# DARWIN'S PRINCIPLE: THE USE OF CONTRASTIVE REASONING IN THE CONFIRMATION OF EVOLUTION

**Cornelius Hunter**

I address Elliott Sober's reconstruction of the confirmation of evolution and offer a seemingly minor but important correction. I then survey evolutionary thought in Darwin as well as both before and after Darwin to demonstrate my modified reconstruction. Finally, I explain how this correction reflects the richness of evolutionary thought.

## 1. Introduction

Evolution is both a theory and a fact. The theory of evolution explains how the species arose. The fact of evolution refers to our knowledge that evolution is true, at least as certain as anything in science (Dobzhansky 1973; Lewontin 1981; Eldredge 1982; Futuyma 1982; Campbell 1990; Ridley 1993; Gould 1994; Mayr 2001; Carroll 2006; Coyne 2009; Theobald 2010). The fact of evolution, however, does not directly follow from the theory but instead is supported by a set of epistemological arguments that are independent of the theory. These epistemological arguments are based on contrastive reasoning, which compares evolution, broadly construed and not limited to a particular theory of evolution, with alternative explanations for the origins of species. Elliott Sober has investigated evolution's epistemological arguments, the nature of its contrastive reasoning, and the failure of the alternative explanations. Sober has characterized this contrastive reasoning as Darwin's Principle. According to Sober the alternative explanation that Darwin refutes is separate

Contact Cornelius Hunter at Biola University, 13800 Biola Avenue, La Mirada, CA 90639 (cornelius.hunter@biola.edu).

HOPOS: The Journal of the International Society for the History of Philosophy of Science, vol. 4 (Spring 2014). 2152-5188/2014/0401-0003$10.00. 

ancestry.[1] This article shows that while Sober's work has greatly helped to elucidate the confirmation of evolution, some adjustments to his model are needed. In particular, the alternative explanation that Darwin refutes is not separate ancestry but rather independent creation. This subtle but crucial adjustment resolves several problems with Sober's otherwise excellent analysis.

## 2. Sober's Assessment of Darwin's Principle

Similarities between species are powerful and compelling evidence for common ancestry. Darwin made this argument so often that Elliott Sober refers to it as Modus Darwin. But why is this such a powerful argument? Sober has investigated this question in detail (1999, 2008, 2009). His assessment, simply put, is that the argument from similarities to common ancestry uses a ubiquitous type of contrastive reasoning. Specifically, the reasoning has the form of a likelihood ratio that compares two hypotheses by computing the ratio of the conditional probabilities of an observation given the respective hypotheses (e.g., see eq. [1] below).

Contrastive reasoning is, as Sober notes, a common and important type of reasoning for Darwin and later evolutionists (2008, 190). Their reasoning shows that for many observations, common ancestry is far more likely than the alternative. For instance, in the final body chapter of the *Origin*, chapter 14 before Darwin's final "Recapitulation and Summary" chapter, Darwin uses such contrastive reasoning.[2]

In chapter 14 Darwin makes an argument for common ancestry from the classification of species. Importantly, he points out that it is the neutral or maladaptive characters in the respective species that are the most helpful in the classification of the species, not the adaptive characters. Darwin also shows how these neutral or maladaptive characters provide powerful evidence for common ancestry. Darwin develops these ideas over several pages, and Sober quotes him from within that passage: "adaptive characters, although of the utmost importance to the welfare of the being, are almost valueless to the systematist. For animals, belonging to two most distinct lines of descent, may have become adapted to similar conditions, and thus have assumed a close external resemblance; but such resemblances will not reveal—will rather tend to conceal their blood-relationship" (Darwin 1872, 374).

1. Here, separate ancestry is merely a model of species not having a common ancestor. In this model, similarities in different species must have arisen separately, at least once in the lineage of each species. This concept of separate ancestry does not imply or entail independent creation.

2. I will use the sixth edition of *Origins* (1872) in this article in order to represent Darwin's final arguments.

Sober then models Darwin's argument as a likelihood ratio that uses a maladaptive (or deleterious) character, *T*, shared by species *X* and *Y*, to show that common ancestry (CA) is far more likely than separate ancestry (SA):

$$\frac{\Pr(X \text{ and } Y \text{ have trait } T \mid \text{CA})}{\Pr(X \text{ and } Y \text{ have trait } T \mid \text{SA})}. \qquad (1)$$

While a maladaptive character is unlikely under common ancestry because it would not typically be selected for, the character need arise only once in the common ancestor of species *X* and *Y*. The character is far more unlikely under separate ancestry, however, because it would have to occur twice in independent lineages. Because the lineages are independent, the probability of the maladaptive character appearing twice in separate lineages is equal to the square of the small probability of the character appearing once in a single lineage. So the likelihood ratio equals a small probability divided by its square, or equivalently, the inverse of a small probability. The resulting large number indicates that common ancestry is far more likely than separate ancestry to cause the observed maladaptive character shared by the two species. Ironically, this argument for common ancestry becomes stronger as the character becomes more maladaptive and therefore has lower probability of ever occurring. The important point here is that it is the maladaptive or deleterious characters that best show the very high relative likelihood of common ancestry. As Sober has explained:

> This last result provides a reminder of how important the contrastive framework is for evaluating evidence. It seems to offend against common sense to say that *E* is stronger evidence for the common-ancestry hypothesis the lower the value is of [the probability of *E* given the common-ancestry hypothesis]. This seems tantamount to saying that the evidence better supports a hypothesis the more miraculous the evidence would be if the hypothesis were true. Have we entered a Lewis Carroll world in which down is up? No, the point is that, in the models we have examined, the ratio [the probability of *E* given the common-ancestry hypothesis divided by the probability of *E* given the separate-ancestry hypothesis] goes up as [the probability of *E* given the common-ancestry hypothesis] goes down. . . . When the likelihoods of the two hypotheses are linked in this way, it is a point in favor of the common-ancestry hypothesis that it says that the evidence is very improbable. (2008, 314)

Because this mode of argument was commonly used by Darwin, Sober designates it as Darwin's Principle: "Adaptive similarities provide almost no evidence

for common ancestry while similarities that are useless or deleterious provide strong evidence for common ancestry" (2009, 10051). While Sober's investigations and his modeling of Darwin's arguments are helpful in understanding the arguments for evolution, these investigations are not without fault. In fact Sober's diversions from Darwin, while subtle, are crucial. The result might be better viewed as a rational reconstruction (Lakatos 1970) than merely history within a contemporary philosophical idiom.

In particular, Sober makes four assessments that are misinterpretations of Darwin. Section 3 examines these misinterpretations in detail, whereas the remainder of this section briefly summarizes them. First, according to Sober, Darwin held that adaptive characters are not good evidence for descent. As Sober explains, "Darwin tells us in the *Origin* that when it comes to finding evidence for common ancestry, the adaptive features that provide evidence for natural selection are precisely where one ought not to look" (2009, 10051). Second, as explained above, Sober models Darwin's argument for common ancestry as using maladaptive characters and separate ancestry as the alternative in the likelihood ratio. Third, he states that Darwin presented arguments and evidence for natural selection before common ancestry. Did Darwin write the *Origin* backward? Sober asks (2009). And finally, according to Sober, Darwin's arguments for common ancestry over separate ancestry would be sufficient to show that creationism's insuperable boundaries between "kinds" are a myth. Sober explains: "One of the main objections to Darwin's theory, both when the *Origin* was published and in the minds of many present-day Creationists, is the idea that species (or 'fundamental kinds' of organism) are separated from each other by walls. . . . Darwin thought he had strong evidence for common ancestry. This is enough to show that insuperable species boundaries (and insuperable boundaries between 'kinds') are a myth; if different species have a common ancestor, the lineages involved faced no such walls in their evolution" (2009, 10051). To summarize, these four assessments from Sober are

1. Darwin held that adaptive characters are not good evidence for descent.
2. Darwin's arguments for common ancestry used likelihood ratio reasoning with maladaptive characters and separate ancestry as the alternative.
3. Darwin presented arguments and evidence for natural selection before common ancestry.
4. Darwin's arguments for common ancestry over separate ancestry would be sufficient to show that creationism's insuperable boundaries between "kinds" are a myth.

The next section refers to these assessments by number, 1–4, and explains why they are misinterpretations of Darwin's Principle.

## 3. Sober's Misinterpretations of Darwin's Arguments

This section explains why Sober's four assessments of Darwin's Principle are erroneous.

### 3.1. Sober's Assessment 1

Darwin began chapter 14 of the *Origin* with a lengthy discussion of the state of the art in classifying the species. It was known since antiquity that the different species, when compared to one another, fall into groupings of some sort. And in the century before Darwin, Linnaeus had developed his highly influential Linnaean taxonomy with its binomial nomenclature. But sometimes it seemed more art than science. What were the rules?

Darwin devoted several pages of chapter 14 to this topic and, in particular, the question of which characters should be used. While similarities between species that seem most obvious, such as external similarities and those biological parts that determine an organism's habits and place in nature, might seem to be important in classification, "Nothing can be more false," reported Darwin (1872, 365). For instance, whales and fish have similar body shape and both have finlike limbs, but the whale is a mammal. Whales and fish must be classified in separate lineages, although they share some obvious similarities.

Instead, reproductive organs and embryonic structures had been found to be very important in classification. And structures that were not functionally important were "of the highest service in classification" (Darwin 1872, 366). These "trifling" characters were important, Darwin reasoned, because they are, for instance, correlated with many other characters of the organism.

Darwin conceded that the classification of the species was a difficult problem, but he was building up the argument that the evidence at hand, and in particular the types of characters that were most useful in classification, was best explained by common descent, with modification. Those obvious characters that revealed an adaptation and were important to the organism could be similar in different species because they evolved independently, in separate lineages, such as with the whale and the fish. Such adaptive similarities were referred to as analogical.

However, lesser characters, such as the inflection of the angle of the lower jaw in marsupials or the manner in which the wings of insects are folded, had been found to be important for classification because they would more likely

remain, even through stages of descent with modification. Therefore Darwin concluded, as in the above quote that Sober used, that adaptive characters, while of the utmost importance to the organism, are practically useless to the systematist. In fact they could conceal the true genealogical relationship.

However, none of this meant that adaptive characters were useless in proving common ancestry, as Sober erroneously concludes. In fact, it is quite the opposite; Darwin argued that adaptive characters leave no doubt about common ancestry. Darwin agreed that an adaptive character, when shared between species in different lineages, could not be used to demonstrate the common ancestry of those separate lineages. After all, the adaptive character had arisen independently in the respective lineages. But within a lineage the adaptive character served to leave no doubt about common ancestry. As Darwin wrote in chapter 14:

> We can thus also understand the apparent paradox, that the very same characters are analogical when one group is compared with another, but give true affinities when the members of the same group are compared together: thus, the shape of the body and fin-like limbs are only analogical when whales are compared with fishes, being adaptations in both classes for swimming through the water; but between the several members of the whale family, the shape of the body and the fin-like limbs offer characters exhibiting true affinity; for as these parts are so nearly similar throughout the whole family, we cannot doubt that they have been inherited from a common ancestor. So it is with fishes. (1872, 374)

According to Darwin the adaptive, analogical similarities between species in separate lineages demonstrated, beyond doubt, common ancestry for those species within each of the respective lineages. For within those limited groups, the similarity was no longer analogical. It was a shared character that was derived from a common ancestor. Sober's misinterpretation of Darwin on this point is important because it stems from a deeper misunderstanding of evolutionary thought, as we see next.

## 3.2. Sober's Assessment 2

As we saw above, Darwin concluded that, within a lineage, adaptive characters were powerful evidence for common descent. In addition to falsifying Sober's first assessment, this also raises a problem for Sober's second assessment, that Darwin's arguments for common ancestry use likelihood ratio reasoning with maladaptive characters and separate ancestry as the alternative. Although Dar-

win's reasoning for why adaptive characters prove common descent may not be immediately obvious, at the very least we know that Darwin was able to conclude for common descent without reference to likelihood ratios, maladaptive characters, or separate ancestry. But Sober's second assessment is also a misinterpretation for the neutral or maladaptive characters.

