

# Weak Quantum Theory and the Emergence of Time

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## Abstract

We present a scenario describing how time emerges in the framework of weak quantum theory. In a process similar to the emergence of time in quantum cosmology, time arises after an epistemic split of an undivided *unus mundus* as a quality of the individual conscious mind. Synchronization with matter and other mental systems is achieved by entanglement correlations. In the course of its operationalization, time loses its original quality and the time of physics as measured by clocks appears.

## 1. Introduction

The objective of this contribution is to establish and describe a scenario for the emergence of time in the framework of weak quantum theory (Atmanspacher *et al.* 2002). This framework generalizes quantum theory beyond the domain of ordinary quantum physics, yet maintains essential quantum theoretical features like complementarity and entanglement.

The mysterious origin and nature of time have always been a permanent subject of human thinking and philosophy (Whitrow 1961). Later, also physics and, more recently, brain physiology and neuroscience have contributed to these questions (cf. Atmanspacher and Ruhnau 1997).

Time is given to us in two different forms: first, as internal time, as an immediate mode of our existence, and second, as external time, as an entity that appears in physics and is measured by clocks. Employing a distinction introduced by McTaggart (1908), internal time can be characterized as *A-time*: there is an essential quality of “nowness” which distinguishes present from past and future. The present is continuously moving into the future and thereby turning into past. *A-time* may also admit additional qualities: good and favorable or bad and unfavorable for particular tasks. The Greek notion of *καῖρός* is an example for such a quality. *A-time* is also called “tempus” or “tense” as opposed to “time”, because it underlies the tenses of verbs in many human languages. On the other hand, *B-time* is the time of physics. It is void of any additional qualities, all points of *B-time* are equivalent points on a linear scale. Their only and fundamental distinction is a (partial) ordering in

the sense of “earlier” and “later”. Even this directedness of B-time is absent in physics, if time-inversion symmetry is assumed to hold.

Questions regarding internal and external time cannot be exhaustively addressed without reference to the relationship between mind and matter. Here, we cannot enter into a deeper discussion of this intricate complex of problems, which has a long history and is presently a subject of intensive discussion and research (see, e.g., Pauen 2002). We can only outline the positions which are logically possible in order to provide a coordinate system that may serve to locate our own standpoint.

A first and basic distinction regarding different concepts for mind-matter relations is the distinction between *dualistic* and *monistic* positions. In modern philosophy, Descartes (1988) is usually considered to be a most prominent proponent of dualism. Characterized by the terms *res cogitans* and *res extensa*, mind and matter are fundamentally different substances of different ontological status. A key problem of all dualistic frameworks is the explanation of mutual causation or, more generally, of correlations between mind and matter. After all, mind and matter together are involved in most incidents occurring to us in our world.

Several solutions to this problem have been proposed, among which we only mention Descartes’ theory of causation, Malebranche’s (1980) occasionalism and, in particular, Leibniz’ (1923–) notion of pre-established harmony. According to Leibniz, matter and mind always go in parallel, not because of an interaction between them but because they are perfectly synchronized by their divine creator. The striking similarity between such a pre-established harmony and the interaction-free correlations appearing in quantum systems in entangled states has often been noticed.

It is fair to say that at present, partly because of the difficulties mentioned, ontologically conceived dualistic approaches have largely fallen out of favor. The remaining alternative, monistic approaches to mind and matter, denies the existence of two separate substances. According to the degree of priority attributed to matter or mind, three options can be distinguished.

- *Matter-over-mind* approaches consider some form of matter to be the fundamental substance of the world. There are vast differences among the various concepts of matter in such approaches. If mind is at all admitted as a decent object of investigation, it is conceived as an epiphenomenon, a feature of the “Überbau”, or as a feature emerging from matter. Again, there is a plethora of different conceptions of emergence. The majority of working scientists, biologists and neurophysiologists even more than physicists, seem to favor some version of matter-over-mind approach. This appears to be supported by the impressive success of modern science and fits in very well with the widespread materialist view of the world.

