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On the Foundations of the Theory of Evolution

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Abstract

In this paper we suggest an alternative to standard neodarwinian evolution theory. The problem is that Darwinism, which sees evolution as a consequence of random variation and natural selection is based on a materialistic - i.e. matter-based - view of science, while matter in itself is considered to be a very complex notion in modern physics. More specifically, on a microlevel, matter and energy are no longer retained within their simple form, and quantum mechanical models are proposed wherein potential form is considered in addition to actual form. We suggest that the starting point of evolution theory cannot be limited to actual variation whereupon is selected, but to variation in the potential of entities according to the context. We are developing formalism, referred to as 'Context driven Actualization of Potential' (CAP), which handles potentiality. CAP describes the evolution of entities as an actualization of potential which is defined by the context each instance of time. As in quantum mechanics, lack of knowledge of the entity, its context, or the interaction between context and entity leads to different forms of indeterminism in relation to the state of the entity. This indeterminism generates a - non-Kolmogorovian - distribution of probabilities that is different from the classical distribution of chance described by Darwinian evolution theory, which stems from a 'actuality focused', i.e. materialistic view of nature. In this paper we present a quantum evolution game that highlights the main differences, which stem from applying our new perspective. As a formal framework, CAP makes it possible to unite different aspects and perspectives on evolution. We conclude that it is more fundamental to consider evolution in general, and hence also biological evolution in specific, as a process of 'context driven actualization of potential', for which its material reduction is only a perspective.

Introduction

According to Neodarwinian Synthesis, evolution is a consequence of random variation and natural selection of the 'fittest' (Darwin, 1859; Gould, 2002). In living matter, mutations or any evolutionary novelties randomly arise - 'variation' - and consequently beneficial mutations are preserved because they aid survival, while others will be destroyed because they withhold survival - 'natural selection'. Some have opposed this view on the basis that variation is not merely random

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but in a large part determined by natural law, e.g. Denton, Marshall and Legge (2002) argument extensively on the limited variability of protein folds. Lately, with the upcoming of new experimental techniques and disciplines as Evo-Devo, more and more similar critiques are given paying attention mainly to the 'lawlike' developmental constraints on variation and evolution (Arthur 2004). It is suggested that the role of natural selection in evolution is significantly smaller than was previously accepted by biologists after Darwin. Natural law in this view has a much greater impact on evolution; it can sometimes be seen as the primary factor in explaining evolutionary change. Notwithstanding the fact that this view has its merits in showing us the narrowness of the Darwinian account vis a vis physical science; it is, like its opponent, also essentially based on a classical, determinist conception of the physical world. This paper proposes another critique of neo-Darwinian theory, which derives from a nonclassical and nondeterminist view of physics, as developed recently in quantum mechanics. The notion of variation is examined. What is naturally selected for in the neo-Darwinian view are essentially forms of concrete and actual matter. We present a more general view in which forms of potentiality coexist with forms of actuality. The presence of potentiality states, as we will see, points to a non-Kolmogorovian probability structure at the basis of the context-entity interaction in evolution, which makes possible different pathways of evolution than were allowed for before.

Since the birth of quantum mechanics as a physical theory describing the behaviour of microscopic particles, the notion of 'potentiality state' with respect to different non-compatible contexts has gained importance (Aerts and D'Hooghe, in press). When the mathematical foundations of quantum theory were examined more closely, it turned out that the quantum mechanical nature of the entities is not just due to their microscopic size, but rather can be explained by the presence of potentiality states (superposition states in standard quantum mechanics) and the way in which the context of a measurement - when applied to a quantum entity in a potentiality state - actualizes one of the possible outcomes with a certain probability and induces a state transition towards an eigenstate of the observed outcome. This indeterministic and non-continuous state transition due to interaction with the measurement context is essentially different from the 'free evolution' when no measurement context is applied. In fact, it is often stated that these two types of evolution are contradictious with each other, resulting in many studies of so-called 'quantum paradoxes' suggesting that quantum theory is 'incomplete' and should be replaced by a more general theory in order to describe both kinds of evolution in a unified way (for a more detailed discussion, see Omnès, (1994)).