In addition to Darwin's explanation that the adaptive, analogical similarities demonstrated common ancestry, he also argued that the nonfunctional or maladaptive similarities were not only "of the highest service in classification" but also powerful evidence for common descent. For instance, in chapter 14 Darwin argued:

> Therefore we choose those characters which are the least likely to have been modified, in relation to the conditions of life to which each species has been recently exposed. Rudimentary structures on this view are as good as, or even sometimes better than, other parts of the organisation. We care not how trifling a character may be—let it be the mere inflection of the angle of the jaw, the manner in which an insect's wing is folded, whether the skin be covered by hair or feathers—if it prevail throughout many and different species, especially those having very different habits of life, it assumes high value; for we can account for its presence in so many forms with such different habits, only by inheritance from a common parent. We may err in this respect in regard to single points of structure, but when several characters, let them be ever so trifling, concur throughout a large group of beings having different habits, we may feel almost sure, on the theory of descent, that these characters have been inherited from a common ancestor; and we know that such aggregated characters have special value in classification. (1872, 372–73)

Here Darwin claims that when nonfunctional, trifling characters are shared between species, this can be accounted for "only by inheritance from a common parent" and that we may feel "almost sure, on the theory of descent, that these characters have been inherited from a common ancestor." But how could Darwin be so sure? For it was conjecture that these trifling characters would not be modified throughout the evolutionary process. And even if that was somehow known to be true, it would amount to affirming the consequent to conclude the characters must arise from a common ancestor.

Darwin's reasoning, as Sober correctly points out, is contrastive. As with the likelihood ratio, Darwin's reasoning compares common ancestry with an alternative. This alternative, however, is not separate ancestry as Sober concludes. Nor does Darwin explain that the alternative has lower probability of

producing trifling characters because those characters would have had to have arisen twice.

So what is the alternative against which Darwin is comparing common descent? Darwin briefly alludes to it in his discussion of classification and which characters are most useful, referring to it as the "ordinary view." After explaining that embryonic similarities are important for classification, Darwin writes:

> We can see why characters derived from the embryo should be of equal importance with those derived from the adult, for a natural classification of course includes all ages. But it is by no means obvious, on the ordinary view, why the structure of the embryo should be more important for this purpose than that of the adult, which alone plays its full part in the economy of nature. Yet it has been strongly urged by those great naturalists, Milne Edwards and Agassiz, that embryological characters are the most important of all; and this doctrine has very generally been admitted as true. (1872, 368)

This raises the question of what is this "ordinary view" to which Darwin refers. Here it is worth a brief excursion into a textual analysis to understand Darwin's use of "ordinary." Darwin uses this word relatively frequently. In the *Origin* he uses it 66 times, or about 3.4 uses per 10,000 words. For comparison, that is about twice the rate in Hugh Miller's *Testimony of the Rocks* (1.7 per 10,000 words) and almost four times the rate in the *Bridgewater Treatises* (0.9 per 10,000 words).

Darwin's higher rate is easily understood given his usage of the word. Of its 66 occurrences in the *Origin*, about half (35 occurrences) are used to indicate what a casual reader would expect. That is, those 35 occurrences are used to indicate "typical" or "common." For instance, Darwin writes of "ordinary powers of vision," "an ordinary fish," and "an ordinary flower." In the remaining 31 occurrences, however, Darwin intends a specific meaning that is peculiar to his presentation. These 31 occurrences fall into two categories depending on the context. In 19 of those occurrences, Darwin uses "ordinary" to be roughly synonymous with "natural." In these instances, "ordinary" may refer to heredity, genealogical relationships, or selection that is "natural," in contradistinction to the miraculous or artificial. For instance, in chapter 15 Darwin writes: "These authors seem no more startled at a miraculous act of creation than at an ordinary birth" (1872, 423).

In other such examples, Darwin writes of "ordinary variability" and "descended by ordinary generation." But in the remaining 12 occurrences of "or-

dinary," he has a completely different meaning in mind. Here the context is a theory of origins, and rather than in sympathy to his theory of evolution by natural means, Darwin uses "ordinary" to refer to the theory of independent creation. In these 12 occurrences the word "ordinary" is always followed by "view," except the first occurrence in which it is followed by "belief." In that first occurrence Darwin is referring to the doctrine of the fixity of species: "On the other hand, the ordinary belief that the amount of possible variation is a strictly limited quantity is likewise a simple assumption" (1872, 66).

In the remaining 11 occurrences Darwin is referring, more generally, to the theory of independent creation. For instance, in the next three occurrences (1872, 111, 122, 125), Darwin explicitly defines this "ordinary view" as the doctrine of independent creation. For example, he writes: "On the ordinary view of each species having been independently created" (122). Following these, in the next three occurrences, Darwin includes the words "creation" (351), "independent creation" (354), or "independent creation of each species" (359) to remind the reader what is meant by the "ordinary view." In the remaining five occurrences Darwin continues to provide reminders of the meaning in all except the one occurrence quoted above in which he simply refers to the "ordinary view" in stating that it is not obvious why, "on the ordinary view," embryonic structures should be important in classification.

Given this background of how Darwin uses the word "ordinary," and in particular his use of "ordinary view" as a label for independent creation of the species, we can see how he models the alternative theory against which to compare his common ancestry. When Darwin states that the "ordinary view" has difficulty explaining why embryonic structures are important for classification, he is referring to independent creation not separate ancestry. This becomes even more obvious when we see the reason Darwin gives for why the ordinary view has difficulty. As quoted above, it is because the adult form, alone, "plays its full part in the economy of nature." In other words, Darwin held that if the species were independently created, then the species should fall into categories according to their adult forms, rather than their embryonic forms, because it is the adult that "plays its full part in the economy of nature."

Darwin's premise does not derive from separate ancestry as Sober concludes. There is nothing about separate ancestry, per se, that implies that the species should categorize according to the adult forms because of their importance in the economy of nature. Similarly, later in the chapter Darwin makes several arguments against the independent creation alternative. These arguments do not derive from separate ancestry, per se, or maladaptive characters. For instance, Darwin argued that the very existence of homologous structures posed a problem for the alternative:

> We never find, for instance, the bones of the arm and forearm, or of the thigh and leg, transposed. Hence the same names can be given to the homologous bones in widely different animals. We see the same great law in the construction of the mouths of insects: what can be more different than the immensely long spiral proboscis of a sphinx-moth, the curious folded one of a bee or bug, and the great jaws of a beetle?—yet all these organs, serving for such widely different purposes, are formed by infinitely numerous modifications of an upper lip, mandibles, and two pairs of maxillae. The same law governs the construction of the mouths and limbs of crustaceans. So it is with the flowers of plants. Nothing can be more hopeless than to attempt to explain this similarity of pattern in members of the same class, by utility or by the doctrine of final causes. (1872, 382–83)

This passage offers insight into evolutionary thought. Darwin is not using maladaptive or even neutral designs to argue for common ancestry. The structures of animal appendages and insect mouths work quite well. The crux of the problem, rather, is that there is an underlying design pattern that is used in widely different applications. The design may work fine, but it is not optimized. In other words, these structures are constrained to an underlying pattern rather than being a clean slate, tabula rasa, design that is tailored for each specific application. If the objective is to optimize functionality and utility, then why is there a constraining pattern? Such a compromise, as Darwin pointed out, cannot be explained by the doctrine of final causes.

Of course for all we know that underlying pattern may be necessary. Perhaps to function properly that pattern is best. But it does not seem necessary. The problem is not that arms and legs do not function well but that the underlying pattern seems unnecessary. Presumably there are many different ways to design organisms, and surely they could be highly tailored. What reason could a creator of unlimited knowledge, power, and goodness have for reusing a design instead of starting each one from scratch?

This powerful argument is not based on maladaptive or useless characters that would be unlikely to arise twice in separate lineages, in a separate ancestry model, as Sober models the reasoning. This is a misinterpretation of Darwin and an important stream of evolutionary thought. The point is more profound and concerns what we would expect from independently created species under the doctrine of final causes, which is, as Sober correctly points out, not subject to chance (1999). In other words, independently created species are not species created by chance. Therefore their design patterns (similarities and dif-

ferences) are not governed by the conditional probability for separate ancestry in equation (1).

So Darwin's concern is not that there is a particular problem with the arm and forearm design that is unlikely to arise multiple times by chance, in multiple lineages. His concern, rather, is that such a design reappears in widely different animals, which does not make sense under the doctrine of final causes. Should not, for instance, the bones of the arm and forearm be transposed sometimes?

In the quotation above, Darwin draws on several such examples that refute the alternative to common ancestry. And he makes similar arguments in the surrounding passages in chapter 14. For example, Darwin points out skull homologies that, again, reveal a design constraint that seems unwarranted: "How inexplicable are the cases of serial homologies on the ordinary view of creation! Why should the brain be enclosed in a box composed of such numerous and such extraordinarily shaped pieces of bone, apparently representing vertebrae? As Owen has remarked, the benefit derived from the yielding of the separate pieces in the act of parturition by mammals, will by no means explain the same construction in the skulls of birds and reptiles" (1872, 384). In spite of Sober's assessment that Darwin's Principle uses separate ancestry as the alternative theory, these arguments made by Darwin use independent creation as the alternative. They conclude that many of the designs of the species would never have been designed, not that they are improbable.

Furthermore, Darwin makes a different type of argument against the ordinary view in chapter 14, which also does not fit Sober's assessment. This second type of argument does not say that the alternative is of low probability but rather that the alternative is not scientific to begin with. Early in the chapter Darwin lays the groundwork for this argument when he introduces the subject of classification: "The ingenuity and utility of this system are indisputable. But many naturalists think that something more is meant by the Natural System; they believe that it reveals the plan of the Creator; but unless it be specified whether order in time or space, or both, or what else is meant by the plan of the Creator, it seems to me that nothing is thus added to our knowledge" (1872, 365). Here Darwin echoes Descartes's criticism of Aristotelianism (the qualities themselves are in need of explanation), pointing out that the independent creation hypothesis is vacuous. Later in the chapter, Darwin raises this criticism two more times, reaching the final conclusion that the alternative is not legitimate science: "When we have a distinct object in view, and do not look to some unknown plan of creation, we may hope to make sure but slow progress" (381). "Nothing can be more hopeless than to attempt to explain this similarity of pattern in members of the same class, by utility or by the doctrine

of final causes. The hopelessness of the attempt has been expressly admitted by Owen in his most interesting work on the 'Nature of Limbs.' On the ordinary view of the independent creation of each being, we can only say that so it is;—that it has pleased the Creator to construct all the animals and plants in each great class on a uniform plan; but this is not a scientific explanation" (383).

Thus, Darwin's argument for common ancestry, as quoted by Sober, consists of two types of criticism of independent creation. Sober's modeling of the argument as a contrastive reasoning approach is appropriate, as Darwin is comparing the common descent hypothesis with the alternative. But Sober's characterization of the alternative as separate ancestry is erroneous. As has been suggested, Darwin's alternative is independent creation (Dilley 2012). Darwin argues that independent creation is unlikely because it fails to explain a variety of design patterns between species, ranging from embryonic similarities to the structure of the skull. Darwin also argues that the alternative fails to qualify as legitimate science.

## 3.3. Sober's Assessment 3

Sober has not only incorrectly identified Darwin's chapter 14 alternative as separate ancestry but also concluded that Darwin argues for common ancestry after he argues for natural selection. This seems out of order to Sober since common ancestry has evidential priority over selection. Did Darwin write the *Origin* backward? Sober asks (2009).

