, low numbers. [1:05:30]

Salmen, “I think it also brings us back to the point that the human, in the earlier session, that if we look at a gene as a replicator, we also have to appreciate that it's not just the gene, but the “mechanism” by which the gene replicates. Do we call that whole system the gene or do we recognize it as just the gene? I think that that does suggest, I don't know. It complicates this argument to say that the optimal rate of mutation is determined within the gene. That adds...”

Siegel, “No, it's determined by the organism.” [1:06:00]

Salmen, “Well, then if it's determined by the organism, then that suggests that it's relationship around it...”

Noble, “You've shifted the concept of a gene away from the molecular biological definition.”

Margulis, “This is just what he's [Salmen] said.”

Salmen, “You [Siegel] mean you've turned the gene into something that's actually, the replicator into a relationship between those things as opposed to a code of DNA.” [1:06:18]

Werner, “I mean, I'd be interested in what, you know, you [Noble] and Richard [Dawkins] have some difference of opinion about the replicator concept. You know, in your book [Noble's *The Music of Life*] you basically have the opposite interpretation of, how do you call it? I would like to have you and Richard directly address that issue.”

Noble, “OK. I think we're using the word replicator in slightly difference senses, you see, because I regard a cell as also a replicator, and he says no, it reproduces. Now, what I then need to know is what's the difference between replication and reproduction.” [1:07:12]

Margulis, “There is a big difference.”¹³

Dawkins, “Let me try an analogy. One that I used before. It's the analogy of forest fires, bush fires. So we have a great prairie with dry grass and a fire starts, and sparks fly up and they land and they start a new fire. And sparks fly up and they start a new fire. So, every fire can be said to have a mother fire. So, we have mother fires and daughter fires, and there are lineages of fires. So these little fires clearly are reproducers. If they have parents and daughters, and sparks fly up from one and start a new fire. In order for there to be heredity, it would be necessary that something passes from parent fire to daughter fire which determines or influences the form of the fire. Now, these fires are different. Some of them have a slight blue tinge because there's copper in the soil, some of them burn faster than others because there's, it's a windy place. And what I'm saying is that the characteristics of these fires are all determined by the local conditions of the grass, the wind, the soil geology, etc., the soil chemistry. Nothing passes in the spark that goes from parent fire to daughter fire. If something did pass from the parent fire to the daughter fire, if something went in the sparks such that a blue fire here gave rise to a blue fire there, that would be true heredity. That would be true replication of something.” [1:08:47]

Something *is* carried between these parent and offspring fires, tiny embers (sparks) at the kindling temperature, $\approx 300^{\circ}\text{C}$. The heat needed to kindle dry grass is inherited from parent fire to offspring fire.

Noble, “Well, if it was something that was carried that made that happen.”

Dawkins, “That's right.”

Noble, “Yes, that's right.”

Dawkins, “Yes, something that determines the difference between these different fires.” [1:08:54]

¹³ [Noble] According to Lynn Margulis, replication is a molecular process, a chemical polymerization that links nucleotides to form complementary chains. Whereas *replication* occurs in the test tube without the presence of the living on site, *reproduction*, intrinsically a process of cells (and organisms composed of cells) is a property only of autopoietic entities i.e., live beings.

In this bush fire analogy, the heat to set the offspring fire would be the DNA. Like DNA it would explain the similarity between the fires, the differences between fires would be like epigenetics, a function of the environment and fuel available where the offspring fire started.

Noble, "So using that as the base story, I mean, it seems to me that the early cells must have done something that's different because they must have transmitted their membrane systems to the daughter cells. I mean, they just divide and they transmit that. So I'm saying that, in that sense, cells are inheritors that replicate."

Dawkins, "But only if there are differences between cells, and the focus is always on differences. If something non-genetic transmits differences, then you've got a point. But I'm suggesting that it probably doesn't." [1:09:35]

Noble, "Ah! Yes, that probably is where the fault line lies, because I think that I'm more inclined to take seriously the specificity of the cell in addition to the specificity of the genome, which is my explanation for why cross-species cloning is so extremely rare. I'll also repeat the point I made earlier on that I don't myself see why cells should not have evolved, just minus the genomes for a moment, as well as genomes evolving, which again would be an explanation for why cross-species cloning is so extremely rare. So probably the real fault line between us lies on the question of how specific is the cell information?" [1:10:25]

Dawkins, "Specific for me would have to mean individual differences."

Noble, "Between individuals, in other words, can there be variations?"

Dawkins, "Well, between cells at least."

Noble, "Well, let me then, I think I'll have to do another step as a physiologist. I find when I study heart cells, none of them are the same. It's actually remarkable. The stochasticity in gene expression..."

Dawkins, "Within one heart?"

Noble, "Yes, within one heart. The stochasticity..."

Dawkins, "They're a clone. They're not, the genetics are identical." [1:11:01]

Noble, "They've got, yes, but let's try to sort of focus on what it is that is actually different here. Clearly these have all got the same genome."

Dawkins, "Yeah."

Noble, "Their expression levels, I'm saying, are different from one cell to another. Now, we also think that it is the case that, you see, to some extent this makes sense in terms of preventing cardiac arrhythmia because some of those differences are actually functionally significant in terms of trying to prevent reentrant arrhythmia. Sorry for the technicality here. Now, a cell that's in the right region to be, say, an endocardial cell, or an epicardial cell, with different expression levels, knows that it is that. And therefore, its inheritance is actually carried through to the next generation. So I would say that within multi-cellular organisms there are processes that at least..."

