QUANTUM ASPECTS OF LIFE: RELATING EVOLUTIONARY BIOLOGY WITH THEOLOGY VIA MODERN PHYSICS

by Anna Ijjas

Abstract. In the present paper, I shall argue that quantum theory can contribute to reconciling evolutionary biology with the creation hypothesis. After giving a careful definition of the theological problem, I will, in a first step, formulate necessary conditions for the compatibility of evolutionary theory and the creation hypothesis. In a second step, I will show how quantum theory can contribute to fulfilling these conditions. More precisely, I claim that (1) quantum probabilities are best understood in terms of ontological indeterminism, but (2) reflect nevertheless causal openness rather than divine indifference or arbitrariness, and (3) such a genuinely creative universe can be considered as the work of a loving Creator. I ask subsequently whether these necessary conditions are also sufficient for the compatibility of evolutionary theory and the creation hypothesis. Finally, I will show that relating evolutionary biology with theology via quantum theory could also shed some light on the nature of life.

Keywords: creation; evolution; indeterminism; probability theory; problem of evil; quantum physics

Quantum mechanics has been often cited as a solution for famous philosophical and theological problems: postmodern antirealism, immortality of the soul, or the two-nature doctrine of Chalcedon are just a few examples of many weird suggestions. In most debates, quantum aspects of life or evolution have, however, been widely neglected. Although the scholarly reticence is understandable in light of the pseudo-scientific abuse of quantum theory, the neglect of modern physics appears nevertheless premature when considering the structural similarities between quantum mechanics and evolutionary theory; apparently, both theories are of statistical nature. In quantum mechanics, the physical state of a system can only be described in terms of fuzzy probabilities; theoretical predictions with certainty are, in general, impossible. Basic evolutionary mechanisms, in particular mutations or variations in the genetic material, are commonly considered as genuinely random processes. It is also this statistical character

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that makes a theistic interpretation of both scientific theories difficult: a world dominated by blind chance could hardly be the work of a loving Creator.

In the present paper, I shall address the question of whether quantum theory can contribute to reconciling evolutionary biology with the creation hypothesis. After giving a careful definition of the theological problem, I will, in a first step, formulate necessary conditions for the compatibility of evolutionary theory and the creation hypothesis. In a second step, I will show how quantum theory can contribute to fulfilling these conditions. More precisely, I claim that (1) quantum probabilities are best understood in terms of ontological indeterminism, but (2) reflect nevertheless open-endedness of natural processes rather than divine indifference or arbitrariness, and (3) such a genuinely creative universe can be considered as the work of a loving Creator. I ask subsequently whether and to what extent these necessary conditions are also sufficient for the compatibility of evolutionary theory and the creation hypothesis. Finally, I will show that relating evolutionary biology with theology via quantum theory could also shed some light on the nature of life.

Problems

The creation hypothesis lies at the heart of Christian theism. Simply put, it explores the relationship between God and the world to which He stands as Creator. According to the traditional doctrine, as formulated, for example, by Saint Augustine, in the beginning God created the Universe out of nothing (*creatio ex nihilo*). Although there is an ongoing debate on how to properly interpret the phrase "in the beginning" in Gen 1:1,[1] it is widely agreed that the core message of *creatio ex nihilo* is the fact that, directly or indirectly, everything owes its existence to God. However, the creation hypothesis cannot be reduced to *creatio ex nihilo*. On the contrary, creation also means that God sustains the Universe and creatively acts in it (*creatio continua*). In other words, *creatio continua* is "the theological doctrine that deals with God's relation to the processes of change, especially God's relation to the emergence of novelty" (Drees 1990, 146–47). Therefore, the doctrine of *creatio continua* seems to presuppose a sort of guidance or purpose behind all natural processes. As emphasized by Arthur Peacocke, it is this dynamic aspect of the creation hypothesis that makes it sensitive to scientific cosmology.[2]

Whether the creation hypothesis is compatible with evolutionary biology is the most hotly debated issue at the intersection of science and theology today. Opponents argue that the Darwinian theory not only provides a complete account of the origin and evolution of life on Earth, but also makes the theistic claim obsolete, as spontaneous and undirected chance mechanisms governing the evolutionary processes exclude *creatio* *continua* by definition. Proponents of theistic evolution, on the other hand, hold that evolutionary chance need not be understood as an undirected random process, and therefore can be reconciled with the creation hypothesis.