We developed a formalism, named 'Context driven Actualization of Potential' (CAP), which resolves this basic problem in a specific way. CAP describes the evolution of an entity in a general way as a process of 'actualization of potential under influence of context'. The context, as we conceive it, is not limited to what in quantum mechanics is called 'a measurement'. If the entity under consideration is in 'free evolution', and hence 'under influence of the rest of the universe', we consider, within the CAP approach, this 'rest of the universe' as the context. This means that if the entity is a microscopic quantum entity, its evolution is under the context 'rest of the universe' is described by Schrödinger's equation. The evolution is in this case continuous and deterministic. However, if for a quantum entity a measurement is performed, then the entity evolves according to the projection postulate, by which the measurement interaction induces a state transition of the entity towards an eigenstate of the observed outcome. In this way, the CAP formalism recovers both types of quantum evolution, the Schrödinger one, and the projection one, as special cases of a global evolution.

A potentiality state is defined with respect to a given context, e.g. the context in which a position measurement is performed, or the context in which a momentum (= mass times velocity) measurement is performed. Because of lack of knowledge about the precise nature of this contextual interaction, one cannot always infer from knowledge about the state of the entity which outcome will occur for a measurement. The resulting quantum probabilities have a very different structure than those encountered in classical experiments. Indeed, in classical theories probabilities of measurement outcomes can always be explained as due to a lack of knowledge about the state of the entity. This leads to a probability model over the set of outcomes, which satisfies the axioms of Kolmogorov. We mention that Andrei Kolmogorov was the first to develop an axiomatic theory of probability (Kolmogorov, 1950). Quantum probabilities are not due to a lack of knowledge about the state of the entity, but reflect the presence of potentiality states and an uncontrollable interaction between the measurement context and the entity which forces the entity to make a state transition towards an eigenstate of the actualized outcome (an eigenstate for an outcome of an experiment is a state for which this outcome occurs with certainty, whenever one chooses to perform this experiment). As a consequence, the resulting probability model over the set of outcomes has a non-classical or non-Kolmogorovian structure, the reason being that some of Kolmogorov's axioms are violated.

The process of 'actualization of potential by means of context' is not limited to evolutions within the micro-world described by standard quantum mechanics. It also appears readily in other fields of science, for example in cognition (Broekaert et al, 2005); in the social sciences (Aerts and Aerts, 1994); and in language (Aerts et al, 2005). In the present paper we explore the role of potentiality states and contextual change in evolution. Specifically, we discuss the relevance of the general CAP framework for Neodarwinian evolution (based upon random variation and selection by 'fitness').

Section 1: Classical versus Quantum Evolution

Let us illustrate the main differences between classical and quantum evolution with a simple example. Consider a point particle, which is fired with a certain momentum (= mass times velocity, a basic fundamental physical quantity for both classical and quantum mechanics) straight towards a plate containing a slit. This defines a measurement of position (x and y coordinates of the slit on the plate). If the particle hits the plate, it gets destroyed and the measurement yields a negative result 'the bullet didn't pass the plate'. If however, the particle arrives at the plate at the spot (x_0,y_0) where the slit is located, it will pass the plate without any problem, yielding a positive result for the 'plate-test', i.e. 'the bullet did pass the plate via the slit at point (x_0,y_0)'. Next, a second position measurement is made by putting another plate parallel with the first one, such that the slit is located a bit to the left of the first slit. Since the bullet travels straight towards the two plates and the positions of the two slits are different, classical physics predicts that no classical bullet can pass this configuration of two plates with one slit.