Dawkins, "Yeah, though this can be cytoplasmic inheritance within mitotic..." [1:12:04]

Noble, "Would it be what the old geneticists would have called *cytoplasmic inheritance*, yes that's right. Though again, I find I have a difficulty here, because of course part of the way in which that is expressed is by that cytoplasmic inheritance affecting epigenetically the genome. So ..."

Dawkins, "Well, if it does ..."

Noble, "So it's, you know, it's such an inextricable mix-up, isn't it?"

Dawkins, "Yeah. But sort of, we've known about this because liver cells give rise to liver cells and kidney cells give rise to kidney cells."

Noble, "Yes, indeed so, yes."

Dawkins, "They're all having the same genetics."

Noble, "Yes, exactly, yes. But the variations on that, which come down to saying that there's also both nice gradations, nice in the sense that they're meaningful, gradations in expression levels that seem to mean something functionally in the case of the heart. I don't know about the liver because I don't work on it. And in addition to that, there is considerable stochasticity so that if I, for example, put one of Rodger Chen's nice florescent proteins to measure the gene expression levels in neighboring cells, I find even neighboring cells light up to enormously different degrees, which is pretty astounding. So, what I suppose I'm suggesting is that if that happens in multi-cellular organisms, I don't see why it shouldn't happen in unicellular organisms, and then we're back to the question, could there be differences that get transmitted? You see why I'm at least coming from a very different position to pay more attention to the inheritance of epigenetics than would be usually the case from the kind of position that you've come from?"

Dawkins, "If you study the mitotic lineages of cells within a body, liver cells beget liver cells, heart cells beget, so quite clearly there is a non-genetic inheritance mitotically within an organism..."

Noble, "Yeah, which is straightforward and called epigenetic inheritance."

Dawkins, "You could call it epigenetic inheritance."

Noble, "It's sort of the old idea of a 'cytoplasmic inheritance' doesn't quite capture the process of epigenetics, does it? That's the problem, yeah."

Dawkins, "And then if that then carries on to the next generation, and which it appears to do, at least for a few generations..."

Noble, "Yes, that's right, yeah."

Dawkins, "That's kind of interesting. But it doesn't really infringe the patent that DNA has on eternity." [1:14:25]

Noble introduces the problem of cell differentiation seen in many multicellular eukaryotes, including humans. The same organism displays a decidedly enormous range of cell types within its tissues and organs; almost all have the identical genomes. How is this phenotypic difference explained if the DNA alone controls phenotype? Dawkins follows the argument, "That's kind of interesting." The obvious conclusion: that more is going on than DNA alone explains, he downplays, "it doesn't infringe the patent that DNA has

on eternity.” No matter how many times Dawkins repeats dogmatic statements (argumentum ad nauseam) or embellishes them with quasi-religious claims (e.g., “patent on eternity”), he fails to muster observational support or data for “gene-determined evolution”. Yes, DNA does encode information, and mutations do change that information, but the inherited organismal systems that are reproduced and perpetuated (i.e., “naturally selected”) involve metabolism, growth, development, reproduction, social and ecological systems that are far more complex, nuanced and complicit than just a static DNA/RNA informational macromolecular “mechanism.” What exactly is the “patent that DNA has on eternity”? Dawkins asserts that to change (evolve), an organism’s DNA/RNA must change. The gene (DNA/RNA) is replaced by a mutated form. No species of animal alive at the end of the Cambrian survives today, 542 million years later. Genes are not immortal and everlasting. How can they be if mutations form the basis of evolution? The argument is over the sources of *novelty* and its contribution to evolution. Novelty is the opposite of eternal.

Wallin (1927) fully notes that cell differentiation into specialized tissues and organs in animals needs to be understood as interactions, metabolic and reproductive, between inherited units that comprise the populations inside cells. He argued that organellar components, notably mitochondria (of eukaryotic cells), for him primarily cells of animal tissue, are products of the integration of original symbiotic bacteria. He called the cells and tissues “microsymbiotic complexes”. Multiple copies of organelles and genes within them and within nuclei generate redundancy by provision of extra microsymbionts and their genes that with time may be used for multiple and new purposes.

Noble, “Ah, well that’s where [we disagree].”

Dawkins, “Which is an empirical question as you’ve said.”

Noble, “You see, that’s right, we agreed on that, that’s right. The question of immortality, you see, I come back to the case that my germ line goes back, you know, an immortal line.” [1:14:43]

Dawkins, “Oh, but that’s your germ line...”

Noble, “Yes, and goes all the way back to the cells that he’s [Bell] dealing with.”

Dawkins, “Yes, but as far as we know, that’s the DNA and...”

Noble, “No, that’s where I’m not sure.”

Dawkins, “We don’t know. We don’t know, but I’d be surprised.” [1:14:57]

Noble, “But it’s very nice to get to the point, Richard, where you and I now agree on what we don’t agree on, which is a very, very good state to be at. We’ve taken 30 years, roughly speaking to get to this point.” [1:15:10]

Dawkins’s arguments for the gene’s eye view were devastated repeatedly throughout the debate. His comment, “ We don’t know, but I’d be surprised,” is most telling. He refused to be surprised, even when presented with compelling evidence that, no matter what the truth might be, the best evidence refutes most of the gene’s eye view. Dawkins has written *The God Delusion*, excoriating faith when it contradicts evidence, but he reveals himself to be closed to surprise. He clings to the orthodox mainstream idea of the

past 70 years as if scientific hypotheses may not be falsified and are chiseled, like the Ten Commandments, in stone.