In what follows, I will first describe the problem of reconciling evolutionary theory with theism as a twofold incoherence problem, that is, I will present two fundamental beliefs of theism that cannot be compatible with evolutionary theory at the same time. Subsequently, I argue that this contradiction should be taken seriously in order to preserve the rationality of theism. Finally, I give a brief overview of contemporary models of reconciling evolutionary biology with Christian theism.

Blind Chance versus Block Universe? Dawkins's famous thesis stating that "Darwin made it possible to be an intellectually fulfilled atheist" has become a quasi-synonym for the (alleged) incompatibility of evolutionary biology and theism (Dawkins 2006b, 6). Evolutionary theory has been claimed to make the God hypothesis not only dispensable, but also untenable-—insofar it contradicts natural science.

For the atheist argument to work, interpreting probability statements of evolutionary theory in terms of pure chance seems to be crucial.[3] However, if the origin and development of life is nothing but a series of undirected random processes, it is simply meaningless to speak of creative acts of God; chance excludes purpose by definition. Therefore, the creation hypothesis could be saved if evolutionary probabilities were interpreted in a pure epistemological sense. According to this interpretation, uncertainty of theoretical predictions is exclusively due to our ignorance, and has nothing to do with nature; probability statements of evolutionary theory reflect solely lack of knowledge, while in reality natural processes are completely determined and occur out of necessity. There is no doubt that such a probability interpretation is compatible with the creation hypothesis, in so far in determining the physical properties of our universe, God creates conditions which are necessary for life to evolve. Moreover, in a deterministic world the God-given set of initial conditions, physical parameters, and natural laws lead to the result intended by God with certainty; nothing is left to chance eventually causing unwelcome surprises. However, there is a price to pay for reconciling evolutionary theory with the creation hypothesis this way: the problem of evil arises in a more acute form. If the universe is completely deterministic, everything occurs because God wants it. To put it in Kenneth Miller's words:

> When a stray bullet is randomly fired into a crowd, God decides who will get hit, and who will survive. When the biggest hurricane of the year hits Key West and not Miami, it had to be God's will. You could, I suppose, cast the Almighty in this guise, make Him a cosmic tyrant, a grand puppeteer pulling every string at once, and then nothing would be left to chance. (Miller 2002, 234)

If the factual degree of pain and evil sentient organisms suffer from, or inflict upon one another is the creator's will, then this being cannot be the morally perfect God of theism, and such a person is hardly worth being worshipped by the creatures.

To sum up, in confronting the God hypothesis with evolutionary theory, theism is left with the following dilemma: either a probability interpretation in terms of blind and undirected chance is correct, or the proper interpretation is an epistemic one. Obviously, theism is incompatible with both options, since the first option makes the very idea of creation, in particular the doctrine of *creatio continua*, obsolete, while the second option implies a more acute form of the problem of evil. In face of this, is there really a choice to be made between theism and evolutionary theory?

Why Take the Problem Seriously? Of course, one could conveniently dissolve the dilemma by declaring such incompatibilities completely unproblematic. Such incompatibilities become problematic only if we commit ourselves to the idea of objective and universal truth inseparably connected with the law of noncontradiction. Abandoning realism and redefining truth in terms of postmodern relativism, on the other hand, dispenses one from being bounded by logical rules.

Yet, giving up the universality of the law of noncontradiction implies the loss of meaning and intelligibility.[4] It follows that theological statements can at best serve as expression of emotions or volitions when giving up the law of noncontradiction.

Assuming that theological statements are meaningful and truth-relevant statements, theism faces the task of demonstrating that probability statements of evolutionary theory need neither be interpreted in an epistemological sense, nor are the same probability statements to be interpreted in terms of blind chance or arbitrariness. Finally, it has to be shown that there is a third option of interpreting probability statements of evolutionary theory which is compatible with the creation hypothesis without sharpening the problem of evil. In short, theism should offer a third option besides blind Darwinian chance and pure Laplacian determinism.

Perspectives for Theistic Evolution. In the field of science and religion, a good deal of important work has already been done to reconcile evolutionary dynamics with the creation hypothesis. In studying the subtle and complex interplay of random mutations in the DNA and their (more or less) deterministic selection through the environment, which are (allegedly) causally independent, most approaches focus on the latter and follow a sort of "top-down strategy," aiming to show how necessity (or law-likeness) brings order into chaos arising due to randomness.

