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The Evolutionary Indeterminism Thesis

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Evolutionary indeterminists argue that, in addition to any indeterminism introduced by quantum events, at least some evolutionary processes are themselves fundamentally indeterministic. That is, they maintain that the chance element in evolutionary processes results from indeterminism in the processes themselves, rather than simply from our cognitive limitations. Not everyone has been persuaded. A number of philosophers have argued that claims for evolutionary indeterminism are premature at best and deeply confused at worst. They maintain that evolutionary processes can and should be understood as deterministic processes. According to them, "chance" is merely a word denoting our ignorance of causes. This controversy is now one of the liveliest topics in the philosophy of biology. This article reviews the main arguments on each side, showing how the issues at stake in this debate raise fundamental questions about the nature of science as an explanatory enterprise and of the world it seeks to explain.

Keywords: evolution, determinism, indeterminism, fitness, drift

I returned, and saw under the sun, that the race is not to the swift, nor the battle to the strong...but time and chance happeneth to them all.
—Ecclesiastes 9:11

Chance is a word devoid of sense; nothing can exist without a cause.
—Voltaire

In the early decades of the 20th century, physics underwent a dramatic revolution in which the classical, deterministic worldview associated with Newtonianism gave way to a conception of the world transformed by discoveries in quantum mechanics. According to this conception, probabilities do not simply reflect our limitations as cognitive agents; they reflect the fundamental physical structure of the world. Despite insistence by some scientists that quantum phenomena must be deterministic after all (memorably expressed in Einstein's assertion that "God does not play dice"), physics shows no signs of returning to a deterministic conception of the world.

According to some thinkers, evolution is also fundamentally indeterministic. They argue that, in addition to any indeterminism introduced by quantum events, at least some evolutionary processes are themselves fundamentally indeterministic. If true, this would represent a revolution in our understanding of evolution on a par with the revolution that shook physics a century ago.

Claims of imminent scientific revolution are a dime a dozen. Bona fide scientific revolutions, however, are hard to come by. Is there reason to conclude that we are on the brink of such a momentous event? Not everyone has been persuaded. A number of philosophers have argued that claims for evolutionary indeterminism are premature at best and deeply confused at worst. They maintain that evolutionary processes can and should be understood as deterministic processes. Evolutionary indeterminists, of course, disagree. The controversy continues unabated and is now one of the liveliest topics in the philosophy of biology.

The moment is opportune for an overview of this debate, both for its intrinsic interest and because a number of far-reaching issues are at stake. Although at one level the debate between evolutionary indeterminists and evolutionary determinists is a local disagreement about the nature of evolutionary processes, at a deeper level it concerns both the purpose of scientific theories and the fundamental relationship between biology and the physical sciences. Arguments for evolutionary indeterminism typically presuppose that, both methodologically and conceptually, biology enjoys considerable autonomy from the physical sciences. Arguments for evolutionary determinism, on the other hand, take consilience within and among the findings of various branches of science as a fundamental value for an integrated scientific conception of the universe. The issues raised in the debate over evolutionary indeterminism thus go to the heart of our understanding both of science as an explanatory enterprise and

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of the world it seeks to explain. To clarify these issues, the arguments for and against evolutionary indeterminism must be examined with some care. First, however, it is essential to understand the terms of the debate and to be as clear as possible about what the debate over evolutionary indeterminism is, and is not, about.

Evolutionary indeterminism

Although it will require some unpacking, the claim advanced by evolutionary indeterminists can be stated quite simply.

> **The evolutionary indeterminism thesis:** The probabilistic concepts that appear in evolutionary theory represent genuine indeterminacies in evolutionary processes themselves, rather than being required simply because of our cognitive limitations. Evolutionary processes contain indeterministic elements in addition to any indeterminism resulting from events at the subatomic level.

Evolutionary determinists reject this claim and defend its contrary.

> **The evolutionary determinism thesis:** The probabilistic concepts that appear in evolutionary theory are required because of our cognitive limitations, but they do not represent genuine indeterminacies in the evolutionary processes themselves. Evolutionary processes contain no indeterministic elements other than those resulting from indeterminism among events at the subatomic level.