- *Mind-over-matter* approaches are adopted in a rather diffuse way by many esoteric circles. An intellectually viable example of this conception is the philosophy of Hegel (1969, 1977), for whom the substance of the world is of genuinely spiritual nature such that events in the material world are manifestations of the dynamic and dialectic self-reflection of this universal spirit.
- *Neutral monistic* approaches consider matter and mind to be different manifestations, on a par with each other, of an underlying substance that in itself is neither matter nor mind. This is the point of view we shall adopt. It is presently gaining ground among professionals (e.g., Chalmers 1996) addressing the mind-matter problem. It was clearly formulated by Spinoza (1985), for whom, out of a possible infinity of *modi* in which one and the same universal substance could manifest itself, mind and matter are the two *modi* that are accessible for human beings. In the 20th century, neutral monism was strongly advocated by Jung. He started out from his theory of the collective unconscious, an extension of the individual mind into a transpersonal collective domain regulated by general abstract but emotionally laden patterns, which he called *archetypes*.

Later, and partly under the influence of Pauli (see Atmanspacher *et al.* 1995, Meier 2001), the archetypes turned into even more abstract regulative principles within the domain of an *unus mundus* that is imagined to be neutral with respect to the distinction between mind and matter. Synchronistic phenomena, so-called meaningful coincidences, could thus be described as partly physical and partly psychological manifestations of archetypal configurations. Pauli, one of the fathers of quantum theory, compared this structure with quantum theory and proposed to conceive the distinction of matter and mind as a kind of symmetry breaking in the *unus mundus*. Material and mental descriptions of the *unus mundus* were thus considered as complementary in the sense of quantum theory. In the same way, the causal order of the physical world and the order of sense and meaning in the psyche were interpreted as complementary.

Choosing one of these three options has, of course, a bearing on how the relationship between internal and external time is understood. For instance, materialist viewpoints typically postulate the priority of physical B-time and consider internal A-time to be a derived notion.

However, such a derivation has turned out to be extremely difficult. Even in physics, it is, for instance, very problematic to derive the directedness of time in thermodynamics from a time-symmetric physical background. As yet, no satisfactory derivation of the second law from a microscopic statistical theory exists. At this place, it is not possible to

give a comprehensive review of the complicated and controversial subject of the directedness of time in physics (Zeh 2001). The basic task is to define various “arrows of time” and to relate them to each others.

The directedness of internal A-time is usually called “psychological time arrow”. It is sometimes considered to result from the thermodynamic time arrow defined by the increase of entropy according to the second law of thermodynamics (Zeh 2001). As far as the increase of entropy is considered as a loss of information about the microscopic state of a system, the very notion of a loss of information already presupposes a psychological time arrow.

Even more difficult is the derivation of the unique and characteristic quality of “nowness” in internal time – in fact, to such an extent that this problem is often evaded or declared as meaningless. In view of the difficulties to derive A-time from B-time, it is worthwhile to assume internal A-time as primary and to try to construct B-time from it. *A priori*, a loss of qualities should be more easily understandable than their generation. Further below, we shall propose a plausible pathway from A-time to B-time.

The overall approach presented in this study, however, starts from a neutral monistic conception of mind and matter. We shall locate the origin of time in personal consciousness assuming that time is essentially and intimately related to our form of existence as conscious individual beings. By contrast, time does not seem to be relevant in the unconscious. Already in dreams the dimension of time starts fading away and the deeper parts of unconscious and, even more so, the collective unconscious are entirely timeless. Jung’s *unus mundus* is explicitly assumed to be timeless (Atmanspacher *et al.* 1995).

There is a long tradition in philosophy relating time to our form of existence. For Augustinus (1991), A-time is the mode and limitation of the finite rather than infinite existence of human beings. For Kant (1929) time is similar to Newton’s B-time. He considers time to be the form of the interior sense of humans, prior to and a prerequisite for any act of cognition. Also in the 20th-century philosophy of existence (Husserl 1950–, Heidegger 1927) A-time is tied to human existence as an essential determining feature. There are, of course, alternatives to our approach. For instance Primas (2003), in a remarkable study about the origin of time, associates a time of A-type to a mental domain of the world in general, that is independent of human consciousness.