Nevertheless, this too is incorrect because Darwin's first major argument in the *Origin* does indeed use contrastive reasoning, comparing his common ancestry model with independent creation. This argument comes at the end of chapter 2, and it is based on Darwin's discussion of variation and comparisons between species, in the first two chapters. Darwin writes:

> Finally, varieties cannot be distinguished from species,—except, first, by the discovery of intermediate linking forms; and, secondly, by a certain indefinite amount of difference between them; for two forms, if differing very little, are generally ranked as varieties, notwithstanding that they cannot be closely connected; but the amount of difference considered necessary to give to any two forms the rank of species cannot be defined. In genera having more than the average number of species in any country, the species of these genera have more than the average number of varieties. In large genera the species are apt to be closely, but unequally, allied together, forming little clusters round other species. Species very closely allied to other species apparently have restricted ranges. In all these

> respects the species of large genera present a strong analogy with varieties. And we can clearly understand these analogies, if species once existed as varieties, and thus originated; whereas, these analogies are utterly inexplicable if species are independent creations. (1872, 47)

Here Darwin argues that the evidence suggests that the different varieties of a species may eventually become different species, suggesting a common ancestry model. However, this evidence is "utterly inexplicable if species are independent creations." In the following chapters Darwin argues for natural selection, so the ordering is not selection followed by common ancestry as Sober concludes.

## 3.4. Sober's Assessment 4

According to Sober, Darwin's arguments for common ancestry, using separate ancestry as the alternative, were sufficient to show that creationism's insuperable boundaries between "kinds" are a myth. Sober explains, as noted above: "One of the main objections to Darwin's theory, both when the *Origin* was published and in the minds of many present-day Creationists, is the idea that species (or 'fundamental kinds' of organism) are separated from each other by walls. . . . Darwin thought he had strong evidence for common ancestry. This is enough to show that insuperable species boundaries (and insuperable boundaries between 'kinds') are a myth; if different species have a common ancestor, the lineages involved faced no such walls in their evolution." In other words, in Sober's assessment, Darwin first compared separate ancestry with common ancestry. The evidence was highly unlikely given separate ancestry, so common ancestry was confirmed. Given that common ancestry was confirmed, this meant that the supposed insuperable boundaries between species or "kinds" must have been a myth. Simply put, the confirmation of common ancestry led to the refutation of creationism's insuperable species boundaries. But in fact Darwin's argument was the reverse of this. It was not the success of common ancestry that led to the failure of creation ideas, but rather it was the failure of creation models that led to the success of common ancestry. And this failure of creation models was crucial, as even Darwin admitted to significant problems with the common ancestry model.

Darwin explained, "We shall never, probably, disentangle the inextricable web of the affinities between the members of any one class" (1872, 381). And again, Darwin argued that the questions and issues he had raised could be explained by his theory only "to a certain extent": "On the theory of natural

selection, we can, to a certain extent, answer these questions" (384). Darwin also admitted to difficulty in explaining the final reduction of rudimentary structures: "There remains, however, this difficulty. After an organ has ceased being used, and has become in consequence much reduced, how can it be still further reduced in size until the merest vestige is left; and how can it be finally quite obliterated? It is scarcely possible that disuse can go on producing any further effect after the organ has once been rendered functionless. Some additional explanation is here requisite which I cannot give" (401). So in other words, while Darwin did argue that his theory explained much of the evidence, providing explanations that were "to a large extent simple," he also agreed there were difficulties (383). And yet at various points Darwin expressed near certainty in his theory. By the end of chapter 14, he was quite certain: "Finally, the several classes of facts which have been considered in this chapter, seem to me to proclaim so plainly, that the innumerable species, genera and families, with which this world is peopled, are all descended, each within its own class or group, from common parents, and have all been modified in the course of descent, that I should without hesitation adopt this view, even if it were unsupported by other facts or arguments" (403).

As Sober points out, Darwin's certainty derived from his contrastive type reasoning in which the strength of the argument did not lie in the high conditional probability of the evidence given common ancestry but rather in the low conditional probability of the evidence given the alternative. The alternative, however, was not separate ancestry but rather independent creation. So whereas Sober's assessment is that Darwin concluded that creationism failed as a consequence of first confirming common ancestry, Darwin's reasoning was the exact opposite. Darwin argued that creationism failed, which then served to confirm common ancestry.

## 4. Darwin's One Long Argument

Sober's misinterpretations of Darwin discussed above are not limited to chapter 14 of the *Origin*. For chapter 14 is not exceptional but rather representative of Darwin's thought. Darwin called his book "one long argument," and this section reviews the recurring structure of that argument. It can be characterized, as Sober has, as a likelihood ratio. The conditional probability of the evidence given Darwin's theory of evolution is often weak, as Sober has pointed out. But that relative weakness is inconsequential compared to the complete failure of the alternative. The alternative is not separate ancestry as Sober concludes but independent creation. So Darwin's one long argument is an ongo-

ing defense of evolution, with Darwin arguing that his theory is feasible and at least not falsified, contrasted with the utter hopelessness of the alternative.

Darwin explicitly addresses difficulties and objections in chapters 6 and 7, respectively, but difficulties are apparent throughout much of the volume. For example, while artificial selection was known to be capable of inducing tremendous varieties, breeders also had found limits to the change they could bring about. Darwin needed to explain why natural selection was different. Furthermore, how could completely different body plans and novelties arise? There was also the fossil record that revealed an abruptness. And of course there was the basic problem of complex structures and organs arising as a consequence of unguided biological variation.

So Darwin was often on the defensive, not just in chapter 14. Given the failure of independent creation, however, he did not need a stunning victory for his theory. What Darwin needed was merely for his theory to emerge as not obviously false. Thus Darwin made tepid claims for his theory, such as "I think we can obtain some light" and "I do not pretend that I should ever have suspected how poor was the [geological] record" (1872, 120, 282). Many of the difficulties and objections were serious but not nearly as serious as those for independent creation: "We have in this chapter discussed some of the difficulties and objections which may be urged against the theory. Many of them are serious; but I think that in the discussion light has been thrown on several facts, which on the belief of independent acts of creation are utterly obscure" (164). And so while reckoning with how his theory held up under the evidence, as has been noted Darwin consistently returned to the complete failure of independent creation (Gould 1980, 20–21; Nelson 1996). For instance, table A1, panel A, lists two such arguments from Darwin regarding variation in which he points out that under creation there is no apparent reason why varieties within a species should be more prevalent in genera with many species.

Darwin also found fatal problems for independent creation in various evidences of heredity. Table A1, panel B, gives these examples. Not only were these evidences inexplicable on the theory of creation, but they made a mockery and deception of the works of God. The area of biogeography offered up the most refutations of independent creation. Table A1, panel C, summarizes these. For instance, similar environments in distant continents were not filled with similar species. Islands contained species that were similar to those species on the nearby mainland, and bats were found on islands off New Zealand, but no other mammals were on such remote islands. Also, species that were introduced into an environment often outcompeted the indigenous species.

Darwin also identified several anatomical evidences that contradicted independent creation. Table A1, panel D, summarizes these evidences, which were somewhat subtle. They reveal how particular organs or other structures varied between species, compared with their relative importance. Included in this set is Darwin's observation that biological designs, when compared across species, were "prodigal in variety, but niggard in innovation." Darwin also noted that the habits of certain organisms did not make sense when compared to their structures, as table A1, panel E, summarizes. For instance, why would upland geese be created with webbed feet?

We saw in the previous section that Darwin found problems for independent creation in the area of the classification of the species. This was a major area from which Darwin made many observations, as listed in table A1, panel F. Why, for example, should the species form nested clusters as modeled in the Linnaean hierarchy? Darwin also observed that in comparing the species, their respective designs followed clear and obvious patterns. In other words, the designs were not independent. Clearly that would be unlikely on independent creation in which the designs would be independent. Table A1, panel G, lists those arguments.

In these seven panels, Darwin's point often amounts to the observation that biological structures lack evidence of intentional, intelligent design. Occasionally Darwin made that argument by pointing out inefficiencies or the lack of utility of a structure, such as listed in table A1, panel H.

As discussed above, the form of the arguments listed in the eight panels is a likelihood ratio, as Sober has pointed out. Darwin's point is that the evidence is highly improbable given independent creation but less so given his theory. While the former is stated clearly, the latter is often less obvious because Darwin uses extended passages to make the point. Occasionally, however, Darwin's likelihood ratio is succinct and explicit, all in one paragraph. Table A1, panel I, gives examples of these instances. In these examples Darwin explains that on his theory the evidence can be explained and is intelligible, but on independent creation the evidence is wholly inexplicable, utterly obscure, and strange.

As documented in the above-mentioned nine panels, Darwin made extensive use of arguments with the form of a likelihood ratio in which the probability of the evidence on the alternative (independent creation) was zero or small. But Darwin also made powerful arguments for his theory by asserting that independent creation was not proper or legitimate to begin with. For instance, table A1, panel J, lists Darwin's argument that independent creation amounted to anthropomorphizing the Creator. Darwin was addressing the dif-

ficulty of explaining how something as complex as the eye could have evolved. As with the telescope it was tempting to view the eye as having been the product of a high intellect. But Darwin urged that this would be presumptuous as it would assume that the Creator works by intellectual powers like those of man.

Darwin also argued that independent creation was not proper because it violated the basic scientific method, either because it was nothing more than a tautology, restating the observation and adding nothing new, or because it forfeited further investigation or because any appeal to the Creator's intentions was outside the scope of science. These arguments are listed in table A1, panel K.

Finally, Darwin also pointed out that any theory of independent creation was not proper science for the simple reason that it called for the onetime, arbitrary, violation of natural laws. Obviously any such event is not predictable and repeatable, and so any such explanation is not testable. These arguments are listed in table A1, panel L.

Throughout his work Darwin made powerful and consistent arguments of the form of a likelihood ratio for his theory. Sober correctly identified Darwin's use of this type of argument. But the alternative Darwin used in the likelihood ratio was independent creation, not separate descent.

## 5. Darwin's Principle before Darwin

As Darwin said, the *Origin* was essentially one long argument for his theory. Darwin exhaustively examined the biological evidence and repeatedly showed how his theory could explain the evidence, even if research problems remained, and that the alternative was thoroughly refuted. In a sense this was an entirely new genre, as the life sciences had been, for the most part, presented with teleological explanations.

But Darwin's work was not without precedent. For 2 centuries before the *Origin* was published, more general forms of what Sober refers to as Darwin's Principle had been proposed, developed, and exercised repeatedly in geology, cosmology, philosophy, and theology. While a historical analysis is outside the scope of this article, this section presents a brief survey of these precursor movements to Darwin.

### 5.1. The Random Design Argument

As we saw above (regarding table A1, panel G), Darwin argued that under the theory of independent creation of fixed species we would expect a lack of design patterns when comparing different species. The species would be, after

all and by definition, independent. Of course there may be real-world constraints that mandate some similarity between species. But aside from these, Darwin assumed their designs should be random with respect to one another. But we do not see this. As Darwin pointed out, we never find the bones of the arm and forearm, or of the thigh and leg, transposed. Darwin was pointing out that the species reveal design patterns for no known reason.

This argument against independent creation, because observed design patterns are not random, was used long before Darwin. For instance, it was used by Daniel Bernoulli at the Paris Academy more than a century before in his award-winning 1734 essay on the origin of the solar system. The known planets revolved about the sun in the same direction, and they did so in roughly the same plane, the ecliptic. Bernoulli contrasted this with a random design in which the planetary orbits were inclined at random angles. If the planetary orbits had fallen into place by chance, it would be highly improbable that they would just happen to lie in practically the same plane. Bernoulli gave three different calculations, all of which showed that the odds were astronomical. He picked the middle result of the three, which was that the odds of such a coincidental alignment are 1,419,856 to 1. Bernoulli concluded that a single naturalistic process must have formed the orbits. His idea was that the sun's atmosphere was the cause of the alignment of the planetary orbits. He who would deny this, concluded Bernoulli, "must reject all the truths, which we know by induction" (1734/2009).

Twenty years later Immanuel Kant expanded on this argument in his treatise on the origin of the solar system. Kant asked why the planets revolve about the sun in the same direction, for "it is clear that here there is no reason why the celestial bodies must organize their orbits precisely in one single direction, unless the mechanics of their development had determined the matter." If they were arranged by the "immediate hand of God" then we would expect them to reveal deviations and differences: "Thus, God's choice would not have the slightest motive for tying them to one single arrangement, but would reveal itself with a greater freedom in all sorts of deviations and difference" (Kant 1755/2008, 131). The problem is that the planets reveal a pattern for which there is no apparent reason. After Bernoulli and Kant, Buffon and Laplace proposed their own theories for the origin of the solar system. Buffon replaced Bernoulli's solar atmosphere idea with a comet that collides with the sun, spewing forth solar material that would later condense to form the planets. Buffon concluded, "It is therefore extremely probable, that the planets were originally parts of the sun" (1749/1781, 80).