In quantum mechanics, the situation is different. Position and momentum are complementary observables, i.e. if the entity is in an eigenstate of one observable, it necessarily will be in a superposition state with respect to the second observable. This is due to the fact that the position and momentum operators are non commutative, implying they do not have a common set of eigenvectors, which means that it is impossible to be in an eigenstate for both reference frames at the same time. Since one can only claim that a certain observable has a value if and only if the entity is in an eigenstate of this observable, it follows that for a quantum entity it is impossible that at the same time both position and momentum have a value. In mathematical terms this is reflected as follows. The state of the quantum entity is represented in an abstract vector space, a complex Hilbert space. Depending on which context one chooses to actualize the potential (position or momentum) one has to choose either a set of eigenstates of position to express the state of the entity, or alternatively a set of eigenstates of momentum. It is a fact of quantum theory that no common set of eigenstates exists for these two observables. Hence, if the entity is in an eigenstate of position then necessarily it is in a potentiality state with respect to a context defined by a momentum measurement, and vice versa.

So after the first position experiment the quantum entity has changed to an eigenstate of position, corresponding with the position of the slit in the first plate. Hence immediately after this first measurement, the state of the entity will be an eigenstate of position. However, as soon as the particle has passed the first slit, its wave function will spontaneously spread out over space, resulting in a superposition state of position eigenstates. In a sense, one could interpret this as the natural evolution of the state of the entity from a limited class of eigenstates of position towards the larger general class of 'spread out state'. As a result, the probability that the quantum bullet will pass the second slit is - in contrast to the classical bullet - non-zero. This illustrates how by passing from one context and set of eigenstates (position) via a potentiality state (the spread out wavefunction between the two plates) towards the final state which is again an eigenstate of position (after the second plate), the entity can evolve from an eigenstate of position corresponding with the first slit towards a different eigenstate of position defined by the second slit, which is not possible in the classical case.

Section 2: Children Playing a Quantum-like Evolution Game

Let us now propose an example of a entity which evolves from one eigenstate to another eigenstate with respect to a certain context by evolving through a potentiality state, which transcends the mere 'random variation and selection upon fitness' scheme. We consider 6 objects: two pair of scissors, one blue (Sb) and one red (Sr), two rocks, one blue (Rb) and one red (Rr), and two pieces of paper, again one blue (Pb) and one red (Pr). The entity consists of two boxes, each containing exactly two objects. This means that there are two objects left, which can be put in 'a bag of spare parts'. Alexander is playing with the objects in the left box, while Vincent is playing with the objects in the right box. The bag of 'spare parts' lies between them, so they can pick a piece out of this bag if they need to, but the box of the other person is too far away to be able to take a piece out of that other box.

A measurement 'matching blue objects' is performed as follows. The observer (Alexander or Vincent) wants to have two blue objects in his box. First, the observer looks at the pieces in his box. If they both are blue (e.g., Rb, Sb), then the observer is satisfied with this configuration and the measurement yields 'yes', and the state of the entity is unchanged. If they both are not blue (hence both red) then the measurement yields 'no' and the red objects are left in the box as they are. If however one of the two pieces is blue, the measurement proceeds as follows. The observer picks randomly one of the two objects from the bag. If it is blue, he replaces the red object from the box with the blue object from the bag. If it is not blue (hence red), he puts this red piece back in the bag and after some time decides to give it a second try, and takes again at random an object from the bag. If it is blue, then it is used to replace the red object, but if it is again red, then he gives up trying to 'match blue objects' and accepts that there are two objects of the other colour, i.e. the blue object is replaced with the red one. As such, he doesn't have two matching blue objects, but at least there are two matching colour objects (red objects). Obviously, since there are not two matching blue objects, the 'matching blue objects' measurement yields outcome 'no'.

A second class of measurements is based on the children's game 'paper, scissors, rock', in which two players pick at random one of the three possibilities, and then check their moves. If they both made the same choice, it is a draw. If however there is a mismatch, then the rules are as follows:

paper defeats rock, rock defeats scissors, but scissors defeat paper. The measurement 'matching pairs of objects' is defined as follows. If the two objects in the box are the same (i.e. have the same shape), then the measurement yields outcome 'yes', and the state is left as it is (hence the box is in an eigenstate of 'both objects having the same shape').