Both theses concern the relationship between evolutionary theory and evolutionary processes. Evolutionary processes are those biological processes that bring about intergenerational changes in the genotypic or phenotypic composition of a biological population (i.e., Darwin's "descent with modification"). According to the neo-Darwinian account of evolution, such changes are brought about by the interaction of various evolutionary causes, among them selection, drift, mutation, and inbreeding. Evolutionary theory, on the other hand, is the collection of models, principles, generalizations, and subtheories proposed to explain evolutionary change. Examples would be Wright's shifting balance theory, Fisher's fundamental theorem of natural selection, Eldredge and Gould's theory of punctuated equilibria, and the thermoregulatory theory of the origin of feathers. Evolutionary theory is the collection of abstract human constructions intended to account for the concrete facts of the evolutionary process as they are accessible to us through observation and experiment.

Further distinctions are necessary to clarify the terms of the debate. Theories are either probabilistic or classical (nonprobabilistic). Probabilistic theories make use of probabilistic concepts. For example, statistical thermodynamics is a probabilistic theory because (among other things) it makes use of the probabilistic concept of entropy in describing how energy is likely to be distributed in a closed system. Classical theories make no use of probabilistic concepts. Newtonian physics, for example, treats the motion of any object as fully describable in terms of the various forces acting upon it; probabilities play no role whatsoever. Whether or not a theory is probabilistic depends entirely on whether it employs probabilistic concepts.

Processes, on the other hand, are deterministic or indeterministic. A process is deterministic if the events that make up the process are the necessary consequences of antecedent, sufficient causes. To take the classic example, one billiard ball hitting another billiard ball would be a deterministic process if the collision of the first ball with the second was sufficient (in those conditions) to cause the second ball to move. A process is indeterministic if the events that make up the process are not the necessary consequences of antecedent, sufficient causes. According to a widely held interpretation of quantum mechanics, some subatomic processes are not the necessary result of events that preceded them. For example, whereas physicists can assign a probability to the emission of a particular particle from a substance undergoing radioactive decay, they cannot, even in principle, identify a set of sufficient causes for the emission of that particle. Their inability to do so is not a result of cognitive limitations. Instead, it reflects a fundamental fact about the nature of physical reality.

The distinctions between classical and probabilistic theories, on the one hand, and between deterministic and indeterministic processes, on the other, are orthogonal to one another. Newtonian dynamics is thus a classical theory of deterministic processes. Statistical thermodynamics is a probabilistic theory of deterministic processes. Quantum mechanics is (in part) a probabilistic theory of indeterministic processes. Classical theories of indeterministic processes are, perhaps not surprisingly, conspicuous by their absence.

These distinctions are essential for understanding the debate over evolutionary indeterminism. All participants in the debate agree that evolutionary theory as it currently exists, and is likely to exist in the future, makes use of probabilistic concepts such as fitness and drift, and hence that evolutionary theory is a probabilistic theory. But they part company in their explanations of the *sources* of the probabilities that figure in evolutionary theory. According to evolutionary indeterminists, probabilistic concepts figure in evolutionary theory because they represent objectively indeterministic processes in nature and are thus necessarily ineliminable from evolutionary theory. In this respect, evolutionary indeterminists see evolutionary theory as akin to quantum mechanics. According to evolutionary determinists, on the other hand, evolutionary processes per se are fully deterministic, and evolutionary theory employs probabilistic concepts only because we cannot know every microevent transpiring in the course of evolution. They hold that this simply reflects our limitations as cognitive agents; in principle (although not in practice), probabilistic concepts are eliminable from evolutionary theory. Thus, evolutionary determinists see evolutionary theory as a scientific theory akin to statistical thermodynamics.

Quantum indeterminism and evolutionary processes

Perhaps surprisingly, evolutionary indeterminists and evolutionary determinists agree that there is an element of indeterminism in the fundamental structure of physical reality as described by quantum mechanics and that indeterminism at this fundamental level can have effects in biological systems. This point of agreement is encapsulated in the percolation argument.

> **The percolation argument:** Indeterminism in the most fundamental physical processes, as described by quantum mechanics, can "percolate up" into (i.e., have effects in) macrolevel physical systems. Biological systems are macrolevel physical systems. Therefore, indeterminism in the most fundamental physical processes can have effects in biological systems.

