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Quantum Physics and Consciousness: The Quest for a Common Conceptual Foundation

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Abstract

Similar problems keep reappearing in both the discussion about the "hard" problem of consciousness and in fundamental issues in quantum theory. We argue that the similarities are due to common problems within the conceptual foundations of both fields. In quantum physics, the state reduction marks the "coming into being" of a new aspect of reality for which no causal explanation is available. Likewise, the self-referential nature of consciousness constitutes a "coming into being" of a new quality which goes beyond a fully causal account of reality. Both subjects require a categorical scheme which is significantly richer then the one used in addressing factual aspects of reality alone. While parts of this categorical scheme are realized in the formalism of quantum theory, they are seldom applied in the context of consciousness. We show what the structural limitations of a classical categorical framework are, how a richer framework can be developed, and how it can be applied to both quantum physics and consciousness.

Concepts that have proven useful in ordering things easily achieve such authority over us that we forget their earthly origins and accept them as unalterable givens. Thus they come to be stamped as "necessities of thought", "a priori givens", etc. The path of scientific progress is often made impassable for a long time by such errors. Therefore it is by no means an idle game if we become practiced in analyzing long-held commonplace concepts and showing the circumstances on which their justification and usefulness depend, and how they have grown up, individually, out of the givens of experience. Thus their excessive authority will be broken. They will be removed if they cannot be properly legitimated, corrected if their correlation with given things be far too superfluous, or replaced if a new system can be established that we prefer for whatever reason.

Albert Einstein (1916)

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1. Introduction

Ever since the first years of quantum mechanics, scientists and philosophers have tried to relate some of the mysteries of the new theory with the "hard" problem of consciousness.[2] In particular, in the context of the reduction of quantum states (or, in other words, the collapse of the wave function) the role of consciousness has been emphasized repeatedly, e.g. by Wigner (1961) or, more recently, by Stapp (2007). Even experiments have been performed to detect an influence of consciousness on quantum state reduction, see, e.g., Hall *et al.* (1977) and Bierman (2003). A prominent example for an explanation the other way round – consciousness explained by quantum reduction – is the approach of Hameroff and Penrose (1996). In their speculations a collective ("orchestrated") objective reduction (induced by gravity) of assemblies of tubulin molecules in microtubules is assumed to cause consciousness.[3]

In this article, we do not attempt a direct explanation of the phenomenon of consciousness by quantum state reduction or, *vice versa*, a direct influence of consciousness onto quantum matter leading to state reduction. Instead we argue that the similarities in the conceptual obstacles encountered in the discussions of both issues point to the need of a more appropriate categorical scheme.[4]

The present approach may be related to the idea of a "generalized quantum theory" (Atmanspacher *et al.* 2002, 2006): many phenomena in quantum systems as well as in cognitive systems require different approaches to be described properly. In "generalized quantum theory" this is a mathematical formalism, in the present approach the conceptual, respectively categorical, aspects are emphasized. The categorical scheme which is usually applied in the context of the factual aspect of reality – and Newtonian (or, more general, deterministic) physics as part of it – is not adequate in the context of indeterministic phenomena related to the "coming into being" of facts.

For quantum physics, the need for new "rules of thinking" has been emphasized on several occasions. An example is the following quotation by Feynman (1992) with reference to the double slit experiment:

> [The electron] always is going through one hole or the other – when you look. But when you have no apparatus to determine through which hole the thing goes, then you cannot say that it either goes

[2]The term was recently coined by Chalmers (1995), but the general idea behind it has a long history (see e.g. van Gulick 2004).

[3]For a general overview of quantum approaches to consciousness see Atmanspacher (2004) and references therein.

[4]It may turn out that the phenomenon of consciousness depends on the quantum nature of matter on a fundamental level in a way any other property of matter does – elasticity, color, the impenetrability of bulk matter etc. Of course, we do not exclude such a kind of dependency.

> through one hole or the other. (You can always *say* it – provided you stop thinking immediately and make no deductions from it. Physicists prefer not to say it, rather than to stop thinking at the moment.)

Clear experimental evidence in favor of quantum theory has forced physicists to give up the classical way of thinking and replace it by a mathematical formalism with a sometimes counterintuitive physical interpretation. If it would not be for the experimental facts, and if the mathematical formalism describing quantum theory were not so clear and straightforward, the reluctance to accept the rules of the quantum world might be even stronger than it is anyway.

In the context of consciousness, the experimental situation is much less pressing, apart from the fact that we all *know* that the first-person perspective, including subjective experiences (qualia etc.), exists. Furthermore, there is no mathematical formalism in sight which even remotely has the rigor of the formalism of quantum theory. For these (and other) reasons one often tends to apply the conceptual schemes, which are so powerful and convincing in the classical realm of physics, also in discussions of consciousness. However, the questions we ask and the answers we get in such discussions often seem meaningless and inappropriate.