Bell, “We should also point out, though, that epigenetic cues and epigenetic phenomena are restricted to, for want of a better word, “higher organisms” [eukaryotes]. I mean, those are really metazoan-specific phenomena, and maybe, to some degree, in yeast. Certainly there's no evidence that I'm aware of in bacteria or Archaea of epigenetics.”

Noble, “Yes, and if I can just answer that, I'm not a, I'm not a geneticist, ..but let me try to answer what I think you're getting at. It seems to me that the reason why it's in the “higher organisms” [eukaryotes] that one really should ...be looking for possible epigenetic inheritance even across generations, let alone within a same body. It's simply this: that it's in those organisms that the genome is so completely broken up. The number of possible expressions of the same gene is so large, I quoted earlier on the DSCAM example [downs syndrome cell adhesion molecule], but there are many other examples now. I think it's probably the case that more genes in man are broken up than are not broken up. But then you've got to have something else that tells the system, that works out what it expresses from that gene at this time, at that time, and so on. If you look at DSCAM again in drosophila, what you find is that the expression levels of the different splicings that could occur, occur differently during these various stages of development. Now, what makes all that happen? What programs all of that is very interesting, whether that lies all in the DNA or not, it seems to me, is an open question. I think it's open in the case of the very highest organisms precisely because the genome is so broken up. That's the answer I would give.” [1:17:09]

Participant, “In talking about the epigenetics. You can put marks in the histones, like methylation, and acetylation, and that can tell you which gene transcribed or which gene was silenced. And even if in bacteria there are no histones, there is some light proteins, which can fold the DNA as well. And these kinds of errors, which are now coded in the DNA itself, are just passed through a cell to another in the division and at least in the brain, that's quite important.”

Bell, “I mean, but that's a fundamental difference.”

Second Participant, “Even this argument itself is too simplistic because if you look at the level of the immune cell, for example, their differentiation processes depend on cytokine environment.”

Noble, “Exactly.”

Second Participant, “What kind of microbe or organism or even antigen or peptide are affecting the differentiation processes? So to simplify epigenetics to just things like methylation or histone acetylation is far too simplistic to ...”

Noble, “Yes, I agree, and it's no surprise, is it that the, if I remember rightly, the DSCAM system is actually used a lot in the immune system of a fruit fly? Somebody needs to check that, because again – [1:18:27]

Second Participant, “Yeah, I'm not sure about that.”

Noble, "I think that's the case. But you need, it would make sense, because it would give you an enormous range even before all of the factors that you are referring to, is that right?"

Second Participant, "That's true, and also, there's this phenomenon called *paramutation* which occurs in plants, where there's an effect such that the actual affect of the gene or the variant of the gene differs based on the parent that it's inherited from. And they've only just found an example of this in mice, and it was published in Science, I can't remember the details of the paper. Basically what happens in the sperm is that there's a lot of accumulation of RNA. And that actually affects the expression of the gene even before the organism develops. So I mean, it's even changes like that that need to be considered." [1:19:16]

Noble, "Yup, the few cases that we know, I think, of paternal effects transmitted down the generations have been attributed to RNA in the sperm."

Second Participant, "Yeah. Maternal effects exist as well, but I think the statistics that are needed to prove that maternal effects exist haven't yet been developed."

Noble, "There's a lot more work to be done here, I would agree, yeah."

Werner, "Let me get into the issue of the interpretive mechanism that interprets the genome, executes its instructions. Steve's [Bell] example showed that even the evolution of these, what are they? These bacteria..."

Bell, "Archaea."

Werner, "If you have a gradual co-evolution of the interpretive mechanism with the genome. Right?"

Noble, "Right. And that's what he referred to, yes." [1:20:10]

Werner, "So in effect, you do have this co-evolution. You have this high dependence between the interpretive system and the genome. But I tend to side with Richard more in the sense that, there seems to be a programmatic aspect. I think what he's [Dawkins] getting at or it's pretty obvious from the amount of information in the genome, which far outweighs the information in the cell."

Noble, "That's where you and I disagree."

Werner, "What Richard is saying, and what I'm saying too is that the information that's transferred, right? That's actually involved in the morphogenesis, given an interpretive mechanism, is primarily in the genome. That's what determines whether you have three arms or four arms or ten arms. It's not the egg. And you're saying, and this is, you're on thin ice there, because you will be affected by the Muller's ratchet. Right?"

Noble, "I like to be on thin ice. I'm an explorer." [1:21:09]

Werner, "Because the egg, the cell, even if it has a defect, right? This defect would be continued by template reproduction and the next thing. Any defect, by Muller's Ratchet, any deleterious effect would continue." [1:21:30]

Noble, "Yeah, this is Maynard-Smith's argument."

Werner, "Yeah, it's Muller, you know."

Noble, "That's where I first heard of it, yeah."

Werner, "Whereas with the genome, through sexual reproduction, they would be trying to get rid of that. So I mean, that's where the problem is with having just cell template reproduction. And that's why the genomes are so nice, because they're digital, relatively, they can be reproduced, they can be modified and all that." [1:21:55]

Noble, "Yeah. The difficulty, I think, is that it seems to me that most mutations are deleterious."

Dawkins, "Well, more than seems to you, it's true."

Noble, "Yeah. So I'm not quite sure that that is the criteria."