As Bruce Glymour (2001) notes, "There is reason to believe that it is not only possible for [biological] mechanisms to translate quantum indeterminacy into stochastic behavior at macro levels, but also that such mechanisms exist" (p. 527). Others have gone further to explore in detail how this might happen (Stamos 2001). Yet none of this has the slightest bearing on the issue of evolutionary indeterminism, which maintains that there are sources of indeterminism in evolution over and above any indeterminism resulting from quantum mechanical factors. The question is whether there are distinctive forms of *evolutionary* indeterminism in addition to the indeterminism contributed by events at the subatomic level. Evolutionary indeterminists claim that there are; evolutionary determinists deny this. But more clarification is needed.

Reducible versus irreducible indeterminism. To get at this critical issue, we can deploy a further distinction between two different kinds of indeterminism. Indeterminism at the subatomic level is what might be called "irreducible" indeterminism, meaning that the indeterminism in question is fundamental at that level and cannot be explained in terms of indeterminism at some lower level of events. On the other hand, any indeterminism that occurs at the macro level as a result of indeterminacies at the quantum level is reducible indeterminism; it is indeterminism that is not fundamental to the macrolevel but rather has percolated up to that level from some lower level where it *is* fundamental. Indeterminism at the macro level that results from indeterminism at the quantum level is derivative, not fundamental, because its explanation is to be found in events at a lower level of organization. Reducible indeterminism has its ultimate explanation in indeterminism at some lower level. Irreducible indeterminism, by contrast, cannot be explained further in terms of indeterminism at some lower level. But how does this distinction help to clarify the debate over evolutionary indeterminism?

Reducible versus irreducible evolutionary indeterminism. Evolutionary indeterminists and evolutionary determinists agree that evolutionary processes contain *reducibly* indeterministic elements, thanks to quantum-level indeterminism. But because the indeterminism in question has its origin in the subatomic realm, there is nothing distinctively evolutionary about it. The debate between evolutionary indeterminists and evolutionary determinists turns on whether there is irreducible evolutionary indeterminism: that is, sources of indeterminism in evolutionary processes that arise from the nature of those very processes and cannot be attributed to indeterminism percolating up from the quantum level. Evolutionary indeterminists argue that irreducible evolutionary indeterminism is real, whereas evolutionary determinists deny this. This, then, is the point on which the entire debate turns. What sorts of arguments can each side marshal in defense of its claims?

Arguments for irreducible evolutionary indeterminism

Evolutionary indeterminists offer four arguments in support of irreducible evolutionary indeterminism. Each is examined below, along with responses by evolutionary determinists.

The fitness argument. According to standard presentations of evolutionary theory, natural selection is a sampling process operating on heritable variation in fitness among individuals at some level of the biological hierarchy. That is, natural selection is the process that sorts biological entities on the basis of differences in their fitness. Those biological entities with greater fitness will tend to enjoy greater biological success (survival, reproduction, or both) than those entities with less fitness. There is, of course, no guarantee that greater fitness will always translate directly into greater biological success. Although fitter organisms will, on average, tend to be more biologically successful, events can always interfere with this outcome. Hence, "fitness" can be interpreted as a propensity to survive and produce viable offspring (Mills and Beatty 1979). According to a widely accepted view, selection operates directly on such propensities.

Evolutionary indeterminists accept the interpretation of fitness as a propensity, noting that at best there is a probabilistic relationship between fitness and actual biological success. If so, then fitness as a propensity for biological success constitutes a genuinely probabilistic property of biological entities and hence warrants the claim for irreducible evolutionary indeterminism.

Evolutionary determinists reject this argument. The problem lies not with the propensity interpretation of fitness per se, which they can readily accept, but rather with the unexamined assumption that selection operates directly on fitness differences—an assumption that, on closer analysis, turns out to be false. Selection operates on phenotypic differences, but these phenotypic differences need not represent fitness differences (Shanahan 1990).

To make clear the causal structure of selection events, evolutionary determinists may simply describe selection events as follows:

Phenotypic traits → deterministically cause → biological success (in a specified environment)

Notice that the concept of "fitness" nowhere appears in this causal chain. Fitness as a propensity for biological success is not a property that causally interacts with the environment. To see this, consider the following two hypothetical organisms and their properties. (Numbers represent arbitrary values of fitness components—that is, specific properties—which together determine overall fitness.)