The central argument of this article is that the discussions about certain aspects of consciousness require a set of categories which is similar to the one which is implicit in the mathematical formalism of quantum physics but, in general, absent in its conceptual interpretation. The new categorical scheme, in particular the dominant role of the "present" in this scheme, has been developed more than twenty years ago by von Müller (1983).

We are aware that there are numerous interpretations of quantum theory, even though most physicists would agree on the mathematical recipes to calculate measurable quantities. The concepts which we are going to develop do not depend on a particular interpretation of quantum theory, but our argumentation is based on some general features.

We exclude "superdeterministic" interpretations of quantum theory for which it is essential that the initial conditions of a state already contain the information about all measurements (and all results) which will be performed on a system in the future. In particular, these models deny any "free will" decisions of experimentalists concerning future experimental set-ups. Similarly, we explicitly exclude interpretations which rely on "backward causation", where the future outcome of a measurement has an influence on the present quantum state of a system.

There are deterministic interpretations of quantum mechanics, like Bohmian quantum mechanics, for which our arguments do not hold on a fundamental ontic level, but they still do hold on an epistemic level. A similar refinement of arguments would be necessary for the many-worlds interpretation, which on an ontic level is deterministic (there is no state reduction) but where the objective experience of any observer ("objective" in the sense that this experience is shared by all colleagues) is intrinsically probabilistic.

Finally, some of our arguments refer to an ontic correlate of the mathematical description of a quantum state. We assume that the quantum state of a physical system describes more than only the available information about that system and that the state reduction is more than a simple change of knowledge about the system. This rejection of a purely subjective or information-based formalism of quantum theory may be the most restrictive ingredient in our arguments.

Similar statements apply to our view of consciousness. The essential assumptions will be that consciousness is a highly self-referential and, at least on an epistemic level, indeterministic phenomenon. According to our opinion the indeterminism with respect to consciousness is of a fundamental nature. If the reader prefers a deterministic point of view and accepts the indeterminism only on an epistemic level, then the relevance of the categorical scheme to be proposed is also restricted to this epistemic level.

The article is organized as follows. In Section 2 we discuss some of the parallels encountered in the discussions about quantum theory and consciousness. We will introduce the concepts for the formulation of the new categorical scheme. In Section 3 we describe the notion of a categorical scheme and discuss an F-scheme which is applicable whenever one is referring to the *factual* aspects of reality. In Section 4, we will introduce a new set of categories, an E-scheme, which replaces the F-scheme whenever one is referring to the *events*[5] how facts come into being (i.e., "before" they are actually facts). We will discuss the different categories of this scheme and their role in the context of quantum theory and consciousness. Finally, we briefly summarize the results and indicate possible future applications.

2. Parallels in the Fundamental Problems of Consciousness and Quantum Theory

In this section we emphasize some of the parallels between the problem of consciousness and certain problems in the conceptual foundations of quantum theory. This listing serves a twofold purpose: it indicates that the categorical schemes which should be employed in the discussions about quantum theory and consciousness show major commonalities, and

[5] In this article, the notion of an *event* refers specifically to the *process* of "coming into being" of reality and not to its factual results.

it introduces some of the notions which will be used later to formulate the new and more appropriate categorical scheme in the context of “coming into being”, the E-scheme.

2.1 The *Status Nascendi* or “Coming into Being”

The term “fact” will be used to denote the lasting results of an “event”, i.e., the traces or imprints which a previous event has left in the present state of the universe. These traces can be memories (imprints in the neural structure of our brain), books, pictures, fossiles, “documents” (an expression used by von Weizsäcker (1939) in a similar context), or other forms of recording.

In contrast, *status nascendi* (“state of birth”) refers to something “coming into existence”, to the event of a transition from possibility into fact. In quantum mechanics, the *status nascendi* is closely related to the reduction process, i.e., the transition from a state containing a superposition of (classically distinguishable) possibilities to a state describing one definite, classical aspect of reality. While a state consisting of a superposition of possibilities refers to a non-factual presence (we will sometimes use the neologism “preality”), the results of the reduction process or collapse are the facts which remain as objective traces of this transition. The reduction or the transition itself is what many people call the “enigmatic” aspect of quantum theory. It is this transition to which we ascribe the notion of a *status nascendi*.

Consciousness, on the other hand, is permanently *in statu nascendi*. Using a metaphor, one could say that like a flame it is an autocatalytic event that permanently produces the conditions for its own existence. In the case of consciousness these conditions are (a) the content of which we are conscious and (b) the phenomenon that *we* are aware of it, i.e., that it is actively present for *us*. (We will later return to this most interesting relation between consciousness and the present.) This view fits very well with the observation that the neural correlates of consciousness seem to be characterized by a high degree of self-reference, as seen, e.g., in “re-entry loops” (Edelman 2001) or “feedback loops” (Freeman 2000). From a more mathematical perspective, Hofstadter (1980) also states that consciousness is only possible if a certain degree of self-reference is present.