Our starting point in addressing the problem of the origin of time is to apply weak quantum theory to a primarily undivided *unus mundus*. The main theses that we shall develop are:

- The *unus mundus* is timeless and neutral with respect to the distinction of mind and matter. This distinction only arises after an *epis-*

*temic split* of the *unus mundus*, separating a “conscious observer” from the rest of the world. Observables pertaining to mental and material aspects of the *unus mundus* are in general complementary. An epistemic split is the prerequisite for and is inevitably connected with any act of cognition, in the most general sense in which knowledge or information about something is achieved. We shall argue that time can only arise after this epistemic split. One should notice that also animals can learn about their surroundings and have some sense of time. This means that the full human consciousness of a “conscious observer” is not required for the epistemic split and the emergence of time. Primarily, time emerges as A-time, related to the conscious observer. The process of emergence shows a formal analogy with the appearance of time in the Wheeler-deWitt equation (Wheeler 1968) of quantum cosmology, where the quantum state of the universe allows for the interpretation of particular observables as time observables.

- The transfer of A-time to material systems and the synchronization with other observers and material subsystems are effected by entanglement correlations given by the state of the *unus mundus*.
- Physical B-time arises by a complicated process of redefinition, gauging and operationalization certainly requiring full human consciousness. In the course of this process, time loses most of its qualities and may eventually disappear by “deconstruction”.

The material of this work is organized in the following way. In Section 2 we provide an outline of weak quantum theory necessary for the arguments in this paper. Section 3 is devoted to the somewhat problematic notions of the set of observables and of the state of the universe. The crucial role of the epistemic split and, as a consequence, the observer-dependence of the set of observables are pointed out. In addition, we describe how physical quantum theory can be embedded into weak quantum theory. Section 4 starts with a description of a toy model for the Wheeler-deWitt equation. It illustrates how time can arise as a property of a quantum state in an initially timeless situation. Subsequently, we briefly describe how time can be introduced in cosmology by solving the Wheeler-deWitt equation. In Section 5, a partially analogous scenario for the emergence of time in weak quantum theory is worked out. Section 6 contains additional remarks, questions and speculations.

In spite of mutual independence, there will be some overlap between our work and the ingenious study by Primas (2003), in particular concerning the importance of symmetry breaking in the *unus mundus* and the role of entanglement correlations. Similarities and differences between the two approaches will be mentioned along with our presentation. Some

of our ideas will be familiar to the reader, a situation to be expected for such a widely discussed subject.

## 2. An Outline of Weak Quantum Theory

Weak quantum theory is a generalization of quantum theory devised for applications beyond the range of ordinary quantum physics. It was obtained starting from the algebraic formulation of quantum theory and relaxing all those axioms which are specific to the physical world. The remaining more general structure is still rich enough to describe quantum-like phenomena like complementarity (Walach and Römer 2000) and entanglement in a general setting.

Here, we give a short outline of the structure of weak quantum theory to make the present contribution reasonably self-contained. For details as well as for some applications we refer to other publications (Atmanspacher *et al.* 2002, Atmanspacher *et al.* 2004).

In weak quantum theory, the fundamental notions of *system*, *state* and *observable* are taken over from ordinary quantum theory:

- A system  $\Sigma$  is any part of reality, in the most general sense, which can, at least in principle, be isolated from the rest of the world and be the subject of an investigation.
- It is assumed that a system can be in different states  $z \in \mathcal{Z}$ . Epistemically speaking, the notion of a state reflects the degree of knowledge of an observer about the system. Unlike in ordinary quantum mechanics, the set  $\mathcal{Z}$  of states is not assumed to have an underlying linear Hilbert space structure.
- An observable  $A$  of a system  $\Sigma$  is any feature of  $\Sigma$  that can be investigated in a (more or less) meaningful way. Let  $\mathcal{A}$  denote the set of observables. As in ordinary quantum mechanics, observables  $A$  in  $\mathcal{A}$  can be identified with functions on the set of states: Any observable  $A \in \mathcal{A}$  associates to every state  $z \in \mathcal{Z}$  another state  $A(z) \in \mathcal{Z}$ . As functions on the set of states, observables  $A$  and  $B$  can be composed by applying  $A$  after  $B$ . The composed map  $AB$  is also assumed to be an observable. Observables  $A$  and  $B$  are called *compatible* if they commute, i.e. if  $AB = BA$ . Non-commuting observables with  $AB \neq BA$  are called *incompatible* or *complementary*. In ordinary quantum theory, observables can also be added, multiplied by complex numbers and conjugated, and the set of observables is endowed with a rich  $C^*$ -algebraic structure. In weak quantum theory, observables can only be multiplied by the composition mentioned above. This leads to a much simpler so-called *semigroup structure* for the set of observables.