	Organism A	Organism B
Disease resistance	8	3
Visual acuity	7	5
Protective coloration	5	4
Fleetness	4	6
Social status	2	8
Overall fitness (total)	26	26

Although these two organisms differ in their phenotypic properties, they have identical overall fitness. According to the propensity interpretation of fitness, therefore, they have equal probabilities of biological success when situated in the environment in relation to which their fitness values are determined. However, despite their identical overall fitness, in any specific interaction with the environment only a small subset of their phenotypic properties, rather than fitness per se, determines how biologically successful the organism actually is. For example, if a disease epidemic broke out, killing organism B (with low resistance) but sparing organism A (with high resistance), this would be an example of natural selection, despite the absence of overall fitness differences between the two organisms.

It might be tempting to respond that although overall fitness differences play no causal role in differential biological success, various components of overall fitness nonetheless do. In the example above, the two organisms differed in their components of fitness. In an environment that includes a disease epidemic, perhaps it was the fitness difference in one of the components (i.e., disease resistance) that resulted in their differential biological success. But even here, what directly determines an organism's fate is not its propensity for surviving disease but rather the specific way in which its properties in fact interact with those of the environment, resulting in its survival (Shanahan 1989, 1992).

To see this, consider an analogy. For any (fair) coin, we may say that when flipped it has a propensity for coming up heads 50 percent of the time. Suppose that we flip the coin and it comes up heads. If we now ask why it came up heads on this particular toss, it is clear that appealing to its propensity for coming up heads roughly half of the time provides an explanation of sorts, but there is a deeper explanation available in which propensities play no part whatsoever. The factors that caused this particular coin to come up heads on this particular toss were its initial position on the back of the flipper's thumb, the amount of force applied, the number of turns in the air, the elasticity of the surface it landed on, and the like. Knowing that it is a fair coin and thus has a certain propensity may help us to predict how a series of tosses is likely to turn out. But if we flip the coin a number of times, and it comes up heads a certain number of times, it is still not the case that its propensity for coming up heads was the *cause* of this outcome. This outcome came about because of the particular factors operative in each toss of the coin. The total number of times the coin comes up heads is simply a product of these individual factors. The coin's propensity per se plays no causal role whatsoever.

To bring the discussion back to biology, fitness as a propensity for biological success is not a property of an organism that causally interacts with the environment, and thus it plays no causal role in the process of evolution itself. As Elliott Sober (1984) notes, fitness is "causally inert." If so, then an appeal to the propensity interpretation of fitness cannot warrant a claim for evolutionary indeterminism.

Why, then, does the concept of fitness play such an important role in evolutionary theory? For the evolutionary determinist, the answer is straightforward: The concept of fitness allows us to make useful generalizations and predictions. Dark-colored moths in a predominantly dark (e.g., soot-covered) environment are more likely than their lighter conspecifics to enjoy greater biological success in that environment. Hence we are justified in claiming that the dark-colored moths have greater fitness, and we might accordingly expect the relative proportion of dark- to light-colored moths to increase in the course of several generations. One can say that a given organism was more biologically successful than another because of the former's superior fitness, but this is just a shorthand description that leaves open the question of *why* this organism fared better than its conspecifics. As Sterelny and Kitcher (1988) note, "In principle, we could relate the biography of each organism in the population, explaining in full detail how it developed, reproduced, and survived, just as we could track the motion of each molecule of a sample of gas. But evolutionary theory, like statistical mechanics, has no use for such a fine grain of description: the aim is to make clear the central tendencies in the history of evolving populations" (p. 345).

There is no doubt that probabilistic concepts like fitness play an essential role in evolutionary explanations (Ariew 1998). But the considerable utility of the concept of fitness in evolutionary theory provides no reason to conclude that the process of natural selection involves any irreducibly indeterministic element (Graves et al. 1999, Rosenberg 1988, 2001).