In our subjective experience, the time evolution of our mental state consists of thoughts and ideas which more or less suddenly “pop in” and then slowly fade out. If these thoughts and ideas result in a memory (even unconscious for the moment but in principle capable of becoming conscious again) we may refer to them as facts in a wider sense. Even if some of these “sudden insights” may be preceded by neural signals (as indicated by the experiments of Libet *et al.* (1985)), one may conceive this process as a transition from possibilities to a mental (memorial) fact. In this sense consciousness refers to a phenomenon *in statu nascendi*. When the traces of such a "birth of a thought" become conscious again, this should be considered as a new event and not simply as the memory of a fact. In a similar way, reading a book is an event, even if the book refers to facts or if we have read it before.

We will argue in Section 4 that all other categorical features which will be mentioned in the following – autogenesis, self-reference, a distinguished and extended present, and the superposition or paratactic appearance of predications – are a consequence of the fact that both consciousness and quantum theory refer to the *status nascendi* aspect of reality. This will turn out to be the main reason why some of the categorical problems encountered in the context of consciousness are similar to some of the categorical problems encountered in the context of quantum theory.

Finally, we emphasize that the *status nascendi* and, therefore, the applicability of the conceptual scheme we propose is not restricted to the realm of quantum physics and consciousness alone. We already mentioned the phenomenon of a flame or, more generally, autocatalytic processes in chemistry – processes in which the outcomes provide the conditions for their own maintenance. Another example may be the phenomenon of life itself. The higher the degree of recurrence or self-reference, the more prominent will the features be to which we refer. However, while in most cases in chemistry and biology the degree of the *status nascendi* depends on the descriptive level employed for the particular process (and may lose this property when described from a lower level), we assume that in quantum theory as well as in the context of consciousness "coming into being" is more fundamental than for most other processes.

2.2 Autogenesis – The Indeterministic Aspect of Events

In the realm of quantum physics as well as in our own conscious experience, we often perceive the world as indeterministic. As indeterminism can probably not be proven positively, the existence of an irreducible unpredictability will be sufficient for our arguments.

According to the standard interpretation of quantum mechanics, the result of a measurement is not determined or somehow encoded in the degrees of freedom of quantum systems (or even in the degrees of freedom comprising a quantum system together with the environment, including the measuring device) before the measurement is actually performed. Leibniz' principle of sufficient reason does not hold in quantum theory. This view is supported by the violation of Bell's inequalities in quantum theory (Bell 1966), and confirmed by experiments (Aspect *et al.* 1982). Not even *a posteriori* is it possible to find an explanation why, in a given measurement process, a particular possibility emerged as a fact and not one of the other possibilities. According to the present understanding of quantum theory, this form of indeterminism implies not only an epistemic unpredictability but an ontic feature.

Whenever the factual traces of an event cannot be predicted beforehand due to ontic indeterminacy, we will speak of "autogenesis" – the coming into being of something new "out of itself". "New" does not necessarily imply that the output could not have been anticipated as one of several possibilities, but it indicates that it was not predictable which one among those possibilities actually became a fact. And "out of itself" emphasizes that there is no external cause for the resulting state.

A typical example in quantum physics is the outcome of a Stern-Gerlach experiment (an excellent discussion of the Stern-Gerlach experiment in the context of the measurement problem is due to Gottfried (1989)). An electron, prepared, e.g., in an eigenstate for the spin orientation along the x-axis and passing through a magnetic field gradient along the z-axis, will be deviated along the z-direction. There are only two possibilities for this deviation, but it is impossible to predict which of the two possibilities will finally become a fact.

We already mentioned that in the many-worlds-interpretation of Everett (1957) and deWitt (1970) there is no reduction or collapse of a state and thus no indeterminism of quantum theory. The state of the universe is and remains a superposition of all "classical" possibilities. In such a picture all the concepts defined and used here refer to the epistemically "accessible" parts of the universe and not to an overall "God's-eye" perspective. On the epistemic level, also the many-worlds theory is indeterministic, albeit in a non-standard sense: Even if the complete quantum state were known, we can only make a probability statement with respect to the outcome of a measurement that we actually do experience.

In this context we should like to indicate one more parallel between quantum theory and consciousness, which is related to "non-invasive" measurements.[6] In quantum theory it is impossible to perform measurements on systems without a corresponding change of the state of the system (an exception is the case that the state is an eigenstate of the observable corresponding to the measurement). This change is not necessarily due to an interaction (exchange of energy) but can be of a purely quantum mechanical nature. Bohr (1935) remarked in the context of measurements on entangled systems:

[6]So-called interaction-free measurements (Elitzur and Vaidman 1993; see also Renninger 1960) are also accompanied by a change of quantum states, even though there is no interaction between the material components of the systems. In the classical set-up of Elitzur and Vaidman, the state of the photon in the Mach-Zehnder interferrometer is changed due to the presence of the obstacle, however, it is not the photon which "interacts" with the obstacle. This is a situation where the photon and the obstacle are entangled until a further measurement (explosion of the "superbomb" or a detector click for the photon) is performed. The "ensemble reduction" considers only those situations where the photon did interact with the right detector.