Werner, "The trouble is, you don't have sexual reproduction ahead of it [the egg cell of animals]. If you rely on the cells with sexual reproduction, you can get rid of the Muller ratchet problem. Whereas, if you just have the cell, which is passed on from the maternal whatever to the next generation, that would then copy the defect. And that's one reason you need genomes." [1:22:38]

Noble, "I would suggest that it's worth reading a book that has come out just recently, *Freaks of Nature*, by Mark Blumberg, which is another variation on how, from the same genome you can get extremely different phenotypes. But I agree with you, Eric [Werner], this is where our fault line lies. But for you and I, we've tried for about two years now to argue out. Is there more information in the egg cell compared to the genome? And we don't seem to have gotten to the point where we agree."

Werner, "We're getting closer."

Noble, "We're getting closer maybe, yes."

Noble, "OK, two finishing comments, and then we'll go around the panel."

Siegel, "Yeah, well actually I'd like to pounce, I want to pose two experiments that are both doable. First experiment is taking the genome, the nucleus from one organism and putting it into the egg, the cytoplasm of another organism, what are you going to get out? OK?" [1:23:49]

Noble, "Nothing. We know already, it's been done many times."¹⁴

Siegel, "No, in fact Dolly, the original experiment was put into, I mean, it wasn't a different species, but it was actually a different breed, and the progeny, Dolly reflected only the genomic information, it didn't reflect the cytoplasmic information." [1:24:04]

Noble, "No, no, excuse me, I think the, we need to go through the references clearly, because I think the biggest range of evidence in cross-species cloning is that they nearly all do not work. You can get stem cells, certainly, you can get embryonic stem cells, but you can't get an organism. I'll give you the references for that."

Siegel, "But also the fact that it doesn't work, I mean, cloning didn't work for a long time until it did work."

¹⁴ [Noble] That was thought to be true at the time. In fact there is an exception: Sun et al 2005, the goldfish-carp cross-species clone, and it shows that cytoplasmic inheritance can influence the number of vertebrae and the overall body shape.

Noble, "Wait a minute, evidence is evidence." [1:24:36]

Siegel, "No, no, lack of, you're saying lack of evidence is proof of non-existence."

Noble, "No, no, no. This is evidence. You don't get organisms. Also, I have a difficulty with, why did we transfer the whole nucleus? That is also already not transferring the genome."

Siegel, "Agreed. The second experiment is: you can actually eliminate all the symbionts in the human gut, which is the majority of cells in our body. You can replace them with symbionts from another organism. Will that cause a speciation event?"

Siegel pounces with two experiments: the first experiment has been done many times and fails to produce an offspring like the DNA donor. Siegel finally agreed that his idea did not isolate the DNA, but involved the nucleus that is part of the cellular cytoskeletal system; the second experiment uses equally flawed logic. You might be able to replace all of the symbionts in a human with the symbionts of another organism, but they would simply be foreign organisms with no symbiotic relationship to the human.

Bell, "Can I just actually though address your first point, first, which was the DNA transfer experiment. I agree with how in eukaryotes it doesn't work, but with bacteria it's been done. Craig Venter has actually taken the genome of one organism, stuck it into the shell, if you like, of another organism, whether we can call it a species, or not, two different bacterial species, and shown unequivocally that you restore life to that chimeric organism. So it can be done, at least in the microbial field. But again epigenetics [are eukaryotic phenomena]."

Noble, "Should we do that final round up and see whether any of the panel, maybe starting with Martin [Brasier]." [1:26:55]

Brasier, "Thank you, yes. Can I just say to my colleagues how much I've enjoyed the discussions this evening? It's been very convivial, refreshing. I think we have found, certainly, those points of disagreement and actually quite a measure of agreement. It's delightful to hear Richard say he thought symbiosis was important, if rare. I would simply make the point that, as seen from the point of view of a geobiologist, these symbiogenetic events were significant and were important and have had--certainly it's a thing we have to take very much account of--have a huge impact now on the carbon budgets of the planet and obviously some of the major evolutionary stepping stones such as the origins of the eukaryotes." [1:27:41]

Noble, "Steve [Bell], if you want to say anything.

Bell, "Sure, I think a lot of what we've heard tonight has been argued from a very eukaryotic perspective. And I'm not a eukaryote [eukaryote expert]."

Noble, "You would say that, yes."

Bell, "Yeah, and I am very prokaryotic [an expert in prokaryotes]. I think what we have to remember is that many of these events may have occurred early in evolutionary history, and they may be restricted with the systems are now in place in "higher organisms", if you like. That's certainly, you know, the events

of the symbiogenesis, I think arguably have occurred during evolution. Certainly more organisms and possibly in the birth of eukaryotes. Think of the bugs, basically.” [1:28:23]

Noble, “Richard [Dawkins], do you want to say anything in conclusion?”