Thereby, we can basically distinguish two main lines of argumentation, the biologist's manner and the physicist's manner. As indicated by its name, the biologist argues for order arising due to natural forces in purely biological terms. Here, one of the most important contemporary approaches might be the theistic interpretation of convergent evolution, as defended by British paleontologist Simon Conway Morris. He advances the (among biologists widely accepted) view that given similar environments, different organisms arrive at the same function through different evolutionary pathways, or to put it with Conway Morris, evolutionary convergence is "the recurrent tendency of biological organization to arrive at the same 'solution' to a particular 'need'" (Conway Morris 2003, xii). Yet, from this fact Conway Morris infers that the emergence of intelligent life is nearly inevitable—a result which need not, but *can* be interpreted in terms of Creation. On the other hand, one can argue for understanding the interplay of chance and necessity within evolutionary dynamics from a physics point of view; in most cases, that means arguing in terms of nonlinear dynamics. Simply put, the theistic argument is based on the fact that emergent features of complex physical systems constrain the random behavior of their constituents. Note, however, that the adjective "random" is used here to characterize the great instability associated with chaotic systems—a property which is a direct result of nonlinearity allowing for evolution from nearly identical states to extremely dissimilar ones. "In fact, it is randomness constrained by deterministic correlations that is critical for producing the structures we perceive as 'complex'" (Young 1996, 238). Most famously, John Polkinghorne and Arthur Peacocke referred to the behavior of chaotic systems to demonstrate that evolutionary chance does not rule out Creation; rather, it manifests the creativity with and through which God acts in the world, without completely determining it.[5] While most theistic interpretations of evolutionary dynamics prefer the top-down strategy (starting with the law-like environmental selection), little attention has been paid to possible bottom-up solutions (starting with random mutations) which are otherwise not unpopular in the field of science and religion.[6] In what follows, I shall address the question if and to what extent such a model can contribute to reconciling evolutionary theory with the creation hypothesis. In particular, I ask if the bottom-up model I suggest can be considered a complementary account to top-down approaches.

Quantum Mechanics to the Rescue?

Obviously, theism is compatible with evolutionary theory only if the probability statements of the latter reflect neither determinism nor blind chance nor pure randomness dominating evolutionary dynamics. In light of this, the idea naturally arises that quantum mechanics, which is commonly considered to be the only scientific theory implying ontological indeterminism, could support theistic evolution.

However, in the context of evolutionary theory, for any argument in terms of quantum mechanics to be valid, quantum physics must be of relevance in describing evolutionary dynamics. In fact, the connection of biology and physics is still controversial[7]; it is also an open question which aspects of evolutionary dynamics are to be described in terms of quantum mechanics. Yet it is now undisputed that (at least) some probability statements which play a central role in the description of genetic mutations have quantum origin: "point mutations, including base-pair substitutions, deletions; spontaneous mutations, including errors during DNA replication, repair, recombination; radiative physical mutagens (including X-rays and ultraviolet light); and crossing over" (Russell 1998, 207). Moreover, recent research suggests that quantum physics plays a significant role in describing information transport; the aim is a quantum model of how the environment affects induction and conservation of genetic variations.[8] To sum up, there is no question that quantum mechanics is of some relevance for evolutionary dynamics, and thus, integrating quantum probabilities is a necessary condition for evolutionary theism.

The fact that quantum mechanics is of relevance in describing evolutionary processes does not automatically mean, however, that reconciling evolutionary theory and theism no longer presents a problem. As argued above, it has to be shown—as a *conditio sine qua non* for the compatibility of evolutionary theory and theism—that quantum mechanics is indeterministic in an ontological sense, but quantum indeterminism does nevertheless not reflect pure randomness, or arbitrariness. In what follows I will discuss whether these two conditions are fulfilled. First, by relating quantum uncertainty with different kinds of evolutionary chance, I ask if and to what extent quantum probabilities can provide a solution to the very problem of chance in evolutionary theory.

Condition 1: Quantum Indeterminism. In light of classical physics, there is every reason to believe that the world is deterministic[9]; the temporal evolution of physical systems can be completely described by the Newtonian equations of motion and the given initial conditions so that the state of a physical system S at any time t can be uniquely derived from the state S_0 at an arbitrarily chosen time t_0. In quantum mechanics, contrarily, the physical state of a system can be given only in terms of probability statements, that is, generally without certainty.