> Of course there is ... no question of a mechanical disturbance of the system. ... But ... there is essentially the question of an influence on the very conditions which define the possible types of predictions.

Similarly, it is presumably impossible to "measure" the conscious mental state of a subject (either by introspection or by an external observation of reactions to questions etc.) without a massive disturbance of this state, leading to a different temporal development. It should be emphasized, however, that the act of measurement does not causally determine the outcome but is just a trigger for the emergence of one of the possibilities as a fact.

2.3 Self-Reference – A System Observes Itself

In mathematics, self-reference is not a common term (e.g., it has no entry in the *Encyclopedic Dictionary of Mathematics* (Ito 2000)). On the other hand, self-reference is one of the most relevant and often used notions in the context of complex dynamical systems and structure formation. (In many cases the definition of self-reference is of the kind "I know it when I see it".)

In its most general form, self-reference means that the dynamics of a system for which the time evolution depends, at least partially, on states in the past of this system. In many cases, self-reference is used in the context of complex systems which have a natural partition into two (or more) subsystems (for instance a system in contact with an environment). If these subsystems mutually influence each other, one subsystem can effectively act back onto itself via the coupling to the other subsystem.

In the following, we will use the notion of self-reference for systems which have an influence onto themselves due to an act of "self-observation". We shall see that self-reference in this sense is closely related to an inseparability of observer and observed. In the case of consciousness, the relation between self-reference and an inseparability of observer and observed is almost obvious: when a conscious system reflects about its own consciousness, the observed system and the observer system are identical.

This subtle relationship exists also in quantum theory. Let us consider the act of measurement in quantum mechanics in more detail.[7] Generally, one distinguishes the quantum system (QS), about which one wishes to obtain information in an act of measurement, and the measuring device (MS). Initially, the state $|\phi_0\rangle$ of MS is independent of the state $|s\rangle = \sum_i \alpha_i |s_i\rangle$ of QS (the indicated expansion is with respect to the correlates of the pointer basis $\{|\phi_i\rangle\}$ of MS). The initial state $|\Phi\rangle_{init}$ of the total system (QS+MS) is separable. As the result of an interaction between

[7] For a profound discussion of the measurement problem see, e.g., Bell (1993), Gottfried (1989), von Neumann (1932), Wheeler (1983), and references therein.

QS and MS during the process of measurement, the state $|\Phi\rangle$ of the total system can be expressed as a superposition correlating QS and MS:

$$|\Phi\rangle_{init} = |s\rangle\,|\phi_0\rangle \;\longrightarrow\; |\Phi\rangle = \sum_i \alpha_i |s_i\rangle\,|\phi_i\rangle\,. \qquad (1)$$

Such a state is called an entangled state, and sometimes also the two subsystems are denoted as entangled. Strictly speaking, it is not possible to assign a definite state to the subsystems QS and MS separately but only to the total system QS+MS. Only due to the reduction process, in which the result of the measurement process becomes a fact, the states of the two systems become separated, i.e. disentangled.

2.4 Time-Space of the Present – The Absence of Sequentiality

The standard theories of present-day physics make no reference to an explicit "present". While in the Newtonian view of space and time the notion of simultaneity (considered as a relation between two events) is well-defined and, therefore, an objective "present" is not excluded, special and general relativity only allow for a distinction between "causally related" and "causally unrelated" events. For two causally unrelated events the attribute of simultaneity is not an objective statement but depends on the state of an observer (and is, strictly speaking, a matter of convention concerning the synchronization of clocks).

Famous in this context is the quotation of Weyl (1922):

> The objective world simply is, it does not happen. Only to the gaze of my consciousness, crawling along the lifeline of my body, does a section of this world come to life as a fleeting image in space which continuously changes in time.

Here, Weyl explicitly refers to consciousness as the only "organ" by which we are able to detect a "present". A global concept of an objective present seems to be in contradiction with special (and general) relativity.

One might argue that at least along the world-line of an observer there is a well-defined sequentiality of events and, therefore, the possibility of a present in terms of a distinguished, ever-moving "now". However, in view of entanglement situations in quantum mechanics, such a restriction to purely local aspects is difficult to hold. For an entangled state consisting of two subsystems which are far apart, a measurement on one of the subsystems leads to an almost immediate collapse of the total (non-local) wave function. If we attribute more than simply a subjective increase of knowledge to the state reduction of a quantum system and assume it as being related to an objective (ontic) process, this process defines a global simultaneity – "global" at least to the extent that entangled systems can be separated.[8] For this reason, quantum theory is sometimes denoted as "non-local".

