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

Thomas Filk[1] and Albrecht von Müller[2]

[1,2]Parmenides Center for the Study of Thinking, Munich

[1]Institute for Frontier Areas in Psychology, Freiburg

[1]Institute for Physics, University of Freiburg,

[2] Institute for Philosophy, University of Munich

Abstract

There are similar problems which keep reappearing in both, the discussion about the "hard" problem of consciousness as well as 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 "comming into being" of a new aspect of reality for which no causal explanation is available. Likewise, the self-referential nature of consciousness constitutes a "comming into being" of a new quality which goes beyond a fully causal account of reality. Both subjects require a categorial scheme which is significantly richer then the one used in addressing just the factual aspect of reality. While parts of this categorial 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 the classical categorial 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

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 (the term was recently coined by Chalmers (1995), but the general idea behind this term has a long history (see e.g. van Gulick, 2004). 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 this case a collective ("orchestrated") objective reduction (induced by gravity) of assemblies of tubulin molecules in microtubules causes the effect of conscious insight. (For a general overview of "Quantum Approaches to Consciousness" see the contribution of Atmanspacher (2006) in the Stanford Encyclopedia of Philosophy and references therein.)

In this article, we do not assume a direct explanation of the phenomenon of consciousness by quantum state reduction, or, vice versa, a direct influence of consciousness onto a kind of quantum matter leading to state reduction. Instead we argue that the similarities in the conceptual obstacles encountered in the discussions of both issues might have their origin in the need of a more appropriate categorial scheme.[1] In this aspect the present approach may be related to the idea of "generalized quantum theory" of Atmanspacher et al. (2002, 2006): many phenomena, including quantum theory as well as phenomena of cognitive systems, require a different formalism - in "generalized quantum theory" this is a mathematical formalism, in the present approach the conceptual respectively categorial aspects are emphasized. The categorial scheme which is in general 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 phenomena which are non-deterministic and which are related to the "coming into being" of facts rather than already existing facts.

For quantum physics, the need for new "rules of thinking" has been emphasized on several occasions, an example being the following quotation of Feynman (1965) 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 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 wouldn't 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 greater.

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, intentionality, attention, 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 the discussions about consciousness. However, we often experience in such discussions that the questions we ask and the answers we get seem often meaningless

[1] **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.**

and not appropriate, indicating that the employed categories might be inadequate.

The central argument of this article is that the discussions about certain aspects of consciousness require a different 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 categorial scheme, in particular the dominant role of the "present" in this scheme, has been developed more than 20 years ago by one of the authors (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 which should be satisfied.

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 this system in the future. In particular, these models deny any "free will" decisions of the experimentalists concerning future experimental set-ups. Similarly, we eplicitly exclude interpretations which rely on "backward causation", i.e., where the future outcome of measurements 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 his/her collegues) 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 availabe 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, non-deterministic phenomenon. According to our personal opinion the indeterminism with respect to consciousness is of a fundamental natur, but if the reader prefers a deterministic point of view and accepts the indeterminism only on an epistemic level, then the relevance of the new categorial scheme is also restricted to this epistemic level.

The article is organized as follows. In the next Section, we list some of the parallels encoutered in the discussions about quantum theory and consciousness. In this context we will introduce the concepts which we will use in the formulation of the new categorial scheme. In Section 3 we describe the notion of a categorial scheme and discuss the F-scheme which is applicable whenever one is refering to the *factual* aspects of reality. In Section 4, we will introduce a new set of categories, the E-scheme, which replaces the F-scheme whenever one is referring to the *events*[2] 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 categorial schemes which should be employed in the discussions about quantum theory and consciousness show major commonalities, and it introduces some of the notions which will be used later to formulate the new and more appropriate categorial scheme in the context of "coming into being", the E-scheme.

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

2.1 The "statu nascendi" or "coming into being"

The expression "fact" will be used to denote the lasting results of an event, i.e., the traces or imprints which a past 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" (this expression was used by Carl Friedrich von Weizsäcker (1939) in a similar context, or other forms of recording.