Whether the probabilistic nature of quantum mechanics implies ontological indeterminism has been conversely discussed since the foundations of the theory were laid. This question forms a part of the so-called interpretation debate that is struggling with the question as to how to properly understand what quantum mechanics tells us about reality. At the moment, no suggestion is (commonly) considered to provide a definite solution to the interpretational problems. Accordingly, a finite decision in favor of quantum indeterminism cannot be made. Yet, I will show that by considering conceptual issues, there is a good case to be made that quantum mechanics implies ontological indeterminism. That is to say, I will argue that interpreting quantum probabilities in terms of ontological indeterminism is at least as plausible as other interpretations and that each of the other views either has difficulties with self-consistency or leaves the determinism-indeterminism question open.

Metaphysical Determinism versus Principle of Predictability. In discussing determinism in the context of science, it is essential to distinguish between the metaphysical concept of determinism and an empirically testable necessary condition for the metaphysical concept, namely, the principle of predictability.

Obviously, the metaphysical concept of determinism stating that every event in the world is completely determined by other (antecedent) events so that same initial conditions always bring about the same events is an empirically untestable philosophical hypothesis; nothing could prevent a hard determinist from believing that it is just the manifestation of ignorance when an event appears to be caused by chance, while the underlying physical processes are unambiguously fixed.

An empirically testable necessary condition for determinism to be true provides the principle of predictability. Instead of *a priori* preferring a metaphysical position, by referring to the degree of precision a prediction can be made with we obtain an empirical argument for or against determinism: If within a physical theory every future event can be predicted with certainty, the theory can be considered an evidence for determinism. If, on the other hand, there are at least some future events the physical theory cannot predict with certainty, the theory can be considered an evidence against determinism.

In summary, the metaphysical concept of determinism tells the universe how to work, while in applying the principle of predictability, we simply ask the universe how it works (see Table 1).

Is Quantum Mechanics Really Indeterministic? By applying the principle of predictability to quantum mechanics, the question of quantum indeterminism appears to be a fairly easy one to answer. As within quantum mechanics an event is always predicted in terms of probability statements, quantum mechanics does not meet the predictability criterion for determinism that requires predictions with certainty, and therefore quantum indeterminism is to be preferred. However, this argument counts as a rather weak one. The reason for rejecting the principle of predictability as an appropriate criterion for quantum indeterminism may lie in the metaphysical character of determinism, in so far a philosophical belief

Table 1. Determinism versus Principle of Predictability

<table>
<tr><th>Metaphysical Determinism</th><th>Principle of Predictability</th></tr>
<tr><td colspan="2">every event in the world is</td></tr>
<tr><td>fixed by</td><td>predictable by knowing</td></tr>
<tr><td colspan="2">the initial conditions & physical laws</td></tr>
<tr><td colspan="2">so that the future is</td></tr>
<tr><td>contained in</td><td>predictable from</td></tr>
<tr><td colspan="2">the past</td></tr>
<tr><td>empirically untestable belief</td><td>empirically testable hypothesis</td></tr>
</table>

can always be considered true, so that in case of conflict with science the scientific theory will be rejected. Yet it is highly questionable to maintain determinism at the expense of rejecting quantum mechanics representing an empirically extremely well-confirmed scientific theory. Another reason for not accepting the principle of predictability in the context of quantum mechanics is that it does not apply if probability statements need necessarily be interpreted in an epistemological sense. In fact, to argue in this manner is the strategy of most opponents of quantum indeterminism. Therefore, in order to argue for quantum indeterminism, one must show that this is not the case, that is, quantum probabilities need not necessarily be interpreted in an epistemological sense. In what follows, I will do this by reasoning that deterministic interpretations of quantum formalism are far from being compelling.

There are two serious deterministic interpretations of quantum mechanics: many-worlds theory and Bohmian mechanics. Many-worlds theory aims to deduce Born's probability rule from the (allegedly) deterministic Schrödinger equation by assuming the existence of innumerable worlds coming into being in order to realize each possible state predicted by the Schrödinger equation.[10] Bohmian mechanics takes the other, less spectacular way and introduces an additional equation making quantum formalism deterministic. This guiding equation guarantees that a particle always has a well-defined position and trajectory in the 3-dimensional physical space, even though probabilities nevertheless arise because of ignorance of the initial positions that cannot, in principle, be overcome.

The judgment of both theories is not uniform. While many-worlds theory is quite popular, Bohmian mechanics is considered weird among most physicists. Regardless of this, I will now argue that many-worlds theory has difficulties with self-consistency while Bohmian mechanics is formally consistent, but leaves the determinism-indeterminism question open.[11] The meaning of probabilities in the framework of many-worlds theory is, to put it mildly, not clear; any probability not equal to one or to zero is just meaningless, because a certain event E either occurs in a world coming into being for this ground, that is, P(E) = 1, or E is no solution of the Schrödinger equation, and therefore does not occur at all, that is, P(E) = 0.[12] "The moral is that it is impossible to get the right answer for probabilities without adding something to the theory" (Barrett 2003).