However, there is no explicit experimental violation of special relativity due to the fact that the collapse of a quantum state cannot be used for information transfer. Hence, already the assumption of an ontic reduction process in quantum theory introduces an unobservable and observer-independent simultaneity between events.[9] Exactly the same assumption allows us to introduce a distinguished "present" associated with this process which marks the transition from potentiality to facts.[10]

Even more important is the observation that the present related to the reduction process is not a sharp, extensionless point (or hyperplane) between the future and the past, but that we have to attribute an extension to it (measured against a mathematical or hypothetical idealized time). The width of this extension depends strongly on the type of process and can vary between fractions of nano-seconds (for interactions among many degrees of freedom, like in a typical measurement process) and large time-scales up to billions of years (at least in thought experiments like the "astronomical delayed choice" experiment[11]).

The width of the time-space of the present depends on the specific event which is taking place until it becomes a fact in correlation with the extraction of information. The extended present is marked by a loss of sequentiality: it is impossible to attribute a sequential order to events within this extented present. A typical example are scattering processes between particles which, in the context of quantum field theory, can be interpreted as an exchange of other particles. The total amplitude is determined by summing over all possible contributions. This involves sums of the type "a occurs before b *and* b occurs before a". In such cases it is impossible to attribute a sequential order to events a and b. (Similar examples for the impossibility of a sequential ordering for quantum events

[8]Similar considerations led Gödel (1946) to the conclusion that a physical time – with the present marking a transition to an objective reality – is in contrast to special relativity.

[9]In cosmology, a distinguished reference system – and hence a distinguished simultaneity – is given by the center-of-mass system of the observed mass distribution in the universe, which coincides with the reference system with respect to which the microwave background is isotropic.

[10]Recently a Lorentz-invariant formulation of the collapse process in the framework of the Ghirardi-Rimini-Weber model has been formulated by Tumulka (2006). However, the multi-time formalism together with non-local relations among the reduction "flashes" make it difficult to compare this formalism with our framework. In any case, the relevant aspect of our scheme is the partial loss of temporal sequentiality, and this is also present in the model of Tumulka.

[11]The original delayed-choice experiment in the context of double-slits was described in Wheeler (1978). The astronomical delayed-choice experiment is attributed to Wheeler by different sources, but does not appear in Wheeler's own writings; see also the Wikipedia entry on "Wheeler's delayed choice experiment".

are mentioned in Aharonov *et al.* (1998) and Oppenheim *et al.* (2000, 2002).

A process-dependent extended present within which a sequential ordering is illegitimate, is one more distinguished feature that quantum theory shares with consciousness. Already Weyl's observation illuminates the close relation between the present and consciousness, but this relation is even stronger: One cannot even think of experiencing a present without having consciousness and, *vice versa*, one cannot think of being conscious without having the experience of a present! The phenomena of experiencing a present and being conscious of oneself are so closely related that they might be two sides of one coin.

As in quantum theory, it is characteristic for consciousness that it is not experienced as a sharp, point-like present, but rather as taking place in an extended present. Both experiences mentioned above show that the present never has the characteristic of a point-like, unextended now, nor is the state of self-consciousness characterized by this constraint. Like in quantum theory the width of the extension may depend on the kind of process. The experience of a "moment" of insight is not that of a point-like sharp transition, and in particular not that of a clear sequence of ideas, but rather the experience of a fast (but not instantaneous) crystallization of a relational net of ideas. The experience of a great work of art can have a similar effect – it draws us into an extended present. Sequentiality usually comes later. Sometimes composers mention that the idea for a work of music does not arise as a sequence of notes but as a whole, in an extended "moment" of coming into being. Extreme examples of the experience of an extended present are reported for Buddhists in certain states of meditation.[12]

We emphasize that this should not be interpreted in terms of physiological time scales related to the discrimination and sequentialization of stimuli, such as the scales of a few milliseconds (below which it is impossible for us to discriminate temporally separated stimuli) or the range of 30-70 milliseconds (below which we can discriminate but not sequentialize temporally separated stimuli). Likewise, the above mentioned experiences of an extended present are not primarily seen as psychological phenomena but as mental correlates of the time-space of the present.

As another remark concerning the time-space of the present we should clarify our point of view with respect to the "blockworld" picture which is usually favored in the context of relativity (and to which the quotation of Weyl refers). The essential ingredient of our categorical scheme (see Section 4) is the loss of sequentiality for events even along the world-lines of physical systems and within the boundaries set by relativity for possi-

[12]In a recent article Franck and Atmanspacher (2008) speculate about a relation between an extended present and "attention".

ble causal dependencies. As mentioned above, this loss of sequentiality is most obvious in the "sum-over-histories" representation of quantum theory. It is the temporal counterpart of the loss of the spatial localizability of events. This loss of sequentiality is part of present-day quantum theory, although it is not emphasized in standard textbooks.