If not, the observer selects at random one of the two objects from the bag and one of the two objects in his box. Next, the two selected objects play the 'paper, scissors, rock' game. If the selected object from the bag wins, it replaces the selected object from the box. Otherwise (in case of a draw or loss), the selected object from the bag plays the 'paper, scissors, rock' game against the second object from the box. Again, if the object from the bag wins, it replaces the object in the box. If the object selected from the bag loses or makes a draw against both objects from the box, the measurer continues by taking the second object from the bag and plays the 'paper, scissors, rock' game, applying the same rules as he did for the first object from the bag. So if both objects from the bag lose or draw against both objects of the box, the observer will keep the same (different) objects in his box and the measurement yields 'no', i.e. 'he did not succeed in matching two objects of the same shape in the box'. In the other case, he has replaced an object from his box with an object from the bag; if the two objects in his box now have the same shape, the measurement yields 'yes' ('I have now two objects with the same shape in my box'); if not, the measurement yields 'no'.

For clarity, let us briefly discuss the possible results of this measurement procedure, abbreviating P(aper), R(ock) and (pair of) S(cissors) with their initials:

1) Initial state of the box: PP, RR or SS: the measurement always yields outcome 'yes'.

2) Initial state of the box: PR, PS or RS. Let us consider the case PR (such that the different possible configurations of objects in the bag is given by PR, PS, RS or SS). The discussion for the two other cases (i.e. the box containing PS or RS) is analogous (under cyclic permutation of P, R and S).

2a) Box: PR (bag: PR): R from the bag always loses or draws against P or R from the box, P wins against R from the box, so the final configuration of the box is PP (bag: RR); hence the outcome is 'yes'.

2b) Box: PR (bag: PS). If P is selected from the bag, it draws against P from the box, but wins against R, so the new state becomes PP (bag RS) ; hence 'yes'. If however S is selected, it loses from rock but wins against P, so final state of the box is SR (bag: PP), and outcome 'no'.

2c) Box: PR (bag: RS). R from the bag always loses or makes draw, S loses against R but wins against P, so the new state of the box is SR (bag: RP), outcome 'no' is given to the experiment.

2d) Box: PR (bag: SS). S wins against P, new state SR (bag : PS) but since these are different objects, the measurement yields outcome 'no'.

One can show that for this entity and set of experiments one can derive a violation of Bell's inequalities (Bell, 1964), which proves that this entity cannot be described within a Kolmogorovian, i.e. classical scheme. Readers interested in the technical details are referred to a more elaborate article on this matter (Aerts, Bundervoet, de Ronde, D'Hooghe, Riegler, in press).

Next, let us look at the possible evolutions for a compound entity of two boxes with actualization driven under the context of 'matching colour' measurements.

Let the entity be prepared in the configuration (Pb, Sr) for Alexander's box, and (Pr, Sb) for Vincent's box. Hence, the bag contains (Rb, Rr). Now the 'matching blue objects' context can be applied, such that after the measurement two possibilities can be realized: either Alexander succeeds in getting two 'matching blue' objects such that consequently Vincent has two red objects, or else Vincent succeeds in obtaining two blue objects, and Alexander ends up with two red objects. When they continue playing the 'colour matching game', they find that they cannot change their state with respect to colour: Alexander stays in an eigenstate of having two blue objects, and Vincent stays in an eigenstate of 'red objects'. So in this scheme, no further 'evolution' is possible.