Laplace replaced Buffon's idea with his Nebular Hypothesis, which called for a cloud of material about the sun that rotates and condenses to form the

planets and sun. It was, claimed Laplace, the "true system of the world" (quoted in Brush 1996, 22). In spite of their theoretical differences, both Buffon and Laplace used the random design argument, using their own refined versions of Bernoulli's calculation to support their confident conclusions. Buffon found that "by the doctrine of chances" the odds of such a coincidental alignment of the planetary inclination angles would be 7,692,624 to 1 (1749/1781, 65). Laplace made several calculations, eventually finding the odds of the solar system's patterns to be 537 million to 1 if they had arisen by chance (Brush 1996, 21).

Bernoulli, Kant, Buffon, and Laplace established a tradition of using the concept of random design as a null hypothesis to argue against independent creation. In this tradition theories were underdetermined and in most cases opposing or even mutually exclusive. But confidence was high, not so much from theoretical successes but from the clear refutation of the null hypothesis. Darwin's arguments from random design parallel these earlier arguments from cosmology.

## 5.2. The Dysteleology and Problem of Evil Arguments

More prevalent in the *Origin* are Darwin's many arguments from lack of function, inefficiency, and dysteleology in general, such as in table A1, panels B, D, E, H, and I. The argument that a Creator would not have intended the unsavory aspects of this world was common before Darwin and traces back to antiquity. For instance, Lucretius wrote: "That in no wise the nature of all things / For us was fashioned by a power divine- / So great the faults it stands encumbered with" (58 BCE/1957, 194–95).

In the seventeenth century the continental theologian and philosopher Nicolas Malebranche addressed this problem of an imperfect, unsavory world. Malebranche explained that God is concerned not only with the final result of the creation process but also with the process itself. A more perfect world would require a more complex creation process characterized by special divine action. But maximum simplicity is representative of God's character. Rather than specify the particulars of creation, God uses uniform and universal processes. A reduction of the world's imperfections would mean more special divine action and a loss of simplicity in the creation process (Rutherford 2000, 173). So 2 centuries before Darwin, Malebranche was proposing creation by natural law to explain the world's dysteleology.

Malebranche's formulation suggests a trade-off between the world's imperfections and the complexity of the process that creates the world. Could there be an optimal solution? This approach is clearer in the later work of Gottfried

Leibniz, whom Malebranche influenced. Yes God would use only natural law and not resort to special divine action, even if it meant more imperfections, but Leibniz added another metric to the optimization problem. In Leibniz's theodicy the objective was not so much to minimize imperfection or evil but to maximize the good-to-evil ratio in the world. God could create a world with much less evil, but this world would have far less good. More evil allows for a great deal more good, thus increasing the good-to-evil ratio until it reaches a maximum value. Implicit in Leibniz's formulation is the absence of special divine action, which Leibniz abhorred.

In the eighteenth century, philosopher David Hume, with whom Darwin was well familiar, pointed out how the world's evil contradicted natural theology. His character Philo acknowledged the strength of the design argument but pointed out that "a perpetual war is kindled amongst all living creatures," and nature is arranged so as "to embitter the life of every living being" (Hume 1854, 194). Philo concluded, "Here I triumph" (201).

This argument that imperfections and evil would not have been intended by a designer, and so require an origins process that is strictly by natural law, was by no means limited to philosophical treatises. In the seventeenth century, Anglican cleric Thomas Burnet wrote his influential geological work, *Telluris Theoria Sacra* (The sacred theory of the earth), in which he advocated a modified creation story that substituted various mechanistic events, such as comet strikes, for divine action. For Burnet the earth's geology revealed "a World lying in its rubbish" (Thomson 2005, 145). He argued that such features as jagged coastlines and mountainous terrain refuted divine design. Instead, such structures were the result of a sequence of natural events.

Likewise, the leading botanist John Ray was concerned about nature's "errors and bungles" (1717/1977, 51). Ray saw the powerful signs of God's design in nature. But for him, while the wonders of nature reveal a design from the mind of God, the problems of nature reveal a process of creation independent of special divine action. Influenced by Ralph Cudworth of the Cambridge Platonists, Ray called for a Plastic Nature, which could lead to imperfect results.

The argument against special divine action from imperfections and evil sometimes drew on more subtle problems with nature. We saw this above (in table A1, panels B, D, E, H, and I), where often Darwin pointed out more subtle evidences in biology that confounded notions of creation and so required origins by natural law. This too did not begin with Darwin. For example, as we saw above Kant argued that if God had directly created the planetary orbits then they would not fall into the obvious pattern of the ecliptic. But Kant also noted that while the planetary orbits roughly fell into a com-

mon plane, they did not do so exactly. From planet to planet there were inevitably a few degrees of deviation. If for some divine reason the planets should be in a common plane, then we should expect it to be exact. As Kant explained:

> If it was for the best that the planetary orbits were oriented on a common plane, why are they not oriented with extreme precision? And why has a portion of that deviation remained in place, when it should be avoided? . . . And why are their orbits not perfectly circular, if only the Wisest Intention, reinforced with the greatest capability, worked to produce this arrangement? Is it not clear to see that the cause which set up the orbital paths of the celestial bodies, while striving on its own to bring them to a common plane, could not achieve that completely. . . . If what the philosopher said is true, that God constantly practices geometry and if this is reflected in the methods of the general natural laws, then certainly this principle of the unmediated work of the Omnipotent Will would be perfectly traceable and the latter would reveal in itself the perfection of geometrical precision. (1755/2008, 131–32)

Both on the continent and in Britain, nature's patterns, inefficiencies, and outright evils indicated a lack of divine intention and so a need to be explained by natural law. In Darwin's time the poet Alfred, Lord Tennyson, expressed this concern with nature's evil. After reading Robert Chambers's *Vestiges of the Natural History of Creation*, Tennyson finished his *In Memoriam* in which he raised the question, "Are God and Nature then at strife, That Nature lends such evil dreams?"

## 5.3. The Anthropomorphic Warning

So Darwin's concerns about imperfections, inefficiencies, and dysteleology were not unprecedented. This is also true of his warning about anthropomorphizing God, listed in table A1, panel J. Since the early church, apophatic theology has been concerned with anthropomorphizing God or even affirming positive attributes of God. That which is infinite, Tertullian reasoned, is known only to itself. In the Middle Ages, Maimonides's negative theology described what God is not, to avoid positive descriptions that would exceed our knowledge of the divine. In the seventeenth century, Spinoza warned of such anthropomorphizing when he wrote to a friend:

> Further, when you say that if I deny, that the operations of seeing, hearing, attending, wishing, and the like, can be ascribed to God, or that they exist

> in Him in any eminent fashion, you do not know what sort of God mine is; I suspect that you believe there is no greater perfection than such as can be explained by the aforesaid attributes. I am not astonished; for I believe that, if a triangle could speak, it would say, in like manner, that God is eminently triangular, while a circle would say that the divine nature is eminently circular. Thus each would ascribe to God its own attributes, would assume itself to be like God, and look on everything else as ill-shaped. (1674/2008, 127)

Similarly Hume responded to the design arguments of the natural theologians with much the same warning. Natural theologians ascribed the complexity of the world to the Creator, but as Hume pointed out this amounted to anthropomorphizing God:

> But as all perfection is entirely relative, we ought never to imagine that we comprehend the attributes of this divine Being, or to suppose that his perfections have any analogy or likeness to the perfections of a human creature. Wisdom, Thought, Design, Knowledge; these we justly ascribe to him; because these words are honourable among men, and we have no other language or other conceptions by which we can express our adoration of him. But let us beware, lest we think that our ideas anywise correspond to his perfections, or that his attributes have any resemblance to these qualities among men. He is infinitely superior to our limited view and comprehension; and is more the object of worship in the temple, than of disputation in the schools. (1854, 142)

Darwin's argument in table A1, panel J, parallels this warning in which Darwin concludes that while the eye, as with the telescope, appears to be designed, such reasoning is presumptuous as it assumes that the Creator works by intellectual powers like those of man.

## 5.4. The Intellectual Necessity and Miracle Arguments

Table A1, panel K, lists the arguments from the intellectual necessity of evolution in which Darwin points out that independent creation is not a scientific explanation. Table A1, panel L, lists the arguments against miracles associated with independent creation. Here Darwin's arguments stood on several long-standing traditions dating back 2 centuries. There was in the seventeenth century, for instance, the Protestant doctrine of cessationism (Shaw 2006), religious rationalism, and deism, which eschewed miracles. And in the early

eighteenth century, a massive debate ran for decades in England, which produced increasing skepticism toward miracles (Burns 1981).

On the continent Lutherans such as Leibniz and Christian Wolff strongly refuted the Creator's use of miracles in the origins and maintenance of the world. Wolff argued that God would not intervene against creation because natural, law-based action is a work of God's wisdom but supernatural action is only a product of God's power. Therefore a world with fewer miracles is to be esteemed more highly. In fact, following Leibniz, Wolff argued that once the world has been created, subsequent divine intervention is a sign of a blemish that is in need of removal. And so miracles not only are not a work of God's wisdom, they also require less divine power than a world without miracles. Wolff concluded: "The natural way, as the superior way, must always be preferred over the way of miracles, and therefore miracles cannot occur except where God cannot achieve his goal in the natural way." Wolff pointed out that only in the initial creation act were miracles needed. From then on natural law reigns (quoted in Saine 1987, 109–11). By the mid-eighteenth century, Hume added his weight to these various traditions in his critique of miracles in *Enquiry Concerning Human Understanding*, and miracles were increasingly viewed with skepticism.

One of the arguments against miracles, dating back to seventeenth-century deism, was that God's truth should be equally available to all people via nature, rather than via the historical contingencies of supernatural events and revelation communicated by the church and its missionaries. Natural law was an equalizer, and this urge was no less important in the nineteenth century when Anglican privilege suppressed Dissenters not just religiously but economically as well. Medical schools were brimming with dissident ideas challenging the design arguments. And the Bridgewater Treatises, which had exhaustively argued that nature revealed God's wisdom and goodness while calling for all manner of minor and major miracles, were written off as "Bilgewater." Charles Babbage, reformer, polymath, and creator of the Difference Engine, authored the irreverent *Ninth Bridgewater Treatise*, countering the authorized volumes, which critics such as Babbage saw as suggesting a Creator with both a lack of foresight and a lack of dignity. In Babbage's narrative God created the laws, which created the species, thus displaying "a degree of power and of knowledge of a far higher order" (Desmond and Moore 1991, 213). Charles Lyell agreed and saw Babbage's "estimate of the Creator's attributes much higher" than those proposing an interventionist Creator (214, 212–20).

Baden Powell, mathematician at Oxford and Anglican priest, also approved of Babbage's thought. In 1838 he wrote that scientific and revealed truths are of different natures, and any attempt to combine and unite them would

infallibly injure both (Powell 1838, 231). And what if science finds evidence for gaps in nature that cannot be explained by law-based theory? Powell left no doubt that future discoveries would ultimately explain the "apparent anomaly":

> So strong is the inductive assurance of this, that we may safely allow any such apparent exceptions to await their solution without in the least influencing our opinion of the soundness of the broad principle of the continuity of physical causes: a principle of that truly philosophical character which no exception in detail can subvert, or render, in some form, inapplicable or unfruitful. No inductive inquirer can bring himself to believe in the existence of any *real hiatus* in the continuity of physical laws in past eras more than in the existing order of things; or to imagine that changes, however seemingly abrupt, can have been brought about except by the gradual agency of some regular causes. On such principles the whole superstructure of rational geology entirely reposes; to deny them in any instance would be to endanger all science. (1855, 354–55)

Powell's point that science requires naturalistic explanations was inextricably linked with the problem with miracles. As Powell explained, it was fallacious to infer a miracle from evidence of a discontinuity in nature: "Thus enough has probably been said to show how completely fallacious is the inference that in such cases as those referred to, because we find an apparent interruption in the observed series of organic remains, therefore we are to conclude a real interruption in the order and continuity of organic existence" (1855, 356).