Adding something to the theory would, however, contradict its main aim not to presuppose anything but the Schrödinger equation. In Bohmian mechanics, interpreting probabilities is a more subtle issue. A proper probability interpretation must be compatible with the claim that at each point of time each particle has—just as in classical physics—both a definite position and a definite momentum. Thus, naturally (and this is indeed the most common understanding among Bohmians), Bohmian probabilities are considered long run relative frequencies. Thereby, the relative frequency of an outcome is the occurrence of the relevant outcome divided by the total number of observations. For example, if you toss a coin ten times and get heads seven times, the relative frequency of getting heads is 0.7. Increasing the number of tosses, you should get (approximately) as many heads as tails so that the relative frequency of heads becomes 0.5; but can you thus infer that the probability of getting heads is 0.5? By affirming this question, you consider probabilities as long run relative frequencies. Clearly, (if consistent) a relative frequency interpretation preserves determinism. More exactly, it works only if determinism is true. Yet its consistency depends on whether relative frequencies can in fact be transferred into probabilities. In order to justify their interpretation, advocates of the relative frequency interpretation refer to a mathematical theorem, the Law of Large Numbers (LLN), which defines the (formal) relation between relative frequencies and probabilities. Interpreting probabilities in terms of relative frequencies fails, however. Since, to put it with U.S. philosopher Craig Callender, LLN solely states that "probability is close to long run relative frequency, probably. Clearly, the second use of probability needs a non-probabilistic explication to avoid circularity."[13] In other words, LLN cannot provide a probability interpretation in terms of relative frequencies, insofar as LLN itself is in need of a probability interpretation. In consequence, the only possibility to preserve determinism is an interpretation of probabilities by way of the wave function which—in the framework of Bohmian mechanics—not only "guides" each particle to follow a well-defined trajectory, but also defines the probability distribution of the particle's position. Obviously, in favor of a realist interpretation which is a necessary condition for determinism, the wave function itself has to correspond to an element of reality. In fact, the Bohmian wave function is often considered as representing a real physical field. However, this interpretation leads to difficulties; in order to describe a many-particle system containing n particles we need to write its wave function in a 3n-dimensional phase space. Moreover, it is unclear what the ontological relation of the wave function to its particle is. Does the particle "produce" its wave function the same way an electron produces the electromagnetic field around itself, or vice versa? Either way, for a realistic interpretation of the wave function one has to accept a quite strange metaphysical assumption. On the other hand, interpreting the guiding wave function with the help of irreducible dispositions of the particle to move in a particular direction given its position and the external forces makes such a weird metaphysical hypothesis like a 3n-dimensional field for each particle dispensable.[14] Therefore, it is safe to say that Bohmian mechanics does not just leave the question open if quantum mechanics is deterministic, but its deterministic interpretation comes with a more burdensome metaphysical price tag.

In summary, neither the many-worlds theory nor Bohmian mechanics provide a no-go argument for interpreting quantum probabilities in terms of indeterminism. Rather, it seems that deterministic interpretations fail mainly because the metaphysical concept of determinism is considered a necessary overall context for quantum formalism. However, as long as there is no compelling interpretation of quantum mechanics in terms of determinism, applying the principle of predictability in order to argue for (ontological) indeterminism cannot be regarded inappropriate.

Condition 2: No Randomness. The fact that there is no compelling deterministic interpretation of quantum theory allows for applying the principle of predictability. Since in quantum formalism predictions can usually be made only in terms of probabilities ($\neq 0, 1$), quantum theory yields an empirical argument for ontological indeterminisim. However, quantum indeterminism can be fruitfully embedded in a theistic context only if quantum probabilities reflect open-endedness or creaturely creativity instead of blind, undirected chance incompatible with divine love.

In this context, the most significant approach is a probability interpretation in terms of so-called *single case propensities*. Thereby, propensities are regarded dispositional properties of physical systems, that is, categorically irreducible features of these systems. In certain situations, the propensities become actualized which is manifested by probabilities being objective features of these situations. Clearly, in the framework of propensity interpretations, probabilities do not reveal randomness or undirected chance. On the contrary, probabilities are considered to reveal the irreducibility of the first-person perspective in nature, manifesting creaturely creativity. To put it another way, if there are alternate possibilities in a given situation, the reason for realizing any of these possibilities lies within the system itself so that it can only be objectified in terms of probabilities, and cannot be translated into a fully deterministic third-person description. This means that in the framework of single-case propensity interpretations probabilities ($\neq 0, 1$) reveal both the existence of alternate possibilities in a concrete situation and the existence of dispositional properties of the corresponding physical system.