In contrast, "statu nascendi" ("being in the state of birth") denotes "something coming into existence". It refers to the event itself, i.e. the transition from possibility into fact. In quantum mechanics, the "statu nascendi" is closely related to the reduction process, i.e., the transition from a state consisting of superpositions of classically distinguishable possibilities to a state describing one definite, classical aspect of reality. While a state consisting of superpositions of possibilities refers to a non-factual presence (we will sometimes use the nickname "preality" in this context), the results of the reduction process or collapse are the facts which remain as objective signs 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 "status nascendi".

Consciousness, on the other hand, is in a permanent "status 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 come back 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-referentiality, as seen e.g. in the "reentry loop" of Edelman (see, e.g., Edelman, 2001) or the "feedback loops" of Freeman (see, e.g., Freeman, 2000), just to mention a few. Comming from a more mathematical perspective, Hofstadter (1980) also states that consciousness is only possible if a certain degree of self-reference is present.

In addition, 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 in a wider sense as facts. Even if some of these "sudden insights" may be preceeded 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 also consciousness refers to a phenomenon in a "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 as simply the memory of an old event. In a similar way, reading a book is an event, even if the book refers to past events or if we have read the book before.

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

Finally, we should emphasize that the "statu nascendi" and, therefore, the applicability of the new 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 general, autocatalytic processes in chemistry - processes for which the outcomes provide the conditions for their own survival. Another example may be the phenomenon of life itself. The higher the degree of recurrency or self-referentiality, the more prominent will be the features to which we refer in our new conceptual scheme. However, while in most cases in chemistry and biology the degree of this "statu nascendi" depends on the descriptive level employed for this particular process (and may, when described from a lower level, loose this property), we assume that in quantum theory as well as in the context of consciousness this "coming into being" is more fundamental than for most other processes. For these reasons we will concentrate on these two phenomena.

2.2 "Autogenesis" – the non-deterministic aspect of events

In the realm of quantum physics as well as in our own conscious experience, we often perceive the world as non-deterministic. As non-determinism can probably not be proven positively, the existence of irreducible non-predictability would also 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. Leipniz' 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, 1982). Not even *a posteriori* is it possible to find an explanation why, in a given measurement process, a particular possiblity emerged as a fact and not one of the other possibilities. According to the present understanding of quantum theory, this form of non-determinism implies not only an epistemic but an ontic impredictability.

Whenever the factual traces of an event cannot be predicted beforehand due to ontic impredictability, we will talk 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 among those possibilities actually became a fact. And "out of itself" emphasizes that there is no external cause for the final state.

A typical example from the realm of 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 can be found in the textbook of Gottfried (1989): An electron, prepared, e.g., in an eigenstate for the spin orientation along the x-axis and passing though 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 not possible, even in principle, to predict in this situation which of the two possiblities will finally become a fact.

We already mentioned that in the so-called "many-worlds-interpretation" of Everett (1957) and de Witt (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 in this article refer to the epistemically "accessible" parts of the universe and not to an overall "Gods-eye" perspective. On the epistemic level, also the many-worlds theory is non-deterministic, albeit in a non-standard sense: Even if the complete quantum state could be known, we can only make a probability statement with respect to which outcome of a measurement 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. In quantum theory it is impossible, even in principle, to perform measurements on systems without a corresponding change of the state of the system (an exception being 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 remarks in the context of EPR-measurements: "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..." (Bohr, 1935). [3]

A similar statement seems to be true in relation to consciousness: It is presumably impossible to "measure" the conscious mental state of a person (either by self-introspection or by external observation of the reactions to questions etc.) without a massive disturbance of this state leading to a different temporal developement. 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.

[3] **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 an EPR-like 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.**

2.3 "Self-referentiality" – a system observes itself

In mathematics, "self-reference" is not a common expression (e.g., there is no corresponding entrance in the *Encyclopaedic Dictionary of Mathematics* (2000). On the other hand, self-reference is one of the most relevant and often used expressions in the context of complex dynamical systems and structure formation. (In many cases the definition of self-reference is of the level "I know it when I see it".)