Powell drew the obvious conclusions about the origins of species. They were the result of law-based, natural causes that did not transcend the regular order of nature. Such events were part of a regularly ordained mechanism of evolution:

> But however little we know of the laws or causes of these changes, one thing is perfectly clear, *the introduction of new species was a regular, not a casual phenomenon*; it was not one preceding or transcending the order of nature; it was a case occurring in the midst of ordinary operations going on in accordance with ordinary causes. The introduction of a new species (however marvellous and inexplicable some theorists may choose to imagine it) is not a solitary occurrence. It reappears constantly in the lapse of geological ages. It recurs regularly in connexion with those changes which determined the peculiar characters we now distinguish in different formations. It is part of a series. But a series indicates a principle of regularity and law, as much in organic as in inorganic changes. The event is part of a

> regularly ordained mechanism of the evolution of the existing world out of former conditions, and as much subject to regular laws as any changes now taking place. (1855, 359–60)

And the eminent John Herschel urged natural causes, rather than an intervening, meddling Creator. The birth of a species must be no more miraculous than the birth of a child, for theories of origins must present a gradual development (Desmond and Moore 1991, 214–15). As Herschel wrote in 1836, "The origination of fresh species, could it ever come under our cognizance, would be found to be a natural in contradistinction to miraculous process—although we perceive no indications of any process actually in progress which is likely to issue in such a result" (quoted in Gillespie 1979, 31).

Likewise, William Whewell (1837) raised the specter of a law-based scientific theory of creation. And in 1844 Robert Chambers, in his anonymously published *Vestiges of the Natural History of Creation*, argued that just as the inorganic world has one final comprehensive law of gravitation, so too the organic rests on the one law of development (Gillispie 1951, 153). Surely it was ridiculous, wrote Chambers, to expect a deity "to interfere personally and specially on every occasion when a new shell-fish or reptile was to be ushered into existence" (quoted in Browne 1983, 167). *Vestiges* was not a serious scientific work and was speculative, but it influenced many, including evolution cofounder Alfred Wallace.

As Desmond and Moore put it, by Darwin's day the "lawful" approach was carrying the day (1991, 214). Cultural preferences had shifted to a transcendent Creator using natural laws and preplanning, rather than an intervening Creator using miracles. So much so that John Millais's 1850 painting *Christ in the House of His Parents*, which portrayed an all-too-real incarnation with the boy Jesus in his father's messy carpentry shop, drew scathing criticism from *The Times*, *Blackwood's Magazine*, and Charles Dickens, who castigated the work as "mean, odious, revolting and repulsive" (quoted in Wilson 1999, 129–30).

And although botanist and Darwin confidant J. D. Hooker found special creation and evolution at an empirical standoff—neither theory with a clear advantage—he opted for the latter for its "great organizing potential." It was not that evolutionary theories were "the truest," he wrote to William H. Harvey in 1859: "But because they do give you room to reason and reflect at present, and hopes for the future, whereas the old stick-in-the-mud doctrines . . . are all used up. They are so many stops to further inquiry; if they are admitted as truths, why there is an end of the whole matter, and it is no use hoping ever to get any rational explanation of origin or dispersion of species—so I hate them" (quoted in Gillespie 1979, 33).

Along with the random design argument, dysteleology and evil, and the anthropomorphic warning, Darwin's intellectual necessity and miracle arguments rest on a long and substantial historical development. This brief historical summary shows that there was precedent for Darwin's various arguments that independent creation was untenable. These arguments did more than merely inspire evolutionary thought—they mandated it. As Browne put it, both Wallace and Darwin first believed in transmutation, and so they sought a suitable mechanism (1983, 169). Darwin's detailed critique of independent creation as applied to biology and the origins of species launched a new genre, but a strong foundation had already been laid.

## 6. Darwin's Principle after Darwin

Three and a half years after the *Origin* was published, Darwin responded to a critic in the leading magazine, the *Athenaeum*. The critic accused Darwin of ignoring other explanations and claiming his theory alone explained the various observations of biology. Darwin responded that while he thought his theory did the best job of explaining the evidence, that was somewhat beside the point. One could choose from other explanations, but what was important was the admission that species had not been created immutable:

> I ought to have made this admission expressly; with the reservation, however, that, as far as I can judge, no theory so well explains or connects these several generalizations (more especially the formation of domestic races in comparison with natural species, the principles of classification, embryonic resemblance, &c.) as the theory, or hypothesis, or guess, if the reviewer so likes to call it, of Natural Selection. Nor has any other satisfactory explanation been ever offered of the almost perfect adaptation of all organic beings to each other, and to their physical conditions of life. Whether the naturalist believes in the views given by Lamarck, by Geoffroy St. Hilaire, by the author of the 'Vestiges,' by Mr. Wallace and myself, or in any other such view, signifies extremely little in comparison with the admission that species have descended from other species, and have not been created immutable; for he who admits this as a great truth has a wide field opened to him for further inquiry. (Darwin 1887, 22)

Darwin's point here underscores, once again, the likelihood ratio reasoning. The details of how the species arose were yet to be understood, and so the numerator of the likelihood ratio was somewhat underdetermined. Hence the naturalist could choose between explanations from Darwin, Lamarck, Geof-

froy St. Hilaire, Wallace, and so forth. But what was clear was that the evidence refuted independent creation. The conditional probability of the evidence given creation was small, and so the likelihood ratio was large. This did not mean that Darwin's particular explanation was necessarily the right answer, but it did mean that some naturalistic explanation was. Theoretical agreement was less important than understanding the failure of the null hypothesis.

One hundred twenty-five years later, one of the leading evolutionists of the ctwentieth century, Ernst Mayr, echoed much the same point. Darwin's theory, or variations thereof, had prevailed. But that was mostly due the failure of the alternatives: "The greatest triumph of Darwinism is that the theory of natural selection, for 80 years after 1859 a minority opinion, is now the prevailing explanation of evolutionary change. It must be admitted, however, that it has achieved this position less by the amount of irrefutable proofs it has been able to present than by the default of all the opposing theories" (Mayr 1988, 192). In fact, Darwin's theory underwent substantial adjustment and revision. One thing that remained consistent, however, was Darwin's Principle, broadly construed as discussed above. That is, the evidence for evolution derives from contrastive reasoning. And the evidence was not so much the designs that were highly functional or patterns that reflected rational design but rather those observations that made no sense on design or independent creation.

Darwin applied this reasoning to biology and the origins of species, and after Darwin it became ubiquitous in the literature. A complete review of the post-Darwin literature is beyond the scope of this article. Instead this section summarizes two representative works concerned with presenting the evidence for evolution as a fact: a popular book and an undergraduate-level textbook.

## 6.1. Example 1: Why Evolution Is True

We begin with the popular book *Why Evolution Is True* by Jerry Coyne (2009), professor at the University of Chicago. Like Darwin, Coyne demonstrates repeatedly how the evidence refutes creationism and intelligent design. Table A2, panel A, lists Coyne's biogeography arguments that have changed little since Darwin. As Coyne summarizes, "The main lesson of biogeography is that only evolution can explain the diversity of life on continents and islands." In other words, as Coyne repeatedly shows, the evidence refutes the alternative explanations of design and creation.

Similar to Darwin's, table A2, panel B, lists Coyne's examples of various anatomical structures that make little sense and so confound design. For example, turtles have only four limbs, and penguins swim with the same types of bones used for flight in other species.

Darwin briefly considered altruistic behaviors but treated them more as a phenomenon to be explained rather than as evidence for evolution. Since then much more attention has been given to altruistic behaviors, and they too have been found to defy creation and design, as Coyne points out in the table A2, panel C, arguments.

Following Darwin, Coyne also points out that attempts to classify the species reveal relationships that would be unnecessary if the species were designed and independently created. Table A2, panel D, lists these arguments.

Darwin had pointed out that the designs of the different species followed patterns rather than taking "a sudden leap from structure to structure" (1872, 156) as might be expected on independent creation. We never find the arm and forearm transposed. Coyne also points out nonrandom patterns, but this time in the fossil record. Table A2, panel E, lists these arguments.

After Darwin, the use of dysteleology arguments in Darwin's Principle gradually increased. For instance, about 25 years after the *Origin* Joseph Le Conte, professor at the University of California, Berkeley, pointed out that teeth in whales were useless and that the development patterns in fish revealed "a bungling piece of work" (1891, 162). Such examples proliferated, particularly with the explosion of new molecular biology data in the mid-twentieth century. Table A2, panel F, lists Coyne's dysteleology arguments, which include the traditional arguments from visible structures as well as molecular designs that make little sense.

As in Darwin's writings, the likelihood ratio reasoning is sometimes more explicit in the literature. Such instances do not merely point out the low conditional probability of creation and design but also that this constitutes evidence for evolution by virtue of eliminating the alternative. Also, after Darwin, evolutionists increasingly expressed the likelihood ratio reasoning with exclusivity phrases such as "only evolution" and "nothing except evolution" can explain the evidence. This observation and expression was popularized with a 1973 paper by leading evolutionist Theodosius Dobzhansky entitled "Nothing in Biology Makes Sense Except in the Light of Evolution" (1973). So Darwin's typical expression, that the evidence is "utterly inexplicable" on independent creation, is now often replaced with the more terse expression that "only evolution" explains the evidence. Table A2, panel G, lists Coyne's likelihood ratio arguments in which he uses such expressions and points out that bad designs are evidence for evolution by virtue of refuting their creation and design.

Finally, Darwin's arguments for the intellectual necessity of naturalistic explanations has continued and grown stronger since the *Origin*. As Le Conte pointed out:

> Evolution is certainly a legitimate induction from the facts of biology. But we are prepared to go much further. We are confident that evolution is *absolutely certain*. Not, indeed, evolution as a special theory—Larmarckian, Darwinian, Spencerian—for these are all more or less successful modes of explaining evolution . . . but evolution as a law of derivation of forms from previous forms; evolution as a law of continuity, as a universal law of becoming. In this sense it is not only certain, it is axiomatic. . . . The origins of new phenomena are often obscure, even inexplicable, but we never think to doubt that they have a natural cause; for so to doubt is to doubt the validity of reason, and the rational constitution of Nature. So also, the origins of new organic forms may be obscure or even inexplicable, but we ought not on that account to doubt that they had a natural cause, and came by a natural process; for so to doubt is also to doubt the validity of reason, and the rational constitution of organic Nature. The law of evolution is naught else than the scientific or, indeed, the rational mode of thinking about the origin of things in every department of Nature. . . . The law of evolution is as certain as the law of gravitation. Nay, it is far more certain. (1891, 65–66)

Here Le Conte pointed out that even though the question of how evolution occurred may be unsettled, the question of whether evolution occurred is settled. For to doubt evolution is to doubt the validity of reason. This argument that the supernatural alternatives to evolution are not legitimate science is common in the literature. Table A2, panel H, lists Coyne's use of this argument in which he points out that the alternatives are not only untestable and entail a capricious creator; they also are an end of scientific inquiry.

## 6.2. Example 2: Evolution Textbook

Next we summarize the undergraduate textbook *Evolution* authored by Mark Ridley, then professor at Emory University (1993). In his chapter on "the evidence for evolution," Ridley begins by outlining the likelihood ratio argument:

> In this chapter, we shall be asking whether, according to scientific evidence, one species has evolved into another in the past, or whether each species had a separate origin and has remained fixed in form ever since that origin. For the purposes of argument, it is useful to have some articulate alternatives to debate between. We can discuss three theories: (a) evolution; (b) "transformism," in which species do change, but there

> have been as many origins of species as there have been species; and (c) separate creation, in which species originated separately and remain fixed. (1993, 37)

Ridley's chapter is shorter than a full-length book treatment, such as Darwin's or Coyne's, but follows the same evidential arguments, using Darwin's Principle to evaluate the scientific evidence. Table A3, panel A, lists Ridley's examples of anatomical structures that, once again, refute separate or independent creation. Ridley also warns the student of the common misconception that vestigial structures are not necessarily useless structures. What is important is not so much their degree of function or efficiency but rather that they would not have been independently designed for the particular species in question.