With respect to the extended present, we indicated the possibility that a consistent theory of quantum state reduction (based on an ontic reduction process) may involve a "global present" and thus violate the blockworld picture of relativity. This problem is closely related to the question of why conscious systems (and *only* conscious systems) experience a particular moment as a present. We are convinced that a consistent theory of consciousness as well as a consistent theory of quantum mechanics (including the reduction process) will only be possible in the context of a consistent theory of the present.

There are approaches which try to explain the conscious experience of a present (together with a factual past and an open future) within the framework of a blockworld as a general feature of so-called "information gathering and utilizing systems" (for a recent review see Hartle 2005). We believe that approaches of this kind miss essential features of the consciousness discussion. However, a complete assessment of this point would extend far beyond the scope of this article (and leave the realm of science). For the present purpose we consider primarily the loss of a strict sequentiality of time.

2.5 Paratactic Predications – Superposition States

One of the most fundamental (and perhaps one of the least understood) properties of quantum theory is the superposition principle. The Schrödinger equation is linear, which is why we can represent its solutions as elements of a vector space. Mathematically, the states of quantum theory are represented by the one-dimensional complex linear subspaces (complex rays) of a Hilbert space, i.e., the state space is a projective space. For such linear spaces a unique sum is not defined.[13] On the other hand, the relative phase between two vectors has measurable consequences in the superposition.

If we avoid the addition of vectors and restrict the discussion to linear subspaces, the superposition principle may be replaced by the following statement: For any state ω there exist observables A such that ω is not dispersion-free with respect to A, i.e., such that $\omega(A^2) \neq \omega(A)^2$. To be dispersion-free implies that the variance of A in the state ω is zero, i.e., that the result of a measurement of A in the state ω yields always the same

[13] We can decide whether a given state is a superposition of two other states, i.e., whether it is a subspace of the plane spanned by the two other states, but in contrast to the sum of two vectors this leaves us with an infinite number of possible superpositions.

result. (In vector notation one would say that the vector corresponding to the pure state is an eigenstate of A.) If a state ω is not dispersion-free with respect to an observable A, this means that repeated measurements of A on systems prepared in the state ω may yield different results. But as ω is supposed to be pure, it cannot be interpreted as a mixture of states for each of which a measurement of A yields unique results.

This property – repeated identical measurements yield different results even for systems prepared in the same pure states – is one of the characteristic features of quantum theory, and corresponds directly to the non-commutativity of observables. Any observable can be decomposed into propositions (formally this is achieved by the so-called spectral decomposition). That is, for any possible result a of a measurement of A we can formulate the proposition "a pure state yields the result a" and its negation "a pure state does not yield the result a". A pure state which can be expressed as a superposition of different eigenstates (corresponding to different eigenvalues) may, therefore, be interpreted as a coexistence of mutually exclusive propositions (not in the sense of "either–or" but rather in the sense of "both–and"). We will use the term "paratactic" (with the meaning of "standing side by side") for this coexistence of predicates. Of course, this coexistence only holds for the "preality" of quantum theory, i.e., immediately before one of the predicates becomes a fact due to the reduction process.

A similar phenomenon can be attributed to conscious states, albeit not as mathematically well-defined as in quantum theory. Conscious states can be in a "superposition" with respect to certain properties or predicates. Consider, for instance, the example of a triangle. While the word itself does not require us to specify the exact kind of triangle (acute, obtuse, rectangular etc.), a diagram of a triangle has to specify the angles and the length of the sides. However, when we think of a triangle, our mental state is in a kind of superposition of various angles, sides and different types of triangles. Even though we seem to have an image of a triangle in our mind, this triangle is not specified with respect to the length of its sides or its angles. (Of course, we *can* concentrate on a triangle with a particular shape, but this is not what happens when we think of a triangle in general.)

A related example is the mental representation of the Necker cube, a two-dimensional projection of a three-dimensional cube. When we *look* at a Necker cube, the mental state reconstructs a three-dimensional perspective even though the drawing is ambiguous with respect to this perspective. When the stimulus is switched off, we retain the mental image of a cube, but the conscious impression of a perspective is lost.[14]

[14] A mathematical model which can explain the occurrence of such superposition states has been developed by Atmanspacher *et al.* (2004, 2008).

3. The F-Scheme for the Factual Aspects of Reality

By categories we mean most fundamental thinking patterns used to address reality. A "categorical apparatus" is a set of mutually interdependent categories. One cannot replace or substantially modify one of the categories without rendering the entire apparatus disfunctional. Changing only one category while leaving the other categories of the apparatus unchanged necessarily leads to a loss of conceptual coherence. In this and the following section we will introduce two types of such an apparatus which are both needed to address "reality" comprehensively. Depending on whether "reality" refers to facts or to events – the *status nascendi* of facts – it will be the F-scheme or the E-scheme, respectively, that should be employed. For a full and comprehensive assessment of reality always both schemes are involved with different emphasis, depending on the issue.

Before we introduce the F-scheme in this section, we briefly raise the question of which aspects of reality need to be addressed by a categorical apparatus. We suggest the following four components:

(1) a basic pattern to describe time (and space),
(2) a basic pattern how events are interrelated,
(3) a basic structure of a predication space,
(4) a basic epistemological relation between observer and observed.