Next, let us consider the "matching shapes through the 'paper, scissors, rock' game" measurements. Let Alexander be in an eigenstate of blue objects, e.g. (Pb, Rb) and Vincent in an eigenstate of red objects (Sr, Pr). Consequently, the bag contains (Rr, Sb). If Alexander performs the 'matching shapes measurement' such that Rr is chosen from the bag, it will always lose (Pb) or make a draw (Rb) and be put back into the bag. However, if Sb is selected, it can win from Pb, and replace this object in Alexander's box. Hence the new state of Alexander's box becomes (Sb, Rb) such that the bag contains (Pb, Rr). If we now again apply the 'matching shapes' context, then if Alexander selects Rr from the bag, this object defeats Sb, such that Alexander's box changes into the new configuration (Rr, Rb), which is an eigenstate of 'matching shapes experiment', but a potentiality state with respect to the 'matching colour' context. Note that the bag now contains (Pb, Sb). Next, Vincent could apply the 'matching shapes' context on his box. Pb always loses (Sr) or makes a draw (Pr) if played against an object from Vincent's box, but if Sb is selected from the bag, it defeats Pr, such that the new configuration of Vincent's box becomes (Sr, Sb), which is a potentiality state with respect to the 'matching colours' context. In this way, the compound entity of Alexander's and Vincent's box is brought into a potentiality state with respect to the 'matching colours' experiment. Next, let us see what happens if a 'matching colours' context is applied. Let Vincent perform the measurement 'matching colour blue'. His box contains (Sr, Sb), the bag contains (Pr, Pb) and Alexander's box contains (Rr, Rb). Hence with non-zero probability Vincent could change his configuration into (Sb, Pb), which is an eigenstate of colour blue. Following, Alexander can apply the 'matching colours context' to obtain his new stable configuration, namely of red objects (Rr, Pr) or (Rr, Sr), depending on which object was selected from the bag.

This toy model demonstrates that by applying a different context and considering potentiality states of the entity with respect to the initial context, new ways of evolution are possible. E.g. the box of Vincent changed from a 'red' eigenstate with respect to the context of 'matching colours' towards a 'blue' eigenstate by considering intermediate potentiality states, realized by actualizing under the "matching shapes through the 'paper, scissors, rock' game" context. Evolution is thus realized by actualizing the potential under different contexts (CAP). CAP has major implications for evolution theory, which up till now only considered eigenstates of the 'selection upon fitness' context, while potentiality states were excluded. If we take notice of the fact that the physics underlying Neodarwinian evolution theory has entirely changed, it is no surprise that evolution theory will have to change. A first step in that direction is to provide a broader view on evolution that contains Darwinian evolution (defined by variation and selection upon fitness with respect to a certain context) as a special case, in the sense that all intermediate states in the evolution of the entity are classical states, and eigenstates of the considered 'selection upon fitness' context, while potentiality states are excluded, but that contains also evolutionary processes going trough potentiality states toward different contexts and bringing forth entirely different situations. As we show in this article, Neodarwinian evolution is then but a small part of the whole picture of evolution.

Conclusion

As we have argued using the model of Alexander and Vincent playing the quantum evolution game, if evolution is realized by inducing different, non-compatible contexts to the entity, then evolution along potentiality states could result in new states unrealizable by classical means. Hence pathways for evolution exist which do not exist in the classical case. In this approach, Darwinian evolution, based on natural selection of materially actualized states, can be regarded as a special case of a more general type of evolution, in which potentiality states and contexts different from the material context play a fundamental role. The framework of CAP also makes it possible to view biological evolution as one of the possible types of evolution, and for example cultural evolution as another type of evolution within the framework (Gabora and Aerts 2005). Also, CAP promises to help build an evolution theory, which can cope with more recent developments in physics and with the idea of a physical aspect of evolution compatible with these modern physical theories (i.e. quantum mechanics). A promising future discussion could be made on the relation between quantum indeterminism of potentiality states and the presumed randomness of variation, which lies at the basis of the Darwinian theory. As philosopher of science Karl Popper pointed out, randomness, or indeterminism of results, is a necessary condition for natural selection, which he regards as a form of downward causation, to have any explanatory power (Popper 1982). But until recently, no 'hard' sciences had come up with a founded view on indeterminism. Quantum mechanics is probably the first candidate to serve this role. We conclude that it is more fundamental to consider evolution in general, and hence also biological evolution in specific, as a process of 'context driven actualization of potential', for which its material reduction is a reduction within one specific context, namely the context of these moments of evolution which are actual within this materialistic context.

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