Ridley also notes the long-standing evidence that the species fall into a hierarchical classification scheme that refutes independent creation. Table A3, panel B, lists this argument.

Ridley's random design arguments add the genetic code, protein comparisons, and the molecular clock to Darwin's evidences. Ridley also points out how the fossil record sequence refutes separate creation. Table A3, panel C, lists these arguments. Often the dysteleology evidence refutes independent creation so clearly that it is, as Ridley explains, "immediately persuasive." His examples are listed in table A3, panel D.

Finally, Ridley provides the intellectual necessity arguments, including the design inference's problem of an infinite regress and the fact that in scientific theories supernatural events do not take place. This leaves supernatural explanations with no theory at all. Ridley's intellectual necessity arguments are listed in table A3, panel E.

As we have seen, Darwin's Principle predates Darwin in the history of thought. In the centuries before Darwin, naturalists, philosophers, and theologians pointed out a variety of crucial problems with traditional views of creation. Darwin applied this rationale to biology, and the problem of the origin of species, with great success, and this tradition has continued since Darwin. The problems with creation fall into two broad categories: evidences and arguments that show it to be false and evidences and arguments that show it to be unscientific. The corollaries to these problems are that evolution is true and that it is necessary for legitimate science.

## 7. Conclusion

It is well understood that evolution is a fact, but it is not well understood how we know that evolution is a fact. It is not that evolutionary theory explains the

mysteries of how life arose from an inorganic world or how life then diversified into millions of species. Yet evolution is a fact. That knowledge, as Sober points out, comes from powerful contrastive thinking. The empirical evidence, alone, does not provide such certainty.

Contrastive thinking is pervasive in evolutionary thought, and it repeatedly confirms the fact of evolution using a variety of evidences. The alternative model, against which evolution is compared, is independent creation. Since the seventeenth century, scientists, philosophers, and theologians have elucidated a wide spectrum of refutations of design and creation. With Darwin these refutations were applied to the origin of species. These arguments form the epistemological foundation of evolution. They are not merely a motivation for evolutionary thought; they establish the fact of evolution. Without them we could not know, as we do, that evolution is a fact.

This epistemological foundation of evolution is not merely scientific. Instead, the scientific evidence is interpreted philosophically and theologically. For evolution is a much richer research program than merely the scientific investigation of empirical evidence. It incorporates fundamental tenets from philosophy and theology. Therefore our understanding that evolution is a fact derives from a range of knowledge far broader than the mere empirical evidence. Indeed the empirical evidence, taken alone, has presented various scientific problems for evolutionary theory, which form the basis of the evolutionary research program.

So while evolutionary theory works on the daunting task of reconstructing the many myriad pathways life took in producing the biological world, evolution, per se, is known to be fact. As Stephen Jay Gould put it, "Facts do not go away when scientists debate rival theories to explain them. Einstein's theory of gravitation replaced Newton's, but apples did not suspend themselves in midair pending the outcome. And human beings evolved from apelike ancestors whether they did so by Darwin's proposed mechanism or by some other, yet to be discovered" (1994, 254). In other words, while science researches how evolution occurred, philosophy and theology confirm that evolution occurred. Darwin is rightly viewed as a seminal thinker and father of modern evolutionary thought. But he did not merely amass a wide range of scientific evidence. He interpreted and explained that evidence according to an epistemological framework that had been constructed in the previous 2 centuries.

That framework came from a range of thinkers, working in various traditions, who converged on similar ideas for how to interpret scientific evidence in the historical sciences. And the application of these ideas has consistently confirmed the fact of evolution. Whether the evidence is a new species in the seventeenth century or a new genome in the twenty-first century, it consistently

affirms an evolutionary origin. And that affirmation rests on a rich history of thought that combines science, philosophy, and theology.

## Appendix

Table A1. Darwin's Arguments

| Page | Quote |
|---|---|
| | A. Variation arguments |
| 44 | Where many species of a genus have been formed through variation, circumstances have been favourable for variation; and hence we might expect that the circumstances would generally be still favourable to variation. On the other hand, if we look at each species as a special act of creation, there is no apparent reason why more varieties should occur in a group having many species, than in one having few. |
| 47 | Species very closely allied to other species apparently have restricted ranges. In all these respects the species of large genera present a strong analogy with varieties. And we can clearly understand these analogies, if species once existed as varieties, and thus originated; whereas, these analogies are utterly inexplicable if species are independent creations. |
| | B. Heredity arguments |
| 130–31 | He who believes that each equine species was independently created, will, I presume, assert that each species has been created with a tendency to vary, both under nature and under domestication, in this particular manner, so as often to become striped like the other species of the genus; and that each has been created with a strong tendency, when crossed with species inhabiting distant quarters of the world, to produce hybrids resembling in their stripes, not their own parents, but other species of the genus. To admit this view is, as it seems to me, to reject a real for an unreal, or at least for an unknown, cause. It makes the works of God a mere mockery and deception; I would almost as soon believe with the old and ignorant cosmogonists, that fossil shells had never lived, but had been created in stone so as to mock the shells living on the sea-shore. |
| 415 | How inexplicable on the theory of creation is the occasional appearance of stripes on the shoulders and legs of the several species of the horse-genus and of their hybrids! |
| 417 | If species be only well-marked and permanent varieties, we can at once see why their crossed offspring should follow the same complex laws in their degrees and kinds of resemblance to their parents,—in being absorbed into each other by successive crosses, and in other such points,—as do the crossed offspring of acknowledged varieties. This similarity would be a strange fact, if species had been independently created and varieties had been produced through secondary laws. |
| 422 | It cannot be maintained that species when intercrossed are invariably sterile, and varieties invariably fertile; or that sterility is a special endowment and sign of creation. |
| | C. Biogeography arguments |
| 110 | It is difficult to imagine conditions of life more similar than deep limestone caverns under a nearly similar climate; so that, in accordance with the old view of the blind animals having been separately created for the American and European caverns, very close similarity in their organisation and affinities might have been expected. This is certainly not the case. |

Table A1 (*continued*)

| Page | Quote |
|---|---|
| 111 | It would be difficult to give any rational explanation of the affinities of the blind cave-animals to the other inhabitants of the two continents on the ordinary view of their independent creation. |
| 322 | A volcanic island, for instance, upheaved and formed at the distance of a few hundreds of miles from a continent, would probably receive from it in the course of time a few colonists, and their descendants, though modified, would still be related by inheritance to the inhabitants of that continent. Cases of this nature are common, and are, as we shall hereafter see, inexplicable on the theory of independent creation. |
| 334 | These cases of close relationship in species either now or formerly inhabiting the seas on the eastern and western shores of North America, the Mediterranean and Japan, and the temperate lands of North America and Europe, are inexplicable on the theory of creation. |
| 347–48 | In St. Helena there is reason to believe that the naturalised plants and animals have nearly or quite exterminated many native productions. He who admits the doctrine of the creation of each separate species, will have to admit that a sufficient number of the best adapted plants and animals were not created for oceanic islands; for man has unintentionally stocked them far more fully and perfectly than did nature. |
| 350 | But as these animals and their spawn are immediately killed (with the exception, as far as known, of one Indian species) by sea-water, there would be great difficulty in their transportal across the sea, and therefore we can see why they do not exist on strictly oceanic islands. But why, on the theory of creation, they should not have been created there, it would be very difficult to explain. |
| 351 | New Zealand possesses two bats found nowhere else in the world: Norfolk Island, the Viti Archipelago, the Bonin Islands, the Caroline and Marianne Archipelagoes, and Mauritius, all possess their peculiar bats. Why, it may be asked, has the supposed creative force produced bats and no other mammals on remote islands? |
| 352 | As the amount of modification which animals of all kinds undergo, partly depends on the lapse of time, and as the islands which are separated from each other or from the mainland by shallow channels, are more likely to have been continuously united within a recent period than the islands separated by deeper channels, we can understand how it is that a relation exists between the depth of the sea separating two mammalian faunas, and the degree of their affinity,—a relation which is quite inexplicable on the theory of independent acts of creation. |
| 354 | Why should this be so? why should the species which are supposed to have been created in the Galapagos Archipelago, and nowhere else, bear so plainly the stamp of affinity to those created in America? . . . Facts such as these, admit of no sort of explanation on the ordinary view of independent creation. |
| 359 | The relations just discussed,—namely, lower organisms ranging more widely than the higher,—some of the species of widely-ranging genera themselves ranging widely,—such facts, as alpine, lacustrine, and marsh productions being generally related to those which live on the surrounding low lands and dry lands,—the striking relationship between the inhabitants of islands and those of the nearest mainland—the still closer relationship of the distinct inhabitants of the islands in the same archipelago—are inexplicable on the ordinary view of the independent creation of each species. |
| 419 | Such cases as the presence of peculiar species of bats on oceanic islands and the absence of all other terrestrial mammals, are facts utterly inexplicable on the theory of independent acts of creation. |

Table A1 (*continued*)

| Page | Quote |
|---|---|
| 419 | We see this in the striking relation of nearly all the plants and animals of the Galapagos archipelago, of Juan Fernandez, and of the other American islands, to the plants and animals of the neighbouring American mainland; and of those of the Cape de Verde archipelago, and of the other African islands to the African mainland. It must be admitted that these facts receive no explanation on the theory of creation. |
| | D. Anatomy arguments |
| 120 | When we see any part or organ developed in a remarkable degree or manner in a species, the fair presumption is that it is of high importance to that species; nevertheless it is in this case eminently liable to variation. Why should this be so? On the view that each species has been independently created, with all its parts as we now see them, I can see no explanation. |
| 122 | On the ordinary view of each species having been independently created, why should that part of the structure, which differs from the same part in other independently-created species of the same genus, be more variable than those parts which are closely alike in the several species? I do not see that any explanation can be given. |
| 156 | Nature is prodigal in variety, but niggard in innovation. Why, on the theory of Creation, should there be so much variety and so little real novelty? |
| 414 | We can, in short, see why nature is prodigal in variety, though niggard in innovation. But why this should be a law of nature if each species has been independently created, no man can explain. |
| | E. Habits-structure arguments |
| 142 | He who believes that each being has been created as we now see it, must occasionally have felt surprise when he has met with an animal having habits and structure not in agreement. What can be plainer than that the webbed feet of ducks and geese are formed for swimming? Yet there are upland geese with webbed feet which rarely go near the water; and no one except Audubon has seen the frigate-bird, which has all its four toes webbed, alight on the surface of the ocean. |
| 160 | Thus, we can hardly believe that the webbed feet of the upland goose or of the frigate-bird are of special use to these birds; we cannot believe that the similar bones in the arm of the monkey, in the fore-leg of the horse, in the wing of the bat, and in the flipper of the seal, are of special use to these animals. We may safely attribute these structures to inheritance. |
| | F. Classification arguments |
| 104 | The several subordinate groups in any class cannot be ranked in a single file, but seem clustered round points, and these round other points, and so on in almost endless cycles. If species had been independently created, no explanation would have been possible of this kind of classification. |
| 368 | We can see why characters derived from the embryo should be of equal importance with those derived from the adult, for a natural classification of course includes all ages. But it is by no means obvious, on the ordinary view, why the structure of the embryo should be more important for this purpose than that of the adult, which alone plays its full part in the economy of nature. |