Concerning the first component we remark that a pattern to describe "space" is implicit. The notions of time and space are closely interrelated (as already Aristotle noted, and as it became manifest in the theory of relativity). In our context, for instance, temporal non-locality implies spatial non-locality and *vice versa*. However, we will concentrate on the aspect of time for two reasons: Firstly, a smeared-out, spatially extended wave function which does not allow for the localization of objects (or events) within a process-dependent region, is a common and well known feature of quantum theory. An extended present, however, is less common, because time is usually treated as a classical parameter. Secondly, also for the discussion of consciousness the temporal aspect is more relevant than the issue of spatial extension.

We now develop the F-scheme which is used when referring to the factual aspects of reality. As mentioned before (Sec. 2.1), facts are the traces left behind when events have taken place in the time-space of the present. In this sense, facts are the imprints that these events leave in subsequent states of the universe.

In a deterministic (Newtonian) world the state of the universe at a certain instant determines the whole past and future of this universe. In a Newtonian universe everything which happens, will happen, or happened is a fact. The categorical apparatus to describe a Newtonian universe is the F-scheme. In this apparatus, the following four categories fill the functional slots of the general scheme:

(1) *Sequential Time*: Along the world-line of any observer (or object) facts are totally ordered with respect to "before" and "after". The present is a point which separates the future from the past and which plays no distinguished role in the factual aspects of physics. (In a similar way, objects in space have strict relations, i.e., in principle positions can be arbitrarily localized.)
If the flow of facts would not show an unequivocal linear-sequential order, causality could not be maintained and binary predicates related to the concepts of "before" and "after" would be lost.

(2) *Determinism*: Leibniz' principle of sufficient reason holds in its strictest sense. The complete future and past of a closed system are (in principle) determined if the conditions are fixed at some instant in time (usually the initial conditions).
The principle of causality provides for the coherence of reality. If phenomena would just arbitrarily appear or pop into different states without any sufficient cause, reality would become an incomprehensible jumble, i.e., the other three constituents of the F-scheme would collapse.

(3) *Boolean Predications*: Contradicting or mutually exclusive predicates (or "propositions") are realized as "either–or". Logical structure is based on the *tertium non datur*.
Binary predications allow for unequivocal distinctions. This ability would not exist if something could be P and not-P in the same way and at the same time. For the other three constituents of the F-scheme this kind of unequivocal distinctions is a prerequisite.

(4) *Complete Separability of Observer and Observed*: In classical physics it is, in general, taken for granted that an observation does not have any influence on the observed system. Furthermore, because all known interactions decrease with increasing distance between systems, we can always separate a system from the rest of the universe and treat it as closed and independent. There is no distinction between the perspectives of a physically realized observer and a "God's-eye" perspective.
If this clear-cut dichotomy would be violated, i.e., if something can be the observed and the observer at the same time, the observed would be changed through the very act of observing itself and the classical notion of objectivity and clear-cut Boolean predication would be violated.

4. The E-Scheme for Reality "Coming into Being"

The E-scheme refers to the taking place of events themselves, not their traces left behind as facts. An event describes the transition from potentialities (preality) to facts (factual reality). Preality and factual reality together constitute reality, which is the reason why both categorical schemes together are needed to address reality comprehensively. The E-scheme puts the following categories into the four functional slots introduced above:

(1) *The Time-Space of the Present*: The transition from potentialities to facts happens in an extended present (no sequential ordering) as well as space (no spatial ordering). The extension of the "time-space of the present" depends on the process under consideration. With respect to an abstract mathematical time, its extension is characterized by the impossibility to attribute a temporal order to events. A similar statement holds with respect to its extension in space: a relative order for the location of events is not possible.
In quantum theory, an extended present enters because in the "sum-over-histories"-representation of quantum processes one has to sum over all temporal instants of events as well as over all spatial locations of them. The information about relative spatial and temporal locations constitutes itself due to interactions of the components of a process with the environment. Hence, the information leaks into the environment and, *vice versa*, by leaking into the environment it constitutes itself.

(2) *Autogenesis*: Indeterminism implies the violation of Leibniz' principle of sufficient reason. Autogenesis on the lowest level of physical laws means that there is no preexisting cause for something to happen. Therefore, indeterminism is the outside view of autogenesis. On higher levels (in biological or even conscious systems) autogenesis means "something coming into being out of itself", again implying that there is no external cause. In these systems autogenesis is closely related to the phenomenon of "emergence".