The drift argument. A second argument for evolutionary indeterminism focuses on the concept of drift. According to the standard account, "drift" describes a process in which evolutionary change is the result of sampling error. It can occur in several ways (Beatty 1984). First, among sexual organisms a kind of lottery takes place in which some genes do, and some do not, find their way into gametes and hence have the possibility of being transmitted to the next generation. If there is no strong selection for or against the genes in question, gene frequencies can drift in a direction unrelated to selection pressures. Despite the lack of selective advantage of a trait in a population, that trait might still increase in the population from one generation to the next just because more of the individuals possessing that trait happened by chance to survive and reproduce than did those lacking the trait. Because such changes are random with respect to fitness differences among individuals, they cannot be predicted from a knowledge of fitness differences. At best, we can assign probabilities to estimates of the relative frequencies of such traits in future generations. According to evolutionary indeterminists, such probabilities in evolutionary theory represent irreducible indeterminism in the processes themselves.

Critics of evolutionary determinism have insisted that drift is both real and an indispensable concept in evolutionary theory (Brandon and Carson 1996, Millstein 1996, 2002). In response, evolutionary determinists point out that establishing the reality (or evolutionary significance) of drift is one thing, but showing that drift entails a distinctive form of evolutionary indeterminism is another matter entirely. They maintain that the fundamental principle of evolutionary determinism is operative here no less than in cases of natural selection: Whether the events in question concern genes or phenotypic characteristics, in all contexts outside of the peculiar domain of quantum mechanics we are justified in assuming that identical causes result in identical effects. Given the same genetic and developmental events, in the same environment, the same evolutionary effects will follow. If the evolutionary indeterminist responds that this is more a restatement of determinism than an independent argument for it, the evolutionary determinist can reply that the burden of proof lies with the evolutionary indeterminist to show why this general principle, accepted by evolutionary indeterminists in all contexts outside of quantum mechanics, fails to apply with equal force to evolutionary processes.

Rather than make a direct appeal to principles, the evolutionary determinist can also ask us to consider the nature of drift as a causal process by considering a relatively simple example. Suppose that a forest fire sweeps through an area, killing 90 percent of a breeding population, and that survival is unrelated to fitness differences. Presumably one could not, before the fire struck, predict to a high degree of accuracy precisely which organisms would survive and which ones would perish based on a knowledge of the particular traits of each organism. Yet in retrospect the differential survivorship is fully explainable in terms of a set of sufficient causes that resulted in precisely that outcome. Some organisms survived because they were located near the periphery rather than near the center of the fire and so were able to escape. Those able to escape did so because their sensory organs interacted with factors in the environment such that they identified the location of the fire, engaged their locomotory apparatus, and fled directly away from it. Others perished because their brains misinterpreted the data from their sensory organs and ran toward, rather than away from, the fire. The behavior of each of these organisms could be specified further in terms of individual neurobiological and physiological processes. In each case the organism possessed some set of physical properties that, in causal interaction with the environment, resulted in differential biological success. At no point is there any need to appeal to irreducibly indeterministic processes. As Barbara Horan (1994) notes, "As far as we know, the macroscopic environment faced by individual organisms is replete with deterministic processes, so all possible worlds that agree with this one in all respects relevant to the origin, course, and extent of a natural disaster...that creates a founder population, will also agree on the subsequent sample of breeding individuals....The same fire...in the same conditions would create the same sample" (p. 84). "Drift" in this view is simply a term referring to those evolutionary processes resulting in differential biological success, the causes of which we are ignorant (Rosenberg 1994); the indeterminacy is entirely in our understanding of the processes rather than in the processes themselves.

An experimental confirmation of evolutionary indeterminism? A third argument for evolutionary indeterminism proposes to dispense with thought experiments by treating the issue as an empirical problem that can be settled by experimental investigation. Brandon and Carson (1996) note that "if [evolutionary] determinism is true...then identical organisms in identical environments should have identical evolutionary fates" (p. 329). They offer an experimental test of the evolutionary determinist thesis: Many organisms are clonable, and clones may be placed in the same carefully controlled environment, with the results recorded. When this is done, the results are unequivocal. Despite the genetic identity and identity of environmental conditions for the plants grown by Bever (1994), there were significant differences among the phenotypes of the resulting plants. Brandon and Carson take this as an empirical refutation of evolutionary determinism and therefore as a vindication of evolutionary indeterminism.