Although propensity interpretations of quantum probabilities have often been criticized, there seems to be no reason not to regard them as serious candidates for interpreting quantum probabilities. First, the critiques are mostly concerned with technical aspects, and recent (re-)formulations seem to overcome the old problems.[15] Second, there is no commonly accepted epistemic interpretation of quantum probabilities: as we have seen, deterministic concepts mostly fail to track probabilities back to ignorance or lack of knowledge. The possibility of interpreting probabilities in an ontological, yet nonrandom sense shows, on the other hand, that quantum indeterminism is not necessarily identical with pure chance or undirected random behavior.

Results So Far

In order to reconcile evolutionary theory with the theistic concept of creation, I have formulated the necessary condition of ontological indeterminism resulting from creaturely creativity instead of undirected chance. As a matter of fact, evolutionary probabilities of quantum origin meet this criterium, when interpreted in terms of (single-case) propensities; but what about evolutionary probabilities of nonquantum origin?

In giving an answer to this question, it seems useful to make the following distinction: Suppose, first, that all evolutionary probabilities of nonquantum origin need to be interpreted in a purely epistemic sense, that is, *only* evolutionary probabilities of quantum origin reveal characteristics of nature, and therefore the problem of integrating evolutionary probabilities into theism boils down to the problem of integrating quantum probabilities into theism. Yet, *prima facie* it is far from being evident if and why all evolutionary probabilities of nonquantum origin should be interpreted in an epistemological sense. Therefore, we have to consider a second case where we first need to relate probabilities of quantum origin with other concepts of chance in evolutionary dynamics. Only on this basis will it be possible to conclude if and to what extent quantum probabilities can contribute to reconciling evolutionary theory with Christian theism.

To this end, it proves helpful to start with the comprehensive classification recently suggested by U.S. philosopher of science Roberta Millstein.[16] Millstein argues that the different meaning(s) of chance in evolutionary biology can only be understood by way of understanding the causes at work. She identifies seven different conceptions of chance that seem to be of some relevance for evolutionary dynamics:

1. chance as ignorance of the real underlying causes
2. chance as not designed
3. chance as sampling
4. indeterministic chance
5. evolutionary chance (independent of the generally adaptive direction of natural selection)
6. chance as coincidence
7. chance as contingency.

On the one hand, all conceptions of chance have in common that given a specified subset of causes; more than one future state is possible. However, the many future states need not be the manifestation of ontological indeterminism. Rather, it depends on which causes are taken into account (considered chance), which are operating but ignored (ignored chance), and which are prohibited from operating (prohibited chance).

Applying this distinction, let us now turn to the question which kind of physical process may lie behind a certain kind of chance. More exactly, let us see which conception of chance manifests some purely deterministic phenomena and which conception of chance can arise either due to some quantum mechanisms or due to a sort of nonlinear dynamics. Note that (leaving the question open if all kinds of nonlinear dynamics are indeed deterministic) these three types of mechanisms give a complete characterization of evolutionary dynamics. The three sets need nevertheless not be mutually exclusive—with the restriction that in terms of the suggested interpretation quantum phenomena are genuinely indeterministic. In the first case, the theistic integration of chance is a different problem than it is in the second case. For it seems possible—without assuming a divine intervention à la Creationism or Intelligent Design—that it is the deterministic laws themselves by way of which God as Creator realizes His purposes. Such an interpretation of deterministic laws is only implausible if the world as a product of these laws makes the problem of evil unanswerable. I will return to this question in the last section.