Table A1 (*continued*)

| Page | Quote |
|---|---|
| 372–73 | We care not how trifling a character may be—let it be the mere inflection of the angle of the jaw, the manner in which an insect's wing is folded, whether the skin be covered by hair or feathers—if it prevail throughout many and different species, especially those having very different habits of life, it assumes high value; for we can account for its presence in so many forms with such different habits, only by inheritance from a common parent. |
| 383 | Nothing can be more hopeless than to attempt to explain this similarity of pattern in members of the same class, by utility or by the doctrine of final causes. |
| 384 | How inexplicable are the cases of serial homologies on the ordinary view of creation! Why should the brain be enclosed in a box composed of such numerous and such extraordinarily shaped pieces of bone, apparently representing vertebrae? . . . Why should similar bones have been created to form the wing and the leg of a bat, used as they are for such totally different purposes, namely flying and walking? Why should one crustacean, which has an extremely complex mouth formed of many parts, consequently always have fewer legs; or conversely, those with many legs have simpler mouths? Why should the sepals, petals, stamens, and pistils, in each flower, though fitted for such distinct purposes, be all constructed on the same pattern? |
| 413 | This grand fact of the grouping of all organic beings under what is called the Natural System, is utterly inexplicable on the theory of creation. |
| 415–16 | On the ordinary view of each species having been independently created, why should specific characters, or those by which the species of the same genus differ from each other, be more variable than generic characters in which they all agree? Why, for instance, should the colour of a flower be more likely to vary in any one species of a genus, if the other species possess differently coloured flowers, than if all possessed the same coloured flowers? |
| 416 | It is inexplicable on the theory of creation why a part developed in a very unusual manner in one species alone of a genus, and therefore, as we may naturally infer, of great importance to that species, should be eminently liable to variation. |
| | G. Random design arguments |
| 156 | Why should all the parts and organs of many independent beings, each supposed to have been separately created for its proper place in nature, be so commonly linked together by graduated steps? Why should not Nature take a sudden leap from structure to structure? |
| 382 | We never find, for instance, the bones of the arm and fore-arm, or of the thigh and leg, transposed. |
| | H. Dysteleology arguments |
| 420 | On the view of each organism with all its separate parts having been specially created, how utterly inexplicable is it that organs bearing the plain stamp of inutility, such as the teeth in the embryonic calf or the shrivelled wings under the soldered wing-covers of many beetles, should so frequently occur. |
| | I. Likelihood ratio arguments |
| 145 | He who will go thus far, ought not to hesitate to go one step further, if he finds on finishing this volume that large bodies of facts, otherwise inexplicable, can be explained by the |

Table A1 (*continued*)

| Page | Quote |
|---|---|
| | theory of modification through natural selection; he ought to admit that a structure even as perfect as an eagle's eye might thus be formed, although in this case he does not know the transitional states. |
| 164 | We have in this chapter discussed some of the difficulties and objections which may be urged against the theory. Many of them are serious; but I think that in the discussion light has been thrown on several facts, which on the belief of independent acts of creation are utterly obscure. |
| 305 | Thus, on the theory of descent with modification, the main facts with respect to the mutual affinities of the extinct forms of life to each other and to living forms, are explained in a satisfactory manner. And they are wholly inexplicable on any other view. |
| 402 | Finally, as rudimentary organs, by whatever steps they may have been degraded into their present useless condition, are the record of a former state of things, and have been retained solely through the power of inheritance, . . . Rudimentary organs may be compared with the letters in a word, still retained in the spelling, but become useless in the pronunciation, but which serve as a clue for its derivation. On the view of descent with modification, we may conclude that the existence of organs in a rudimentary, imperfect, and useless condition, or quite aborted, far from presenting a strange difficulty, as they assuredly do on the old doctrine of creation, might even have been anticipated in accordance with the views here explained. |
| 413 | These are strange relations on the view that each species was independently created, but are intelligible if each existed first as a variety. |
| 414 | How strange it is that a bird, under the form of a woodpecker, should prey on insects on the ground; that upland geese which rarely or never swim, should possess webbed feet; that a thrushlike bird should dive and feed on sub-aquatic insects; and that a petrel should have the habits and structure fitting it for the life of an auk! and so in endless other cases. But on the view of each species constantly trying to increase in number, with natural selection always ready to adapt the slowly varying descendants of each to any unoccupied or ill-occupied place in nature, these facts cease to be strange, or might even have been anticipated. |
| | J. Anthropomorphization arguments |
| 146 | It is scarcely possible to avoid comparing the eye with a telescope. We know that this instrument has been perfected by the long-continued efforts of the highest human intellects; and we naturally infer that the eye has been formed by a somewhat analogous process. But may not this inference be presumptuous? Have we any right to assume that the Creator works by intellectual powers like those of man? |
| | K. Intellectual necessity arguments |
| 143 | He who believes in separate and innumerable acts of creation may say, that in these cases it has pleased the Creator to cause a being of one type to take the place of one belonging to another type; but this seems to me only re-stating the fact in dignified language. |
| 159 | They believe that many structures have been created for the sake of beauty, to delight man or the Creator (but this latter point is beyond the scope of scientific discussion). |
| 365 | But many naturalists think that something more is meant by the Natural System; they believe that it reveals the plan of the Creator; but unless it be specified whether order in |

Table A1 (*continued*)

| Page | Quote |
|---|---|
| | time or space, or both, or what else is meant by the plan of the Creator, it seems to me that nothing is thus added to our knowledge. |
| 381 | We shall never, probably, disentangle the inextricable web of the affinities between the members of any one class; but when we have a distinct object in view, and do not look to some unknown plan of creation, we may hope to make sure but slow progress. |
| 383 | On the ordinary view of the independent creation of each being, we can only say that so it is;—that it has pleased the Creator to construct all the animals and plants in each great class on a uniform plan; but this is not a scientific explanation. |
| | L. Against-miracles arguments |
| 320 | Nevertheless the simplicity of the view that each species was first produced within a single region captivates the mind. He who rejects it, rejects the vera causa of ordinary generation with subsequent migration, and calls in the agency of a miracle. |
| 423 | These authors seem no more startled at a miraculous act of creation than at an ordinary birth. But do they really believe that at innumerable periods in the earth's history certain elemental atoms have been commanded suddenly to flash into living tissues? Do they believe that at each supposed act of creation one individual or many were produced? Were all the infinitely numerous kinds of animals and plants created as eggs or seed, or as full grown? and in the case of mammals, were they created bearing the false marks of nourishment from the mother's womb? |

Source.—Darwin (1872).

Table A2. Coyne's Arguments

| Page | Quote |
|---|---|
| | A. Biogeography arguments |
| 88 | And if species were created, why did the creator stock distant areas having similar terrain and climate, like the deserts of Africa and of the Americas, with species that were superficially similar in form but showed other, more fundamental differences? |
| 90–91 | Every bit of biogeographic detective work turns out to support the fact of evolution. If species didn't evolve, their geographic distributions, both living and fossil, wouldn't make sense. |
| 91 | Why would a creator put plants that are fundamentally different, but look so similar, in diverse areas of the world that seem ecologically identical? Wouldn't it make more sense to put the same species of plants in areas with the same type of soil and climate? |
| 92 | If the animals were specially created, why would the creator produce on different continents fundamentally different animals that nevertheless look and act so much alike? |
| 92 | No creationist, whether of the Noah's Ark variety or otherwise, has offered a credible explanation for why different types of animals have similar forms in different places. All they can do is invoke the inscrutable whims of the creator. |

Table A2 (*continued*)

| Page | Quote |
|---|---|
| 96 | Creationism is hard-pressed to explain these patterns: to do so, it would have to propose that there were an endless number of successive extinctions and creations all over the world, and that each set of newly created species were made to resemble older ones that lived in the same place. We've come a long way from Noah's Ark. |
| 109 | The main lesson of biogeography is that only evolution can explain the diversity of life on continents and islands. |
| | B. Anatomy arguments |
| 12 | A conscientious designer might have given the turtles an extra pair of limbs, with retractable shovel-like appendages, but turtles, like all reptiles, are struck with a developmental plan that limits their limbs to four. |
| 13 | No intelligent designer would have given us this tortuous testicular journey. We're struck with it because we inherited our developmental program for making testes from fishlike ancestors, whose gonads developed, and remained, completely within the abdomen. We begin development with fishlike internal testes, and our testicular descent evolved later, as a clumsy add-on. |
| 57–58 | In penguins, the ancestral wings have evolved into flippers, allowing the bird to swim underwater with amazing speed. Yet they all have exactly the same bones that we see in wings of species that can fly. That's because the wings of flightless birds weren't the product of deliberate design (why would a creator use exactly the same bones in flying and flightless wings, including the wings of swimming penguins?), but of evolution from flying ancestors. |
| 58 | Wouldn't it be odd if a creator helped an ostrich balance itself by giving it appendages that just happen to look exactly like reduced wings, and which are constructed in exactly the same way as wings used for flying? |
| | C. Altruism arguments |
| 121 | In every case, when one species does something to help another, it always helps itself. This is a direct prediction of evolution, and one that does not follow from the notion of special creation or intelligent design. |
| 122 | As evolution predicts, we never see adaptations that benefit the species at the expense of the individual—something that we might have expected if organisms were designed by a beneficent creator. |
| | D. Classification arguments |
| 9–10 | Matchbooks resemble the kinds of creatures expected under a creationist explanation of life. In such a case, organisms would not have common ancestry, but would simply result from an instantaneous creation of forms designed de novo to fit their environments. Under this scenario, we wouldn't expect to see species falling into a nested hierarchy of forms that is recognized by all biologists. |
| 54 | There is no reason why a celestial designer, fashioning organisms from scratch like an architect designs buildings, should make new species by remodeling the features of existing ones. |

Table A2 (*continued*)

| Page | Quote |
|---|---|
| | E. Random design arguments |
| 29 | So the appearance of species through time, as seen in the fossils, is far from random. . . . No theory of special creation, or any theory other than evolution, can explain these patterns. |
| 53 | If evolution were not true, fossils would not occur in an order that makes evolutionary sense. |
| | F. Dysteleology arguments |
| 12 | And, of course, every instance of a plant or animal that is parasitized or diseased represents a failure to adapt. Likewise for all cases of extinction, which represent well over 99 percent of species that ever lived. (This, by the way, poses an enormous problem for theories of intelligent design (ID). It doesn't seem so intelligent to design millions of species that are destined to go extinct, and then replace them with other, similar species, most of which will also vanish. ID supporters have never addressed this difficulty. |
| 56 | Within the bodies of animals and plants lie clues to their ancestry, clues that are testimony to evolution. And they are many. Hidden here are special features, "vestigial organs," that make sense only as remnants of traits that were once useful in an ancestor. |
| 64 | Tiny, nonfunctional wings, a dangerous appendix, eyes that can't see, and silly ear muscles simply don't make sense if you think that species were specially created. |
| 67 | In contrast, the idea that all species were created from scratch predicts that no such [dead] genes would exist, since there would be no common ancestors in which those genes were active. |
| 69 | But if you believe that primates and guinea pigs were specially created, these facts don't make sense. Why would a creator put a pathway for making vitamin C in all these species, and then inactivate it? Wouldn't it be easier simply to omit the whole pathway from the beginning? Why would the same inactivating mutation be present in all primates, and a different one in guinea pigs? Why would the sequences of the dead gene exactly mirror the pattern of resemblance predicted from the known ancestry of these species? And why do humans have thousands of pseudogenes in the first place? |
| 71 | This [dead genes] makes no sense if dolphins were specially created. |
| 81 | Although organisms appear designed to fit their natural environments, the idea of perfect design is an illusion. Every species is imperfect in many ways. Kiwis have useless wings, whales have a vestigial pelvis, and our appendix is a nefarious organ. What I mean "bad design" is the notion that if organisms were built from scratch by a designer—one who used the biological building blocks of nerves, muscles, bone, and so on—they would not have such imperfections. |
| 85 | But the particular bad designs that we see [such as the recurrent laryngeal nerve] make sense only if they evolved from features of earlier ancestors. If a designer did have discernible motives when creating species, one of them must surely have been to fool biologists by making organisms look as though they evolved. |
| | G. Likelihood ratio arguments |
| 13 | And although selection gives the appearance of design, that design may often be imperfect. Ironically, it is in those imperfections, as we'll see in chapter 3, that we find important evidence for evolution. |

Table A2 (*continued*)

| Page | Quote |
|---|---|
| 18 | Some of the retrodictions that support evolution (as opposed to special creation) include patterns of species distribution on the earth's surface, peculiarities of how organisms develop from embryos, and the existence of vestigial features that are of no apparent use. |
| 56 | And species aren't all that well designed, either: many of them show imperfections that are signs not of celestial engineering but of evolution. Stephen Jay Gould called these biological palimpsests the "senseless signs of history." But they are not really senseless, for they constitute some of the most powerful evidence for evolution. |
| 68 | Only evolution and common ancestry can explain these facts [of pseudogenes]. |
| 78–79 | Now, we're not absolutely sure why some species retain much of their evolutionary history during development. The "adding new stuff onto old" principle is just a hypothesis—an explanation for the facts of embryology. It's hard to prove that it was easier for a developmental program to evolve one way rather than another. But the facts of embryology remain, and make sense only in light of evolution. |
| | H. Intellectual necessity arguments |
| 136 | But first we must ask: What's the alternative theory? We know of no other natural process that can build a complex adaptation. The most commonly suggested alternative takes us into the realm of the supernatural. |
| 137 | In the main, ID is unscientific, for it consists largely of untestable claims. |
| 137 | This is commonly called the "God of the gaps" argument, and it is an argument from ignorance. What it really says is that if we don't understand *everything* about how natural selection built a trait, that lack of understanding itself is evidence for supernatural creation. |
| 137 | Further, ID's own explanation for complex features—the whim of a supernatural designer—can explain *any* conceivable observation about nature. |
| 225 | Furthermore, supernatural explanations always mean the end of inquiry: that's the way God wants it, end of story. |

Source.—Coyne (2009).