In its most general form, self-referentiality denotes the property of 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 itself due to an act of "self-observation". We shall see that in this sense "self-reference" is closely related to a "non-separability of observer and observed". In the case of consciousness, the relation between self-referentiality in the sense defined above and non-separability of observer and observed is almost obvious: when a conscious system reflects about its own consciousness, the observed and the observer system are identical and inseparable.

This subtle relationship exists also in quantum theory. Let us consider the act of measurement in quantum mechanics in more detail (for a profound discussion of the measurement problem see e.g. Neumann (1932), Gottfried (1989), Bell (1993), and Wheeler (1983) and references therein): 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 $|\Phi\rangle_{\rm init}$ of the total system (QS+MS) is separable. As the result of an interaction between QS and MS during the process of measurement, the state $|\Phi\rangle$ of the total system can be expressed as a superposition of correlated states between QS and MS:

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

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 asign 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 state of the two systems becomes separated again.

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 not related" events. For two causally not related events the attribute of simultaneity is not an objective statement but depends on the state of an observer (and is, striclty speaking, a matter of convention concerning the synchronization of clocks).

Famous in this context is the quotation of Hermann Weyl: "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." (Weyl, 1923) 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 EPR-like 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 appart, a measurement on one of the subsystem 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, but instead assume it as being related to an objective (ontic) process, this process defines a global simultaneity - "global" at least to the extend that entangled systems can be separated.

(Similar considerations led Gödel to the conclusion that a physical time - with the present marking a transition to an objective reality - is in contrast to special relativity (Goedel). 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 a non-observable and observer independent simultaneity between events. (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.) Exactly the same assumption allows us to introduce a distinguished "present" associated with this process which marks the transition from potentiality to facts.[4]

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 (measured against a mathematical or hypothetial idealized "time") to the present. The degree of this extension depends strongly on the type of process and can vary between fractions of nano-seconds (for interactions among macroscopically many degrees of freedom, like in a measurement process) and large macroscopic time-scales (up to billions of years - at least in thought experiments like the "astronomical delayed choice" experiment of Wheeler (1993). The "width" of the time-space of the present depends on the specific event, which is taking place until the event 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 which happen within this extented period. 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 de-

[4] **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.**

termined 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 of quantum events are mentioned in Aharonov (1998) and Oppenheim (2000,2002).)

A process-dependent extended present (we will refer to this "present" as a "time-space of the present") for which a sequential ordering of elementary events is not possible, is one more distinguished feature of quantum theory which it shares with consciousness. Already H. Weyl's observation illuminates the close relation between the present and consciousness, but this relation is even stronger: One cannot think of experiencing a present without having consciousness and vice versa, one cannot think of beeing conscious without having the experience of a present! The phenomena of experiencing a present and being conscious of oneself are even so closely related that one can think of them as the two sides of one coin.

Like in quantum theory, it is characteristic for consciousness not to be experienced as a sharp, point-like present, but rather as taking place in an extended present. Both of the above mentioned experiences show that the present has never the characteristic of a point-like, unexpanded now, nor is the state of self-consciousness characterized by this constraint. Like in quantum theory the degree of 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 expanded present. Sequentiality usually comes later. Sometimes composers mention that the idea for a work of music comes not as a sequence of notes but as a whole in a similar "extended" moment of coming into being. Extremes example of the experience of an extended present are reported by buddhist monks in certain states of meditation.[5] We should emphasize that what is not meant in this context are physiological time scales related to sequentializability of stimuli, like the scales of 30 ms (below which it is impossible for us to discriminate temporally separated stimuli) or 70 ms (below which we can discriminate but not sequentialize temporally separated stimuli). Likewise, the above mentioned experiences of an expanded present

[5] In a recent article Franck et al. (2008) speculate about a close relation between an extended present and "attention".

are not seen as primarily psychological phenomena but as mental correlates to the time-space of the present.