Dawkins, “Well, obviously, I mean, prokaryotes are hugely important, and you know, most organisms are prokaryotes, we're mostly prokaryotes, and so much of what I know about biology is irrelevant to the majority of biology. [Laughter] But on the other hand, claims have been made about eukaryotes, which seem to me to be a kind of imperialistic generalization from prokaryotes. So just to reiterate that point, within, eukaryotes are almost entirely prokaryotic in their own cells, that's undoubted. The only point I was disputing after dinner was the suggestion that speciation events are themselves initiated by new symbiotic incursions. I'm pretty sure they're not. While fully admitting that eukaryotes are, themselves, massively symbiotically invaded. But it's all in the past. So, I reiterate that symbiotic invasions are relatively rare, but very important when they happen. On the pre-dinner discussion [Parts 1 and 2], I would reiterate the point that what really matters--the difference between Dennis and me-- is that no matter how important non-genetic elements are in life, and of course they're important, as far as natural selection is concerned, and only as far as natural selection is concerned, what matters is what makes the difference between individual entities that are selected versus individuals that are not. Those differences have to be hereditary differences, and they have to go on for many, many generations. So it doesn't matter how complicated the relationship of genes to their embryonic environment is, it doesn't matter how intricate the feedback loops are, if the differences between individuals can be dissected out by geneticists, natural selection is just like a geneticist. Natural selection simply cares about individual difference, who survives, who doesn't survive, and the consequence of who survives and who doesn't survive is ultimately only a genetic consequence, where genetic is defined generally to include anything that is potentially eternally heritable. That's my point.” [1:30:49]

A bit of self-deprecating humor warmed the audience for Dawkins's closing comments. Dawkins knows and has written brilliantly about evolutionary biology, a century of thought that began with Darwin and culminated with a 1940's mathematical and statistical model of animal evolution, the Modern Synthesis. Ever since, the biological sciences have been trying to pound a tree-shaped peg into a net or web-shaped hole. “There is currently much discussion of the prokaryotic ‘tree of life’, but there are few points of agreement regarding its topology, except that it is not a tree” (Lake 2008). “The increasing recognition that symbioses have greatly altered evolution through genome fusions is creating a need for algorithms that can reliably detect and reconstruct fusions.” (Lake 2009). To repeat Jonathan Bard's comment early in the Homage debate, “It's just not terribly helpful to take the gene's eye view. It's not so much that it's wrong, but it isn't much use...”

Evolution is the history of the dynamic complex Earth system, Gaia. It is not exclusively about the process of living matter. Evolution most certainly cannot be modeled on animals or plants. It cannot be

understood by concentrating on “individuals” or “pure cultures.” It cannot be unraveled by knowing everything there is to know about DNA and RNA.

Dawkins rhetoric is masterful, but in this entire debate, he provides only a single example of a proof. About his statement that junk DNA is “rubbish, that’s left lying around on the hard disk,” Related species of salamander have genomes that differ in size by orders of magnitude. He claims that “any kind of functional explanation is improbable.” Some organisms genomes change in size as a function of the amount of phosphorus they are storing there (Parfrey 2010). Otherwise, Dawkins used glittering generalities, judged, opined, asserted and repeated with little or no evidence. I agree with Dawkins when he says there is a kind of imperialism in evolution. However, I argue that it is neo-Dawinism with ideas largely based in mathematical models and statistics with scant evidence from nature that is imperial. Neo-darwinists make liberal use of Occam’s broom: contrary evidence is “swept under the rug”, ignored, judged inadequate, deemed anecdotal, or conceded to happen, but only rarely and relegated to the long distant past.

Noble sums up the evening’s discussion, “There’s often, in these discussions, a lot of debate about bringing evo and devo [evolutionary and developmental biology] together. Somehow or other, bridging the difference between the gradualists and the saltationists and so on. I would like to suggest, and I hope that this discussion has partly illustrated that, that it might also now be useful to bring some physiological-cumsystems-biological perspective into these discussions because I think that while I would accept what you’ve [Margulis] just said about complexity per se, I think also that to some extent at least, the devil lies in a lot of the detail. And I think that as physiology resurrects itself, after it’s been swept aside by molecular biology for the last 40 years, roughly speaking, I think it’s going to make many more contributions to these kinds of discussions than has been traditional in my subject in the past. I’m extremely rare, being a physiologist who’s prepared to take part in these debates, ...there’s been very little input from the physiological end into all of this, and I think that there should be more. Lynn, over to you, this was your show and you can have the last word. “[1:32:41]

Margulis, “...I’m just feeling humble, and not because lots of criticisms were made [of my ideas], but I would take your point about, there’s never a single cause. You can never do only one thing, and to take an exclusivist attitude toward any of this as if there were a single, correct answer, is suffering from test-itis, I guess it is called. That is, that’s true on a test. It’s true for tests, but it’s not ever true for nature. And so I just...”

Dawkins, “You don’t mean testosterone-itis?”

Margulis, “No, maybe that, too. [Laughter] No, but it’s only on the tests that there’s one correct answer that’s definitive. It’s never true at all in nature. And I just think, I just think, well I quote McHarg [Ian McHarg, landscape architect, ecological planner and environmentalist, University of Pennsylvania], ‘the Earth is not divisible.’ And furthermore, everything is a function of history. Everything. Which makes us underestimate the importance of a very good fossil record in almost everything we talk about. It can’t be interpreted because we don’t have any protistologists who know what, who are alive any more. So I mean,

and to dismiss that record, which is done all the time by evolutionary biologists, makes me very sad. Because a lot of data is known. Almost everything that I've discovered in our own work was done by really fine scientists. But they didn't publish in *Nature* and *Science*, and they didn't publish in the last ten years. They published over a long period of time, and they didn't get paid for getting grants. They got paid because they were professors allowed to pursue the scientific questions that they were interested in: Kirby, Cleveland, and the rest. So, I think it's terribly important to realize that human history is a very tiny subfield in something called natural history, and I for one am very proud to be in that field that doesn't have any grant money, I mean, it doesn't even exist. But that's really the field that is of interest [to me]. That's all.”
[1:35:05]