Table A3. Ridley's Arguments

| Page | Quote |
|---|---|
| | A. Anatomy arguments |
| 46 | It has turned out to be easier to evolve variations on the five-digit theme, than to recompose the limb structure. If species have descended from common ancestors, homologies make sense; but if all species originated separately, it is difficult to understand why they should share homologous similarities. Without evolution, there is nothing forcing the tetrapods all to have pentadactyl limbs. |
| 50 | The vestigial pelvis of modern whales arguably is still needed to support the reproductive organs. However, that possibility does not count against the argument from homology: |

Table A3 (*continued*)

| Page | Quote |
|---|---|
| | for why, if whales originated independently of other tetrapods, should whales use bones that are adapted for limb articulation in order to support their reproductive organs? If they were truly independent, some other support would be used. |
| | B. Classification arguments |
| 53–54 | If they were independently created, it would be very puzzling if they showed systematic, hierarchical similarity in functionally unrelated characteristics. |
| | C. Random design arguments |
| 48–49 | Homologous similarities between species provide the most widespread class of evidence that living and fossil species have evolved from a common ancestor. The anatomy, biochemistry, and embryonic development of each species contains innumerable characters like the pentadactyl limb and the genetic code: characters that are similar between species, but would not be if the species had independent origins. |
| 52 | The similarities and differences in the amino acid sequences of the five proteins are correlated. . . . If the 11 species had independent origins, there is no reason why their homologies should be correlated. |
| 56 | The fit is good evidence for evolution, because if fish, amphibians, reptiles, and mammals had been separately created, we should not expect them to appear in the fossil record in the exact order of their apparent evolution. Fish, frogs, lizards, and rats would probably appear as fossils in some order, if they did not appear at the same time; but there is no reason to suppose they would appear in one order rather than another. |
| 57 | How, for example, could we explain the molecular clock if species have independent origins? |
| | D. Dysteleology arguments |
| 49 | But some homologies are immediately persuasive: the homologies, such as vestigial organs, in which the shared form appears to be positively inefficient. |
| 50 | If we dissect a whale, we find at the appropriate place down the spine a set of bones that are clearly homologous with the pelvis of any other tetrapod. They are vestigial in the sense that they are no longer used<br>to provide articulation for the hind limb; their retention suggests<br>that whales evolved from tetrapods rather than being independently created. |
| 50 | However, there are some homologies that do look positively disadvantageous. One of the cranial nerves goes from the brain to the larynx via a tube near the heart. In fish this is a direct route. But the same nerve in all species follows the same route, and in the giraffe it results in an absurd detour down and up the neck, so that the giraffe has to grow maybe 3–5 meters more nerve than it would with a direct connection. The "recurrent laryngeal nerve," as it is called, is surely inefficient. It is easy to explain such an efficiency if giraffes have evolved in small stages from a fish-like ancestor; but why giraffes should have such a nerve if they originated independently . . . well, we can leave that to others to try to explain. |
| | E. Intellectual necessity arguments |
| 57 | There is another powerful reason why evolutionary biologists do not take the theory of separate creation seriously. Separate creation does not explain adaptation. Living things |

Table A3 (*continued*)

| Page | Quote |
|---|---|
| | are well designed, in innumerable respects, for life in their natural environments; they have sensory systems to find their way around, feeding systems to catch and digest food, nervous systems to coordinate their actions. The theory of evolution has a mechanical, scientific theory for adaptation: natural selection. Separate creation, by contrast, does not explain adaptation. When the species originated, they must have already been equipped with adaptations for life, because the theory holds that species are fixed in form after their origin. An unabashedly religious version of separate creation would attribute the adaptiveness of living things to the genius of God; but even this does not actually explain the origin of the adaptation, it just pushes the problem back one stage. In the scientific version of the theory which we are concerned with here, supernatural events do not take place, and we are left with no theory of adaptation at all. Without a theory of adaptation, as Darwin realized, any theory of the origin of living things is a non-starter. |
| 323–24 | We can accept that an omnipotent, supernatural agent could create well-adapted living things: in that sense the explanation works. However, it has two defects. One is that supernatural explanations for natural phenomena are scientifically useless. The second is that the supernatural Creator is not explanatory. The problem is to explain the existence of adaptation in the world; but the supernatural Creator already possesses this property. Omnipotent beings are themselves well-designed, adaptively complex, entities. The thing we want to explain has been built into the explanation. Positing a God merely invites the question of how such a highly adaptive and well-designed thing could in its turn have come into existence. Theological sophistry about the perfect simplicity of God and the inexplicability of the First Cause can be ignored here: the problem is to *explain* adaptive complexity. The first alternative to natural selection, therefore, is a viciously circular argument, and unscientific. |

Source.—Ridley (1993).

## REFERENCES

Bernoulli, Daniel. 1734/2009. "Physical and Astronomical Researches on the Problem Proposed for the Second Time by the Academie Royale des Sciences de Paris." In *Recueil des pièces qui ont remporté les prix de l'Académie royale des sciences*, vol. 3. Paris: Jombert. Trans. Richard J. Pulskamp. http://cerebro.xu.edu/math/Sources/DanBernoulli/1734_planets%20and%20comets.pdf.

Browne, Janet. 1983. *The Secular Ark: Studies in the History of Biogeography*. New Haven, CT: Yale University Press.

Buffon, George Louis Comte de. 1749/1781. "Of the Formation of Planets." Vol. 1, art. 1, in *Natural History: General and Particular*, trans. William Smellie. Edinburgh: Creech.

Burns, Robert. 1981. *The Great Debate on Miracles: From Joseph Glanvill to David Hume*. London: Associated University Press.

Brush, Stephen. 1996. *Nebulous Earth: The Origin of the Solar System and the Core of the Earth from Laplace to Jeffreys*. Cambridge: Cambridge University Press.

Campbell, Neil. 1990. *Biology*. 2nd ed. San Francisco: Cummings.

Carroll, Sean. 2006. *The Making of the Fittest: DNA and the Ultimate Forensic Record of Evolution*. New York: Norton.

Coyne, Jerry. 2009. *Why Evolution Is True*. New York: Viking.

Darwin, Charles. 1872. *The Origin of Species*. 6th ed. London: Murray.

———. 1887. *The Life and Letters of Charles Darwin, Including an Autobiographical Chapter*. Vol. 3, ed. Francis Darwin. London: Murray.

Desmond, Adrian, and James Moore. 1991. *Darwin: The Life of a Tormented Evolutionist*. New York: Norton.

Dilley, Stephen. 2012. "Charles Darwin's Use of Theology in the *Origin of Species*." *British Journal for the History of Science* 45:29–56.

Dobzhansky, Theodosius. 1973. "Nothing in Biology Makes Sense Except in the Light of Evolution." *American Biology Teacher* 33:125–29.

Eldredge, Niles. 1982. *The Monkey Business*. New York: Washington Square.

Futuyma, Douglas. 1982. *Science on Trial: The Case for Evolution*. New York: Pantheon.

Gillespie, Neal. 1979. *Charles Darwin and the Problem of Creation*. Chicago: University of Chicago Press.

Gillispie, Charles. 1951. *Genesis and Geology*. Cambridge, MA: Harvard University Press.

Gould, Stephen Jay. 1980. *The Panda's Thumb*. New York: Norton.

———. 1994. "Evolution as Fact and Theory." In *Hen's Teeth and Horse's Toes*, 253–62. New York: Norton.

Hume, David. 1854. *Dialogues Concerning Natural Religion*. Rev. ed. Boston: Little, Brown.

Kant, Immanuel. 1755/2008. *Allgemeine Naturgeschichte und Theorie Des Himmels* [Universal natural history and theory of heaven]. Trans. Ian Johnston. Arlington, VA: Richer Resources.

Lakatos, Imre. 1970. "History of Science and Its Rational Reconstructions." In *PSA: Proceedings of the Biennial Meeting of the Philosophy of Science Association*, 91–136. East Lansing, MI: Philosophy of Science Association.

Le Conte, Joseph. 1891. *Evolution: Its Nature, Its Evidences, and Its Relation to Religious Thought*. 2nd ed. New York: Appleton.

Lewontin, Richard. 1981. "Evolution/Creation Debate: A Time for Truth." *Bioscience* 31:559.

Lucretius. 58 BCE/1957. *Of the Nature of Things*. Trans. William Ellery Leonard. New York: Dutton.

Mayr, Ernst. 1988. *Toward a New Philosophy of Biology*. Cambridge, MA: Harvard University Press.

———. 2001. *What Evolution Is*. New York: Basic.

Nelson, Paul. 1996. "The Role of Theology in Current Evolutionary Reasoning." *Biology and Philosophy* 11:493–517.

Powell, Baden. 1838. *The Connexion of Natural and Divine Truth; or, The Study of the Inductive Philosophy Considered as Subservient to Theology*. London: Parker.

———. 1855. *Essays on the Spirit of the Inductive Philosophy, the Unity of Worlds, and the Philosophy of Creation*. London: Longman.

Ray, John. 1717/1977. *The Wisdom of God Manifested in the Works of the Creation*. 7th ed. Repr. New York: Arno.

Ridley, Mark. 1993. *Evolution*. Boston: Blackwell.

Rutherford, Donald. 2000. "Malebranche's Theodicy." In *The Cambridge Companion to Malebranche*, ed. S. Nadler, 165–88. Cambridge: Cambridge University Press.

Saine, Thomas. 1987. "Who's Afraid of Christian Wollf?" In *Anticipations of the Enlightenment in England, France and Germany*, ed. Alan Charles Kors and Paul J. Korshin. Philadelphia: University of Pennsylvania Press.

Shaw, Jane. 2006. *Miracles in Enlightenment England*. New Haven, CT: Yale University Press.

Sober, Elliott. 1999. "Modus Darwin." *Biology and Philosophy* 14:253–78.

———. 2008. *Evidence and Evolution: The Logic Behind the Science*. Cambridge: Cambridge University Press.

———. 2009. "Did Darwin Write the Origin Backwards?" *Proceedings of the National Academy of Sciences* 106 (S1): 10048–55.

Spinoza, Baruch de. 1674/2008. *Spinoza, Correspondence*. Trans. R. H. M. Elwes, 1883. Repr. London: Forgotten Books.

Theobald, Douglas. 2010. "A Formal Test of the Theory of Universal Common Ancestry." *Nature* 465:219–22.

Thomson, Keith. 2005. *Before Darwin: Reconciling God and Nature*. New Haven, CT: Yale University Press.

Whewell, William. 1837. *History of the Inductive Sciences: From the Earliest to the Present Times*. London: Parker.

Wilson, A. N. 1999. *God's Funeral*. New York: Norton.