As a last remark concerning the "time space of the present" we should clarify our point of view with respect to the "blockworld" picture which is favored in the context of relativity (and to which the quotation of Weyl refers). The essential ingredient of our categorial scheme (see 4) is the loss of sequentiality of events even along the world-lines of physical systems and within the boundaries set by relativity for possible causal dependencies. As mentioned above, this loss of sequentiality is most obvious in the "summation over history" representation of quantum theory and is the temporal counterpart to the loss of spatial localizability of events. This loss of sequentiality is part of present day quantum theory, although it is not emphasized in the standard presentations.

In addition the extended present, we indicated the possibility that a consistent theory of the 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 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" (IGUSs) (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 (appart from leaving the realm science). Therefore, we emphasize that for the purpose of this article only the loss of strict sequentiality of time is relevant.

2.5 Paratactic predications – the superpositions of 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 the 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. (We can decide, whether a given state is a superposition of two other states, i. e., whether the given state 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.) 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 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 other states for which a measurement of A yields unique results.

This property - repeated identical measurements yielding 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), i.e., 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-vector 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 "as well ... as"). We will use the expression "paratactic" (in 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 in the reduction process.

A similar phenomenon can also 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. Take, for instance, the example of a "triangle". In contrast to language which does not specify what kind of triangle (acute, obtuse, rectangular etc.) is meant, a diagram of a triangle has to specify the angles and the length of the sides. However, when we think of a general triangle, our mental state is in a kind of mixture of "angles", "lines" 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 lines or the angles. (Of course, we *can* concentrate on a triangle with a particular shape, but this is not what happens when we just think of a triangle.)

A related example is the mental state when we think of a 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 if the stimulus is gone, however, we still have the image of a cube in front of our mental eye but, in general, the conscious impression of a perspective is gone. (A mathematical model which can explain the occurence of such superposition states has been developed by Atmanspacher et al., 2004)

3 The F-scheme for the factual aspects of reality

By categories we mean the most fundamental thinking patterns by which we address reality. A "categorial apparatus" is a set of mutually interdependent categories. It is characteristic for an apparatus in the sense this concept is used here that 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 the two categorial apparatus (the F-scheme and the E-scheme) which both are needed in addressing "reality". 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, which should be employed. It should be kept in mind, however, that for a full and comprehensive assessment of reality always both schemes are involved but with different emphasis depending on the issue.

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

- a basic pattern to describe time (and space)
- a basic pattern how events are interrelated
- a basic structure of a predication space
- a basic epistemological setting between an observer and the observed.

Concerning the first component we should remark that a pattern to describe "space" is implicit. The notion of time and space are closely interrelated (as already Aristotle noted, and as it became manifest in the theory of relativity). In our context, this can be put in the formula that 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 time, however, is less common, because time is usually treated as a classical parameter. Secondly, also for the discussion of consciousness, the temporal aspect is much more relevant than the spatial extension of brain activity.

We now develop the F-scheme which is used when refering 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 world (like a Newtonian universe) the state of the universe at a certain instant determines the whole past and future of this universe (in mathematics, such a space-like "hypersurface" which determines the future and the past of a system is called a Cauchy-surface). In a Newtonian universe everything which happens, will happen, or has happened is a fact. The categorial apparatus to describe a Newtonian universe is the F-scheme.

In the categorial apparatus of the F-scheme the following four categories fill the functional slots in the general scheme of a categorial apparatus:

- *Sequential time*: along the world-line of any observer (or object) events are totally ordered with respect to "before" and "after". The present is a mere 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 events would not show an unequivocal linear-sequential order, causality cannot be maintained and binary predicates related to the concepts of "before" and "after" would be lost.

- *Determinism*: Leibniz' principle of sufficient reason holds in its strictest sense. The complete future and past of a closed system is (in principle) determined if the conditions are fixed at a certain 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 mishmash, i.e., all the other three constituents of the F paradigm would collapse under these conditions.

- *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 $\neg P$ in the same way and at he same time. For the other three constituents of the F paradigm this kind of unequivocal distinctions is a prerequisite.