Noble, “Well, I think this is where we close and say that Balliol is extremely privileged to have the Eastman professors, and to particularly have one who's been so provocative, so active, so, well, I know the word is to stimulate the whole of a debate like this. But not just this evening, throughout virtually the whole year that you've been here, Lynn. Thank you very much.”[1:35:28]

Reflections of an Enlightened Chairman
Afterword
On Voices from Oxford
Homage to Darwin: EVOLUTION
The Balliol College Debate Video & Commentary
Denis Noble
Department of Physiology, Anatomy & Genetics
Oxford University

Richard Dawkins and I have interacted on and off for nearly 40 years now, since even before *The Selfish Gene* (1976). We both know and respect the fact that we disagree about neo-Darwinism, as made clear in *The Music of Life* (Noble, 2006), acknowledged here in MacAllister's transcript and commentary (page 64) and expressed in the video recording itself (at 1:14:43). When Lynn invited me to chair the debate, therefore, I fully expected the disagreements to appear although I tried to be a neutral chairman. That was my role and is why open disagreement occurs so late in the debate.

I also think we owe Richard a vote of thanks for his participation. He is a formidable advocate of science in the public domain. The quality of his popular writing is widely admired. I do not disagree with him, therefore, for trivial reasons.

On the contrary, the origins of the disagreement go very deep. I am a physiologist, and I have always found it difficult to accept that the organism should be relegated to the role of a transient vehicle for its "potentially eternal" genes (see page 4). Functionality lies in high-level phenotypes, such as heartbeats and respiratory rhythms. Those, surely, are the targets of selection: they determine whether we live or die. Bits of DNA can't be the target, they have no such functionality. Their interpretation intrinsically depends entirely on context. Moreover, in my own field of study of heart rhythm, it is easily shown that a purely 'genetic program' cannot be the determinant of that rhythm (Chapter 5 in *The Music of Life*). I first expressed these arguments in writing in *The Music of Life*. Writing that book was a watershed in my thinking about evolution.

The *Homage to Darwin* debate was a second watershed. Like Jim MacAllister, I was deeply puzzled by many of Richard Dawkin's statements, and by what appeared to me to be a glaring problem in the evolutionary biology story as it is often related. My puzzlement is expressed most dramatically in the recording (c. 54:07min) by drawing attention to the certainty with which possible evolutionary mechanisms are asserted with very little actual evidence. When the challenge was thrown out to the participants there was what Jim calls a "telling moment of silence". The way I chose to formulate the challenge was to say that, looking back over the evolutionary process, it might be difficult to distinguish the mechanisms. The

reason is simple. Any alternative process to that of gradual accumulation of mutations would become assimilated into the genome, *even if its origin were Lamarckian*, i.e. triggered in response to the environment. The idea of genetic assimilation was expressed by Waddington many years ago (Bard 2008). We would then need to look for detailed clues in the way in which genome sequences [and their expression] compare between different species [or even in different individuals in the same populations]. When we do that we find that

“The 2001 Nature report of the draft human genome contained two important figures illustrating what genome sequencing had taught us about protein evolution. Using transcription factors and chromatin binding proteins as examples, the figures showed that these classes of protein did not evolve one amino acid at a time. Instead, the two classes of protein “shuffled” and “accreted” copies of functional protein segments called domains as eukaryotes progressed from yeast through nematode worms and *Drosophila* flies to mice and human beings. In other words, proteins diversify through a process of acquiring, amplifying, and rearranging coding sequences for subprotein structures that may be dozens or hundreds of amino acids in length.” (Shapiro, 2011, p 95)

Of course, Shapiro refers to the ancestors of the modern forms, but that the evidence must come from comparison of extant genomic sequences is clear enough.

The debate therefore forced me to go back and do some hard thinking. I had already begun in an article called *Genes and Causation* (Noble, 2008) which introduces what I call the ‘genetic differential effect problem’. Contrary to the view that “only differences in genes are reflected in differences in phenotype”, genetic mutations and knockouts are most frequently buffered and so are *not* necessarily reflected in phenotypes, while a wide range of phenotypes can be expressed using precisely the same genome. This is such a glaring mistake that I could hardly believe that it could have been made, and even less that it should have been a central plank of the neo-darwinist interpretation. Then it suddenly dawned on me that, as many others already indicated, the concept of “a gene” has changed. And it has changed in precisely the way that generates this mistake.

The ‘gene’ was originally the inheritable but hidden (‘hypothetical entity’, Mendel’s “factor”) cause of a phenotype. This is what neo-darwinists mean when they refer to a ‘gene’ as ‘the gene for’ a particular phenotype. The term ‘gene’ was used as a surrogate for ‘that specific phenotype’ actually selected. Using that definition of a gene, the argument is circular; it is necessarily true. But ‘gene’ now means a DNA sequence that does not necessarily have a phenotype! And when the gene does specify a measurable phenotype it is context dependent. The change in definition totally changes the meaning of any statement about genetic causality (Noble 2008).

The confusion over what is meant by ‘a gene’ is central. It is also quite a challenge to tease out the linguistic, scientific and philosophical problems that have been created. This is the purpose of my article in the *Journal of Physiology* (Noble 2011a). My conclusion there is that

“The selfish gene idea is not useful in the physiological sciences, since selfishness cannot be defined as an intrinsic property of nucleotide sequences independently of gene frequency, i.e. the ‘success’ in the gene pool that is supposed to be attributable to the ‘selfish’ property. It is not a physiologically testable hypothesis.” “It is a strange hypothesis that uses its own definition of its postulated entity as its only prediction.”