(3) *Paratactic Predication Space*: In a paratactically structured predication space predications stand side by side, even if they are mutually exclusive. This implies that no logical conclusions with respect to these predications are possible, and thus the *ex falso quodlibet* castastrophe is avoided. What is expressed is constituted by the overall constellation of predications. In quantum theory this category is realized by the superposition principle, where for a property P both P as well as non-P can be true (and along the same line both can also be false).
Parataxis does not imply that the predication space is without any structure. In general, the predications will be related to each other, they form a relational net of predications which is more than simply a set of predicates. In a superposition state the relative amplitudes and phases of the mutually exclusive possibilities express this structure. In poetry, for example, the meaning of (even contradictory) expressions which stand side by side is revealed by the overall constellation of these expressions.

(4) *Self-Reference and the Inseparability of Observer and Observed*: Self-reference means that a system refers to itself. The nature of this reference relation distinguishes different forms of self-reference. In its simplest form it only implies that the state of a system at a certain instant depends on states of the system at previous instances. This is the case for recurrent deterministic algorithms (like $x_n = f(x_{n-1})$) or Newton's equations of motion. In general, this is not the type of self-reference meant in the E-scheme. For being self-referential, we not only require that a system makes use of previous states, but that it represents at least aspects of itself.
In quantum theory, the measurement process is an example of this type of self-reference: the present state of the system – comprising the observer and the observed immediately after the interaction between them has occurred, but prior to the reduction – represents aspects of a previous state of the system. In conscious systems the reflection upon oneself is an example for this type of self-reference. In both cases it is obvious that observer and observed can no longer be separated without loosing essential information about the state of the total system.

The four components of the E-scheme are interrelated, and it is not possible to replace one of them by the corresponding component of the F-scheme without making the whole categorical scheme inconsistent. Here, we only indicate some of the relationships (more details can be found in von Müller (1983, 2003), and von Müller and Pöppel (2003)).

Paratactic predications are necessary for objective, i.e., ontic indeterminacy. If the factual outcome of a process is not determined beforehand but can be one of several possibilities, the event leading to this fact has to comprise all these possibilities. Only in a deterministic setting does the state of a process leading to a certain fact already contain the one possibility which is realized later. Furthermore, an indeterministic transition from possibilities to facts distinguishes a present (as well as a future and a past), and this present cannot be extensionless as otherwise the transition would be discontinuous and random. *Vice versa*, an extended present does not allow for the predicate "a before b *or* b before a" but rather "a before b *and* b before a", thus leading back to paratactic predications. Finally, self-reference is part of any autogenetic and indeterministic process because any reference to an external cause would violate the indeterminacy.

As mentioned before, the total categorical apparatus referring to reality comprises the E-scheme as well as the F-scheme. Depending on whether we concentrate the discussion more on the "coming into being" aspects or more on the factual aspects of reality, we may have to use a mixture of both schemes. This does not only hold for physics, but also for the discussion of consciousness. Factual aspects related to a well-defined memory or logical conclusions have to be treated predominantly within the

F-scheme, while aspects related to "spontaneous insights" and/or "self-reflection" will require emphasis on the E-scheme.

5. Summary and Conclusion

We argue that only to the degree that facts have emerged out of the taking place of reality, the canvas of space-time as used in classical and relativistic physics and the related categorical apparatus of the F-scheme applies. Space-time is characterized by locality. We argue that the categorical prerequisites for locality are linear-sequential time, a Boolean predication space, the principle of causality (*causa sufficiens*, respectively) and a clear-cut dichotomy of subject and object (observer and observed, respectively). These four components are interdependent and form the categorical apparatus of the F-scheme. Its common denominator is comprehensive separability. The F-scheme applies to the factual aspects of reality – and only to them.

We argue that prior to the state of facticity, i.e., for the taking place of reality and the coming into being of facts, the E-scheme applies as a complementary categorical apparatus. It is characteristic for the coming into being of reality that it takes place in the time-space of the present. Its extendedness allows for the phenomenon of autogenesis which, in turn, is characterized by strong self-reference. Both autogenesis and self-reference imply an entanglement of observer and observed. All this requires a paratactic predication space in which the message is not a matter of logical derivations, but emerges out of the overall constellation of heterogeneous predications. The common denominator of the components of the E-scheme is an aspect of inseparable unity – of which the physical counterpart is spatio-temporal non-locality.

We argue that both categorical schemes are needed in order to address reality in a comprehensive way. Classical and relativistic physics address mainly the factual aspect of reality – for which the F-scheme is sufficient. Quantum physics, instead, addresses also the coming into being of facts, the taking place of reality as such. The highly successful mathematical machinery of quantum mechanics encompasses practically all the features of the E-scheme. This the reason why interpretations of quantum physics drawing, implicitly, on the categorical framework of the F-scheme are enigmatic.

Regarding the phenomenon of consciousness no powerful formal description mechanism is available. Therefore, everything hinges on the quality of a conceptual grasp of the phenomena. Based on the richer categorical framework described here, we have shown that consciousness shows all the features of the E-scheme. This means that it essentially is not to be seen as a mere fact, but as an on-going "taking place". Consciousness constantly constitutes itself – in the time-space of the present to which it is, therefore, irreducibly related.

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