Obviously, while "chance as ignorance of the underlying causes" (1) is characteristic only of deterministic processes, both "chance as not designed" (2) and "chance as sampling" (3) can be the result of any kinds of dynamics, as (2) solely means the absence of intentionally guided causes while (3) as discriminate sampling refers to processes (such as natural selection) "in which physical differences among entities are causally *relevant* to differences in which entities are 'picked'." Whereas (3) as indiscriminate sampling is characteristic of processes (like random drift) "in which physical differences among entities are causally *irrelevant* to differences in which entities are 'picked'" (Millstein 2011, 433). "Indeterministic chance" (4), on the other hand, can arise exclusively by way of quantum dynamics, insofar it is the only (known) physical mechanism which implies (a sort of bottom-up) ontological indeterminism. "Evolutionary chance" (5) as well as "chance as coincidence" (6) seem to require genuine indeterminism, since both presuppose the existence of independent causal chains (which is impossible under determinism)—(5) assuming that there are evolutionary phenomena which are causally independent of the adaptive direction of natural selection and (6) defined as the confluence of independent causal chains. Thus, (5) and (6) arise either by way of quantum mechanisms or out of nonlinear dynamics if the latter is inherently indeterministic. Finally, "chance as contingency" (7) can be considered as another label for nonlinear dynamics, insofar as it means the high sensitivity to initial conditions.

To sum up, arguably, quantum physics can contribute to integrating evolutionary chance phenomena into theism if the conception of chance is applied as defined in (2–6). Yet, since both deterministic processes as well as nonlinear dynamics (that may or may not be deterministic) are involved in chance phenomena, integrating chance in evolutionary dynamics into theism boils down to the problem of relating quantum physics and nonlinear dynamics, on the one hand, and to defining the interplay of quantum physics and deterministic dynamics, on the other hand.

Relating quantum physics with classical phenomena in general or nonlinear dynamics in particular represents the most urgent issue in interpretational debates of quantum physics, namely the measurement problem. In asking if there is a clear demarcation between classical and quantum phenomena, the following two situations are logically possible. If there is such a clear cut, quantum and classical physics are complementary, and therefore, integrating evolutionary quantum probabilities into theism provides a complementary view to other approaches briefly mentioned in the section on "Perspectives for Theistic Evolution." However, if there is no such clear boundary, that is to say, if quantum physics is universally valid (which is the most common position among physicists), phenomena just appear to be classical; in reality it is all quantum. In this case, integrating evolutionary quantum probabilities into theism is sufficient to reconcile evolutionary theory with Christian theism.[17] Admittedly, the latter is a rather speculative and highly counterintuitive view. However, it cannot be ignored while the quantum measurement problem is unresolved.[18] Notwithstanding this aporia, either way, integrating evolutionary quantum probabilities into theism presents a necessary condition for a complete account of how chance in evolutionary dynamics are compatible the creation hypothesis.

Thus, let us, in a last step, turn to the question whether fulfilling the condition of ontological indeterminism that results from creaturely creativity instead of undirected randomness is also sufficient for quantum probabilities to be part of a positive account of creation which meets also the problem of evil.

Creation in the Mode of the Possible

The problem of evil is most closely connected with the idea of divine creation, as it arises only if assuming that the universe has been brought into existence by an omnipotent and morally perfect being. *Prima facie*, such a being not only would not want evil, but could also eliminate, or prevent it. The fact that there is evil in the world seems to contradict the belief in the existence of such a being. Therefore, in order to preserve the rationality of theism, the contradiction must be dissolved, that is, an explanation must be developed which could make the existence of both natural and moral evil plausible without abandoning theism.

Traditionally, most Christian theodicies are based on human freedom (free-will defense); thereby, moral evil is considered to be a result of free human actions, whilst natural evil is (somehow) related to the realization of human freedom. The idea of a freedom-centered approach to the problem of evil has recently been revived by both Open Theism and Process Theology. Therefore, we are obviously justified in assuming that a free-will defense plays a central role in (most forms) of Christian theism.

Opponents of a free-will defense question whether human freedom does represent a value which is great enough to outweigh the horrible amount of evil we experience—directly or indirectly—every day. Some others point to the recent scientific claims rejecting the neurobiological reality of human freedom.

Without denying that these are serious critiques, let us now assume both that human freedom is real, that is (at least), some people can (at least) sometimes rationally choose one of (at least two) alternate possibilities, and that such a freedom is worth the horrible amount of evil. In what follows I will point out the significance of this assumption in a theistic context. To put it more precisely, I will claim that taking this assumption seriously implies the necessity of understanding divine *creation in the mode of the possible*.

In order for God to create free persons gradually emerging out of simpler life forms, it is necessary[19] to create a world the very nature of which is creativity, or openness, out of which freedom can gradually arise. It must be a world evolving in mode of the possible instead of developing due to inevitability or arbitrariness. With regard to the properties of natural laws, the consequences may best be spelled out in the words of Kenneth Miller:

> [. . .] our freedom to act has to have a physical and biological basis. Evolution and its sister sciences of genetics and molecular biology provide that basis. A biologically static world would leave a Creator's creatures with neither freedom

nor the independence required to exercise that freedom. In biological terms, evolution is the only way a Creator could have made us the creatures we are—free beings in a world of authentic and meaningful moral and spiritual choices. (Miller 2002, 290)

In returning to our underlying twofold incoherence problem which arises when confronting evolutionary theory with the theistic idea of creation, evolutionary quantum probabilities understood as (single-case) propensities seem to contribute to dissolving the contradiction if a free-well defense is considered a proper approach to the problem of evil.