Predictably, evolutionary determinists find this argument unconvincing. First, this example concerns development rather than evolution. An argument for irreducible biological indeterminism with regard to development will not sustain the claim of irreducible evolutionary indeterminism. Second, even if the connection between developmental indeterminism and evolutionary indeterminism could be made, in the experiments cited there is no way to control for indeterminism resulting from quantum-level effects, which are not at issue in the debate over irreducible evolutionary indeterminism. Third, even if quantum-level effects could be ruled out, it is impossible to eliminate all differences between the plants and their respective environments, and thus it is always possible that undetected differences ("hidden variables") are responsible for the phenotypic variance observed (Weber 2001). As chaos theory makes clear, there are limits to the precision of any measurement of initial conditions, and these limits cannot, even in principle, be transcended. Initial conditions can therefore vary even if we are unable to detect such differences. Over time these small initial differences can be compounded into huge, macroscopically significant effects. Chaos theory gives determinism a new lease on life. Living things are the most complex entities known. It is among living things, most of all, that one would expect to see the effects of chaos in action. An experimental refutation of evolutionary determinism therefore seems doomed to failure.

The scientific realism argument. Evolutionary indeterminists maintain that a commitment to scientific realism requires accepting the idea that the probabilistic concepts appearing in evolutionary theory refer to irreducibly indeterministic processes. Brandon and Carson (1996) point out that in science the positing of theoretical entities is taken seriously only when (a) positing such entities aids the development of theory and (b) the available empirical evidence supports the assumption that such entities exist. But whereas "the positing of genuinely probabilistic propensities governing the evolutionary fates of individual organisms has been an integral part of the impressive development of evolutionary population genetic theories in this century.... the positing of deterministic hidden variables in evolutionary theory serves no theoretical purpose at all" (Brandon and Carson 1996, p. 331). In addition, whereas all the evidence supports the idea of probabilistic propensities, the notion of deterministic hidden variables in evolution is contradicted by the empirical data. On both theoretical and empirical grounds, therefore, evolutionary indeterminism should be accepted.

This argument is problematic for several reasons. First, the relationship between scientific realism and evolutionary indeterminism is far more complex than this argument suggests (Weber 2001). Second, as Brandon and Carson admit, the experimental evidence they cite is perfectly consistent with a deterministic interpretation of evolution. It is therefore difficult to see how the notion of deterministic hidden variables in evolutionary theory is "contradicted by the empirical data." Third, it is far from clear that the positing of probabilistic propensities has been as potent, and the positing of hidden variables as impotent, in the history of evolutionary biology as this argument asserts. What are considered hidden variables at one stage of science (e.g., genes) may become manifest variables at some later stage. Finally, and most critically, this argument conflates evolutionary theory with the process of evolution. Even if a given perspective is theoretically useful, it does not follow that the entities postulated are real (consider the ontological status of epicycles in Ptolemaic cosmology). As Alexander Rosenberg (1994) notes, "The question of whether evolutionary phenomena are stochastic [i.e., indeterministic] is different from the question of whether *our best theory* of these phenomena is unavoidably statistical [i.e., probabilistic]. Our best theory, present or future, may turn out to be statistical because the deterministic facts about evolution are beyond our cognitive and computational powers to apprehend in useful terms" (p. 59). Because both deterministic and indeterministic phenomena can be described probabilistically, the fact that a theory is probabilistic is no guarantee that the processes it describes are indeterministic. Hence, arguments that appeal to a realist conception of science lend no support to the claim of evolutionary indeterminism.

The case for evolutionary determinism

Showing that arguments for a given view fail is insufficient to establish the contrary view, because there may be insufficient reasons in support of either view. What positive arguments can evolutionary determinists offer in support of their view? Besides pointing out that the various arguments for evolutionary indeterminism fail, evolutionary determinists maintain that only their view conforms with the understanding of the world required by the physical sciences. This conviction is encapsulated in the "unity of the sciences" argument.

> **The unity of the sciences argument:** According to our best physical theories, all macrolevel physical processes are (apart from any indeterministic effects percolating up from the quantum level) entirely deterministic. Evolutionary processes such as selection, drift, and migration are all macro-level physical processes. Therefore, evolutionary processes are (apart from any indeterministic effects percolating up from the quantum level) entirely deterministic.