- *Complete separability between 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 between 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.

The above list indicates some of the interdependencies of the categories. A more detailed description of the interdependence of the categories of this apparatus has been shown in [27] (more recent descriptions can be found in [28, 29], an updated extended version is in preparation).

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 always both categorial schemes are needed to address full reality.

The E-scheme puts the following categories into the four functional slots introduced above:

- *The time-space of the present*: The transition from potentialities to facts happens in a "space" which is extended with respect to time (no sequential ordering of elementary events) as well as space (no spatial ordering of events). 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 in the location of events is not possible.

  In quantum theory, an extended present enters because in the "summation over possibilities"-representation of quantum processes one has to sum over all temporal instants of elementary events as well as over all spatial locations of these events. 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.

- *Autogenesis*: Non-determinism 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, non-determinism 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".

- *Paratactic predication space*: In a paratactically structured predication space predications stand side by side, even when they are mutually exclusive. This implies that no logical conclusions with respect to these predications are possible, and thus the "ex falso quodlibet" castastrophy 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 $\neg P$ 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. This set assumes an additional structure. 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 contradicting) expressions which stand side by side is revealed by the overall constellation of these expressions.

- *Self-referentiality and the non-separability of observer and observed*: Self-referentiality means that "a system refers to itself". The nature of this "reference" distinguishes different forms of self-referentiality. 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. However, this is also the case for deterministic algorithms (like $x_n = f(x_{n-1})$)

or Newton's equations of motion. In general, this is not the type of self-referentiality meant in this context. 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-referentiality: the present state of the system - comprising the observer and the observed immediately after the interaction between both systems has occured but before the reduction - represents aspects of a previous state of the system. In conscious systems the reflection upon itself is an example for this type of self-referentiality. In both cases it is also obvious that observer and observed can no longer be separated withouth loosing essential information about the state of the total system.

The four components of the E-scheme are intimately interrelated and it is not possible to replace one of these components by the corresponding component of the F-scheme without making the whole categorial 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 the state of a process leading to a certain fact already contains the one possibility which later is realized. Furthermore, a non-deterministic transition from possibilities to facts distinguishes a present (as well as a future and a past) and this present cannot be extentionless 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 befor a" but rather "a before b AND b before a", thus leading back to paratactic predications. Finally, self-referentiality is part of any autogenetic and non-deterministic process because any reference to an external cause would violate the indeterminism.

As we have mentioned before, the total categorial apparatus refering 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 not only holds for physics, but also for the discussion about consciousness. Factual aspects related to a well-defined memory or logical conclusions have to be treated predominantly within the F-scheme, while aspects releated to "spontaneous insights" and/or "self-reflection" will require emphasis on the E-scheme.

5 Summary and Conclusion

We have argued 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 categorial apparatus, the F-scheme, applies. Space-time is characterized by locality. We have argued that the categorial prerequisites for locality are linear-sequential time, a Boolean predication space, the principle of causality respectively causa sufficiens and a clear-up dichotomy between subject and object respectively observer and observed. These four components are interdependent and form a categorial apparatus, the F-scheme. Its common denominator is comprehensive separability. The F scheme applies to the factual aspect of reality – and only to it.

We have argued that prior to the state of facticity, i.e., for the taking place of reality and the coming into being of facts, as complementary categorial apparatus, the E-scheme applies. Characteristic for the coming into being of reality is that it takes place in the time space of the present. Its expandedness allows for the phenomenon of autogenesis which, in turn, that is characterized by strong self-referentiality. Both, autogenesis and self-referentiality implies an entanglement of observer and observed. And all the above require 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 all the components the E-scheme is an aspect of inseparable unity – of which the physical counterpart is spatio-temporal non-locality.

We argue that both categorial schemes are needed in order to address reality in a comprehensive way. Classical and relativistic physics address mainly the factual aspect of reality – and therefore 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 F-scheme. But the interpretations of quantum physics often draw implicitly still on the categorial framework of the F-scheme, and thus remain rather enigmatic.