Jonathan Bard makes a related, essentially similar, point about the utility of the idea in his opening question in the debate [at Marker 6].

The ‘teasing out’ of the confusion has occupied much of my recent writing. Further problems with the idea of genetic causality are analysed in Noble (2010), while the ‘genetic differential effect problem’ is analysed in Noble (2011b) and Noble (2012). The central insight of those articles is that biology needs to escape from the limitations of the ‘difference’ approach. Unlike the days when we had to define genes as hidden entities, and where measuring differences (strictly therefore the consequences of different alleles at the same locus) was all we could do, we may now identify the genetic material with a chemical, DNA. Like other chemicals in the organism, such as proteins, metabolites, lipids, we can ask questions about their integrated effects. They are multiple as physiology recognizes. It would be as absurd to restrict my science to studying differences as it would be to restrict mathematics to differential calculus, as though the integral sign had never been invented. It seems to me that neo-Dawinism uses the ideas of the mid-twentieth century. The metaphors it uses and favors struggle to reflect what molecular biology has revealed in the last part of that century and the first decade of the 21st century (Shapiro, 2011). It is time to move on.

I am delighted to have chaired the *Homage to Darwin* debate. It was the direct stimulus for my work referred to in this afterword.

Note: all the articles by the author referred to here can be downloaded as the *Music of Life Sourcebook* on www.musicoflife.co.uk

Bard, J. B. L. 2008 Waddington’s legacy to developmental and theoretical biology. *Biol. Theory* **3**, 188–197.

Dawkins, R (1976) *The Selfish Gene*. OUP

Noble, D (2006) *The Music of Life*. OUP

Noble D. (2008). Genes and Causation. *Philosophical Transactions of the Royal Society A* **366**, 3001-3015.

Noble D. (2010a). Biophysics and Systems Biology. *Philosophical Transactions of the Royal Society A* **368**, 1125-1139.

Noble D. (2011a). Neo-Darwinism, the Modern Synthesis, and Selfish Genes: are they of use in physiology? *Journal of Physiology* **589**, 1007-1015.

Noble D. (2011b). Differential and integral views of genetics in computational systems biology. *Journal of the Royal Society Interface Focus* **1**, 7-15.

Noble, D. (2012). A Biological Theory of Relativity. No privileged level of causation. *Journal of the Royal Society Interface Focus* **2**, in press

References for A Commentary On Homage To Darwin Debate

Arthur W (2004) "Toward a spineless stickleback." *Heredity* 93:239–240.

Bermudes D and Back R (1989) "Symbiosis Inferred from the Fossil Record" in *Symbiosis as a Source of Evolutionary Innovation: speciation and morphogenesis*.

Blumberg M (2009) *Freaks of Nature: What Anomalies Tell Us About Development and Evolution*. Oxford University Press. New York, NY.

Boyle JE, Smith DC (1975) "Biochemical Interactions Between Symbionts of *Convoluta roscoffensis*." *Proceedings of The Royal Society of London Series B-Biological Sciences* 189:121

Brorson O, Brorson S, Scythes J, MacAllister J, Wier A and Margulis L (2009) "Destruction of spirochete *Borrelia burgdorferi* round-body propagules (RBs) by the antibiotic Tigecycline." *Proceedings of the National Academy of Science (USA)* November 3, 2009 vol. 106 no. 44 18656-18661

Chapman, M and Alliegro, M (2012) "The Karyomastigont as an Evolutionary Seme." *The Quarterly Review of Biology*, 87:315-324.

Chouard T (2010) Revenge of the hopeful monster. *Nature*, 18:463:864-7.

Davidson A, Chiba S, Barton N and Clarke B (2005) "Speciation and Gene Flow between Snails of Opposite Chirality." *Public Library of Science (PLOS) Biology* 3:9 www.plosbiology.org.

Dolan MF, Melnitsky H, Margulis L, Kolnicki R (2002) "Motility proteins and the origin of the nucleus." *The Anatomical record*. 268:290-301.

Doolittle WF (1999) "Phylogenetic classification and the universal tree." *Science*. 284:2124-2129.

Dubinina G, Grabovich M, Leshcheva N, Rainy F and Gavrish E (2010) "*Spirochaeta perfilievii* sp. nov., oxygen-tolerant, sulfide oxidizing, sulfur and thiosulfate-reducing spirochete isolated from a saline spring." *International Journal of Systemic and Evolutionary Microbiology*, in press.

Fleck L (1935) [1979] *Genesis and Development of Scientific Fact*. 1981 edition. University of Chicago Press. Chicago IL.

Fuerst J and Webb R (1991) "Membrane-bounded nucleoid in the eubacterium *Gemmata obscuriglobus*." *Proceedings of the National Academy of Science (USA)* 88:8184-8188.

Garrity G, Brenner D and Krieg N (2005) *Bergey's manual of systematic bacteriology* (2nd ed.) Springer, New York, NY.

Gould S and Eldridge N (1993) "Punctuated equilibrium comes of age." *Nature* 366 (6452, 1993): 223-227.

Hall JL and D J Luck (1995) "Basal body-associated DNA: in situ studies in *Chlamydomonas reinhardtii*." *Proceedings of the National Academy of Science (USA)* 92: 129-5133.

Hall JL (2011) "Spirochete contribution to the eukaryotic genome." *Proceedings of the National Academy of Science (USA)*, submitted.

Honegger R (2000) "Schwendener S (1829-1919) and the Dual Hypothesis of Lichens." *The Bryologist* 103:307-313.