The unity of the sciences argument is predicated on what could be called "ontological/process reductionism": the principle that biological systems are composed entirely of entities of the sort studied by chemistry and physics, and that biological processes consist entirely of chemical and physical microprocesses. Any indeterminism associated with biological properties would have to be explicable in terms of properties at a subbiological level. But our best understanding of the physical structure of the world provides no reason to suppose that there are sources of indeterminism in physical systems in addition to those associated with quantum phenomena. Were the claims of evolutionary indeterminism true, a fundamental revision in our understanding of the physical world would be required on a par with that which accompanied quantum mechanics a century ago. Evolutionary determinists remain unconvinced that adequate motivation exists for any such drastic revision of worldview. In the absence of such motivation, evolutionary determinism should be embraced.

Despite its apparent simplicity, this argument for evolutionary determinism faces problems of its own. On the one hand, it emphasizes that our understanding of evolution should accord with our understanding of the purely physical domain. If the purely physical domain is deterministic, then so too is the biological domain. Yet our understanding of the physical domain does not come to us in unfiltered form directly from nature itself. It is mediated by our best scientific theories: that is, the theories that have proved most theoretically fruitful and empirically adequate. Those theories tell us that (apart from any quantum-level effects) the physical world is fully deterministic. But if so, then the evolutionary indeterminist can point out that ultimately the evolutionary determinist is putting faith in the referential success of our best scientific theories in a given domain to tell us what the phenomena in that domain are really like. This is, of course, precisely what the evolutionary indeterminist proposes to do with regard to our best theories of evolutionary phenomena. The dilemma: The evolutionary determinist cannot invest faith in the referential accuracy of our best physical theories while rejecting appeals to the referential accuracy of our best biological theories—unless, that is, scientific knowledge in one domain (physics) is to be privileged over that in another (biology). Doing so, however, is likely to encounter intense resistance among those who have labored long and hard to argue that, whereas biology is indeed distinct from physics in fundamental respects, it is no less scientific and no less revealing of the nature of the world (Mayr 1982, 1988).

The evolutionary indeterminism debate and the nature of biology

As David Stamos (2001) speculates, although the debate between evolutionary indeterminists and evolutionary determinists appears to be about the nature of evolutionary processes, at a deeper level the disagreement concerns the more fundamental issue of the relationship between biology and the physical sciences. Evolutionary indeterminists argue that the success of evolutionary theory warrants the claim that the probabilities it uses are objective features of the processes it describes, even if this requires positing indeterminacies that have no explanation in chemistry or physics. Evolutionary indeterminists do not consider this problematic, because evolutionary theory (and biology more generally) already deploys concepts that transcend explication in purely physical terms (e.g., competition, camouflage, mimicry, and sexual selection). Methodologically and conceptually, biology enjoys considerable autonomy from the physical sciences.

Evolutionary determinists, on the other hand, argue that, although biology can and must make use of concepts that have no direct analogue in the physical sciences, nonetheless the processes described by these concepts must all, at the end of the day, be explicable in purely physical terms. Evolutionary determinists uphold consilience within and among the findings of various branches of science as a fundamental requirement for a unified scientific conception of the universe. In support of this value, they can appeal to the example of Darwin, who took the idea of consilience very seriously, as he was convinced (and attempted to convince others) that the broad range of facts drawn from widely different sciences (e.g., geology, embryology, and biogeography) made sense only in light of his theory. In addition, evolutionary determinists can point out that Darwin was genuinely worried that estimates of the age of Earth provided by the physical sciences of his day provided insufficient time for the slow march of evolution to have reached its present state, a worry that would make sense only if he believed that ultimately the physical and biological sciences revealed a single interconnected but immensely complex world.

Alas, evolutionary indeterminists can appeal to Darwin as well, noting that he did not retract his theory in light of the apparently conflicting data coming from the physical sciences, but instead maintained confidence that, so great was the explanatory power of the concepts deployed in his theory, a rapprochement between the physical and biological sciences would eventually be forthcoming. Darwin's confidence in the explanatory power of his theory, as it turned out, was fully justified. Neither philosophical arguments nor appeals to Darwin's historical example are at present sufficient to resolve the debate over evolutionary indeterminism. Yet the issues at stake in this debate raise fundamental questions concerning our understanding of both science and the nature of the world it attempts to explain, and thus are worthy of continued critical reflection.

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