Conclusion

Our starting point was the question whether quantum mechanics can contribute to reconciling evolutionary biology with the creation hypothesis. In this paper, I introduced an approach how such an argument could work. However, I understand my approach as setting the stage for further studies rather than finishing a debate. My results have just opened a third way besides an Einsteinian block-universe view and the Darwinian blind chance interpretation.

Notes

1. Defenders of the kalam cosmological argument assert a temporal beginning, while proponents of the metaphysical cosmological argument advance an understanding in terms of contingency. Cf., e.g., Craig and Copan 2004.
2. Cf. Arthur Peacocke 2004, 79–80.
3. Note that while Dawkins stresses that the engine of origin and evolution of life is arbitrariness, he does not think that chance processes play a central role in evolutionary dynamics. On the contrary, Dawkins believes that it is necessity manifesting itself by way of cumulative selection that makes the God hypothesis obsolete; cf. Dawkins, 2006a), 43–74. Yet it is still controversial which role chance plays in evolutionary dynamics. Timothy Shanahan (1991), for example, argues for considering chance to be essential: "The true test of a concept's explanatory importance for a given domain is whether one can eliminate it and still explain the phenomena in that domain as well as before. On this criterion, 'chance' must be judged to be an ineliminable feature of evolutionary biology." This notwithstanding, even if Dawkins's view on the role of chance in evolutionary dynamics is appropriate, his theist argument does not seem to be compelling, insofar as the interplay of chance and necessity can also be understood in a Christian sense; cf. the section entitled "Perspectives for Theistic Evolution."
4. Cf. Rescher (1973, 235): "To say of reality per se that it is incoherent would be to say of it something that, in the final analysis, is simply meaningless. The hypothesis, that reality is incoherent is ultimately senseless because to ask of reality that it meet this condition is to ask of it something in principle impossible."
5. Cf. Peacocke (2004); Polkinghorne (1996, 2005).
6. An exception is Russell (1998). Here, I develop a somewhat different approach.
7. This problem becomes particularly clear in the so-called evolutionary indeterminism debate. Here, the question is at issue whether biology supervenes physics in a way that (at least) certain probability statements can be considered autonomous, and could therefore be treated independently from the underlying physics; for a comprehensive overview cf., e.g., Shanahan (2003).
8. Cf., e.g., Patel (2001); Davies (2004).
9. Note, however, that it is controversial whether classical thermodynamics is indeed deterministic; cf., e.g., Hoering (1969); Hutchison (1993).

10. DeWitt (1973, 161): "The universe is constantly splitting into a stupendous number of branches, all resulting from the measurement like interactions between its myriads of components. Moreover, every quantum transition taking place on every star, in every galaxy, in every remote corner of the universe is splitting our local world on earth into myriads of copies of itself."
11. For a more detailed discussion cf. Ijjas (2011).
12. Cf. Hemmo and Pitowsky (2007, 333): "The problem of probability in the many worlds interpretation of quantum mechanics arises because the splitting of worlds is unrelated to the Born probabilities. The theory implies that any possible combinatorial sequence of measurement outcomes is realized in some branch of the quantum state regardless of the size of its quantum amplitude (provided it is non-zero)."
13. Callender (2007, 365).
14. Cf. Suárez, "Quantum Propensities," *Studies in History and Philosophy of Modern Physics* 38 (2007): 436.
15. Cf., e.g., Suárez (2007).
16. Cf. Millstein (2011).
17. Cf. Wegter-McNelly (2011, 122): "Most physicists now agree that decoherence [i.e. the loss of identifiably quantum behavior from a simple quantum object when interacting with its environment, A.I.] does not completely solve the measurement problem. [. . .] The counterintuitive result of this diffusion process is that it hides the very behavior that would otherwise mark an individual object as quantum rather than classical."
18. Cf. Young (1996), 239–41.
19. Note, however, that for freedom (in the libertarian sense) to be realized, ontological indeterminism is only a necessary, but no sufficient condition. Cf., e.g., Van Inwagen (2002, 2008).

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