Regarding the phenomenon of consciousness not even a powerful formal description mechanism is available. Therefore, all hinges on the quality of the conceptual grasping of the phenomenon. Based on the richer categorial 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.

References

[1] Y. Aharonov, J. Oppenheim, S. Popescu, B. Reznik, W.G. Unruh; *Measurement of Time-of-Arrival in Quantum Mechanics*; Phys. Rev. A 57 (1998) pp. 4130–4139.

[2] A. Aspect, J. Dalibard, G. Roger; *Experimental Test of Bell's Inequalities Using Time-Varying Analyzers*; Phys. Rev. Lett. 49 (25), (1982), pp. 1804–1807.

[3] H. Atmanspacher; *Quantum Approaches to Consciousness*; Stanford Encyclopedia of Philosophy, 2006, `http://plato.stanford.edu/entries/qt-consciousness/`.

[4] H. Atmanspacher, T. Filk, and H. Römer; *Quantum Zeno Features of Bistable Perception*; Biol. Cybern. 90 (2004) 33-40; and H. Atmanspacher, M. Bach, T. Filk, J. Kornmeier, and H. Römer; *Cognitive Time Scales in a Necker-Zeno Model for Bistable Perception*; Journal of Integrative Neuroscience 6 (2007) in press.

[5] H. Atmanspacher, H. Römer and H. Walach (2002); *Weak quantum theory: Complementarity and entanglement in physics and beyond.* Foundations of Physics **32**, 379–406.

[6] H. Atmanspacher, T. Filk and H. Römer (2006); Weak quantum theory: Formal framework and selected applications; in *Quantum Theory: Reconsideration of Foundations - 3*, ed. by G. Adenier *et al.*, American Institute of Physics, New York 2006, pp. 34–46.

[7] J.S. Bell; *On the problem of hidden variables in quantum theory*; Rev. Mod. Phys. 38 (1966) 447–452.

[8] J.S. Bell; *Against "Measurement"*, in *Speakable and unspeakable in quantum mechanics*; Cambridge University Press, 1993.

[9] D.J. Bierman; *Does Consciousness Collapse the Wave-Packet?*; Mind and Matter 1(1), 2003, pp. 45–57.

[10] N. Bohr; *Can Quantum-Mechanical Description of Physical Reality be Considered Complete?*; Phys. Rev. 48, 1935, pp. 696–702.

[11] D.J. Chalmers; *Facing Up to the Problem of Consciousness*; Journal of Consciousness Studies 2(3), 1995, pp. 200-219.

[12] G.M. Edelman and G. Tononi; *Consciousness - How Matter Becomes Imagination*; Penguin Books, 2001.

[13] A. Einstein; *Ernst Mach*, Phys. Zeitschr. **17** (1916) 101–104.

[14] *Encyclopaedic dictionary of mathematics*; 2nd ed., The Mathematical Society of Japan, Kiyoshi Ito (ed.), MIT-press, Cambridge Massachusetts, and London, 2000.

[15] A.C. Elitzur, L. Vaidman; *Quantum mechanical interaction-free measurements*, Found. of Phys. **23** (1993), 987.

[16] H. Everett; *"Relative State" Formulation of Quantum Mechanics*; Rev. Mod. Phys. 29 (1957) 454–462.

[17] W. Freeman; *Mesoscopic Brain Dynamics*; Springer, 2000.

[18] R.P. Feynman; *The caracter of physical law*; First published by the British Broadcasting Corporation, 1965; Republished by Pinguin Books, London, 1992.

[19] G. Franck and H. Atmanspacher; *A Proposed Relation between Intensity of Presence and Duration of Nowness*; Proceedings of the International Conference *Wolfgang Pauli's Philosophical Ideas and Contemporary Science*; H. Atmanspacher, K. von Meyenn, U. Müller-Herold, R. Nesper, and H. Primas (eds.), 2008.

[20] K. Goedel; *Some observations about the relationship between theory of relativtiy and Kantian philosophy*, in *Collected Works, Volume III: Unpublished Essays and Lectures*, ed. by S. Feferman, Oxford University Press, Oxford, pp. 230-246.