Janicki C. 1915. "Untersuchungen an parasitischen Flagellaten." *Zeitschr Wissensch Zool* 112:573-691.

Jeon KW and Hah JC (1977) "Effect of chloramphenicol on bacterial endosymbionts in a strain of *Amoeba proteus*." *J Protozoology*. May;24(2):289-93

Jeon, KW (1991) in *Symbiosis as a Source of Evolutionary Innovation* (eds Margulis, L and Fester, R) 118-131, MIT Press, Cambridge, MA.

Keeble F (1910) *Plant Animals: A Study in Symbiosis*. Cambridge University Press. Cambridge, UK.

KozoPolyansky, B (1924)[2010] *Symbiogenesis: A New Principle of Evolution*. Translation, Fet, V. Harvard University Press, Cambridge, MA.

Lake J (2008) "Reconstructing Evolutionary Graphs: 3D Parsimony." *Molecular Biology and Evolution* 25:1677-1682.

- Lake, J (2009) "Evidence for an early prokaryotic endosymbiosis." *Nature* 460:20.
- Lovelock, J (1993) "Gaia at 20: An interview with Lynn Margulis and James Lovelock." DVD. *Environmental Evolution Digital InterActive Lecture Series* director Lynn Margulis, Amherst, MA.
- Lovelock J (1995) *The Ages of Gaia: a biography of our living Earth*. Oxford University Press. Oxford, UK.
- Margulis L (Sagan L) (1967) "On the origin of mitosing cells." *Journal of NIH Research*.
- Margulis L (1993) *Symbiosis in Cell Evolution: Microbial communities in the Archean and Proterozoic eons* (2nd edition) W. H. Freeman, New York, NY.
- Margulis L, Chapman M, Dolan MF (2007) "Semes for analysis of evolution: de Duve's peroxisomes and Meyer's hydrogenases in the sulphurous Proterozoic eon." *National Review of Genetics*. 8:1.
- Margulis L and Chapman M (2010) *Kingdoms and Domains: An Illustrated Guide to the Phyla of Life on Earth*, 4th edition, 2nd printing. Academic Press. San Diego, CA.
- McKinnon J, Mori S, Blackman B, Kingsley D, Jamieson D, Chou J and Schluter D (2004) "Evidence for ecology's role in speciation." *Nature* 429.
- Meyer H, Provasoli L, Meyer F (1979) "Lipid biosynthesis in the marine flatworm *Convoluta roscoffensis* and its algal symbiont *Platymonas convoluta*." *Biochimica et Biophysica Acta*. 573:464-80.
- Morrison R (1999) *The Spirit in the Gene: Humanities Proud Illusion and the Laws of Nature*. Cornell University Press. Ithaca, NY.
- Muscatine L, Boyle JE, Smith DC (1974) "Symbiosis of the Acoel Flatworm *Convoluta roscoffensis* with the Alga *Platymonas*." *Proceedings of the Royal Society of London. Series B, Biological Sciences*, 187:221-234.
- Nobel D (2006) *The Music of Life: Biology Beyond the Genome*. Oxford University Press, Oxford, UK.

- Noble D (2010) "Differential and integral views of genetics in computational systems biology." *Interface Focus* (2011) 1. <http://rsfs.royalsocietypublishing.org> accessed on March 16, 2011.
- Nozawa K, Taylor DL, Provasoli L (1972) "Respiration and photosynthesis in *Convolvata roscoffensis* Graff, infected with various symbionts." *Biological Bulletin* 143:420-30.
- Okamoto N and Inouye I (2006) "*Hatena arenicola* gen. et sp. Nov., a Katablepharid Protist Undergoing Probable Plastid Acquisition." *Protist*.157:401-19.
- Pagels H (1988) *The Dreams of Reason – The Computer and the Rise of the Science of Complexity*. Simon and Schuster, New York, NY
- Parfrey L (2010) "Diversity of eukaryotes and their genomes." University of Massachusetts Amherst. Organismic and Evolutionary Biology doctoral dissertation.
- Peichel C, Kirsten S, Nereng, K, Ohgi B, Cole B, Colosimo P, Buerkle A, Schluter D and Kingsley D (2001) "The genetic architecture of divergence between threespine stickleback species." *Nature* 414:901-903.
- Sapp J (2005) *Microbial phylogeny and evolution: concepts and controversies*. Oxford University Press, New York.
- Tamm S (1982) "Flagellated ectosymbiotic bacteria propel a eukaryotic cell." *Journal of Cell Biology* 94:697-709.
- Taylor F (1974) "Implications and extensions of the Serial Endosymbiosis Theory of the origin of eukaryotes." *Taxon* 23, 229–258.
- Taylor, E and McPhail, J (1999) "Evolutionary history of an adaptive radiation in species pairs of threespine sticklebacks (*Gasterosteus*): insights from mitochondrial DNA." *Biological Journal of the Linnean Society* 66: 271–29
- Todd N (2000) "Mammalian Evolution: Karyotypic Fission Theory" in *Environmental Evolution*, eds. Margulis, L. & Olendzenski, L. (MIT Press, Cambridge, MA), pp. 275–278.

Ueshima, R and Asami, T (2003) "Single-gene speciation by left–right reversal A land-snail species of polyphyletic origin results from chirality constraints on mating." *Nature* 425.

Wallin, IE (1927) *Symbiogenesis and the origin of species*. John Wiley & Sons, Inc., Baltimore, MD.

Whittaker RH (1975) *Communities and ecosystems*. Prentice-Hall, New York, NY.