[21] K. Gottfried; *Quantum Mechanics - Vol. I: Fundamentals*; Addison-Wesley Publishing Company, Redwood City, 1989.

[22] J. Hall, C. Kim, B. McElroy, and A. Shimony; *Wave-Packet reduction as a medium of communication*; Foundations of Physics 7, 1977, pp. 759–767.

[23] S. Hameroff and R. Penrose; *Orchestrated Reduction of Quantum Coherence in Brain Microtubules: A Model for Consciousness?*; in *Toward a Science of Consciousness - The First Tuscon Discussions and Debates*, S.R. Hameroff, A.W. Kaszniak, A.C. Scott (eds.); MIT-Press, Cambridge, MA, (1996) 507–540.

[24] J.B. Hartle; *The Physics of 'Now'*; Am. J. Phys. 73 (2005) 101-109.

[25] D.R. Hofstadter; *Gödel, Escher, Bach - An Eternal Golden Braid*; Random House, New York, 1980.

[26] B. Libet; *Unconscious cerebral initiative and the role of conscious will in voluntary action*; Behavioral and Brain Sciences 8 (1985), pp. 529-566.

[27] A.A.C. v. Müller; *Zeit und Logik*; Wissenschaftszentrum Munich (ed.), Wolfang Baur Verlag, Munich, 1983.

[28] A.A.C. v. Müller and E. Pöppel; *Die Erforschung des Denkens*, in *Einsichten – Berichte zur Forschung an der Ludwig-Maximilians-Universität München*, Munich, 2003.

[29] A.A.C. v. Müller; *12 Theses on Reality, Time and Consciousness*, in *Cognitive Processing*, Pabst (2003) 1–2.

[30] J.v. Neumann; *Mathematische Grundlagen der Quantenmechanik*; Verlag von Julius Springer, 1932.

[31] J. Oppenheim, B. Reznik, W.G. Unruh; *Temporal Ordering in Quantum Mechanics*; J. Phys. A: Math. Gen. 35 (2002) pp. 7641–7652.

[32] J. Oppenheim; *When does a Measurement or Event Occur*; Found. Phys. Lett. 13 (2000), pp. 107-118.

[33] M. Renninger; *Messung ohne Störung des Meßobjekts*; Z. Physik 158 (1960) 417.

[34] R. Tumulka; *A Relativistic Version of the Ghirardi-Rimini-Weber Model*; J. Stat. Phys. 125 (2006) 821-840.

[35] H. Stapp; *The Mindful Universe: Quantum Mechanics and the Participating Observer*; Springer-Verlag, 2007.

[36] R.v. Gulick; *Consciousness*; Stanford Encyclopedia of Philosophy, 2004, `http://plato.stanford.edu/entries/consciousness/`.

[37] C.F.v. Weizsäcker; *Der zweite Hauptsatz und der Unterschied zwischen Vergangenheit und Zukunft*; Annalen der Physik 428 (3), 1939, pp. 275–283. *See also* C.F.v. Weizsäcker; *Aufbau der Physik*; dtv, München, 1988.

[38] H. Weyl; *Space - Time - Matter*; Springer, 1923.

[39] J.A. Wheeler, W.H. Zurek; *Quantum Theory and Measurement*; Princeton, Princeton University Press, 1983.

[40] J.A. Wheeler; the original delayed-choice experiment in the context of double-slits has appeared in *Mathematical Foundations of Quantum Theory*, edited by A.R. Marlow, Academic Press, 1978. The "astronomical" delayed-choice experiment is attributed to Wheeler by different sources, but does not appear in Wheelers own writings; see also Wikipedia "Wheeler's delayed choice experiment".

[41] E. Wigner (1961); *Remarks on the Mind-Body Problem*; in *The Scientist Speculates*, I.J. Good, ed., pp. 284-302.

[42] B.S. deWitt; *Quantum Mechanics and reality*; Phys. Today; Sept. 1970, 30–35.