In Atmanspacher *et al.* (2002), weak quantum theory is characterized by a list of axioms. Here we give the most important properties:

- To every observable  $A \in \mathcal{A}$  there is an associated set  $specA$ , which is called its *spectrum*. The set  $specA$  is the set of different outcomes or results of an investigation (“measurement”) corresponding to the observable  $A$ .
- *Propositions* are special observables  $P$  with  $PP = P^2 = P$  and  $specP \subset \{yes, no\}$ . They simply correspond to yes-no alternatives about the system  $\Sigma$ . For every proposition  $P$  there is a negation  $\bar{P}$  compatible with  $P$ . For compatible propositions  $P_1$  and  $P_2$  there exists a conjunction  $P_1 \wedge P_2 = P_1P_2$  and a disjunction  $P_1 \vee P_2 = \overline{\bar{P}_1 \wedge \bar{P}_2}$ . The laws of Boolean propositional logic are assumed to hold for compatible propositions.
- If  $z$  is a state and if the proposition  $P$  is a found to be true for  $z$ , then  $P(z)$  is a state for which  $P$  is true: measuring  $P$  for the state  $P(z)$  will invariably yield the result “true”. This emphasizes the constructive nature of measurement as both preparation and verification.
- The following property generalizes the spectral property of observables in ordinary quantum theory. To every observable  $A$  and every element  $\alpha \in specA$  there belongs a proposition  $A_\alpha$ , stating that  $\alpha$  is the outcome of a measurement of  $A$ . Then

$$A_\alpha A_\beta = A_\beta A_\alpha = 0 \text{ for } \alpha \neq \beta, \quad AA_\alpha = A_\alpha A, \quad \bigvee_{\alpha \in specA} A_\alpha = \mathbb{1} \quad (1)$$

where 0 and  $\mathbb{1}$  are the trivial propositions which are never or always true, respectively.  $A$  and  $B$  are compatible if and only if  $A_\alpha$  and  $B_\beta$  are compatible for all  $\alpha \in specA$  and  $\beta \in specB$ .

Weak quantum theory is general enough to include the concepts of complementarity and entanglement. For complementary observables  $A$  and  $B$  with  $AB \neq BA$  the order of their measurement matters. As in ordinary quantum mechanics, it will generally be impossible to find a state in which both  $A$  and  $B$  have a well-defined value.

Entanglement arises if global observables pertaining to a system  $\Sigma$  as a whole are complementary to local observables pertaining to parts of  $\Sigma$ . In an entangled state, for instance in a state in which a global observable has a well-defined value, there are typical interaction-free entanglement correlations between the results of measurements of local observables. In

ordinary quantum theory, it can be proved that entanglement cannot be used for signal transmission or causal intervention.

Notice that weak quantum theory, at least in its minimal version presented here, does not associate quantified probabilities to the outcomes of a measurement of an observable  $A$ . This is related to the absence of a Hilbert space structure of the set  $\mathcal{Z}$  of states. Moreover, the notion of time is completely absent in the general framework of weak quantum theory, and Planck's constant  $\hbar$ , which controls the degree of non-commutativity in ordinary quantum theory, does not enter into this framework.

At this point, we should indicate another possible enrichment of the axioms of Atmanspacher *et al.* (2002), to which we shall return at the end of this study. One could admit a more general kind of observables without an associated spectrum, for which the notion of *preobservables* might be appropriate. Preobservables could be related to non-categorical states of attention of the observer (cf. Atmanspacher and Fach 2004). Only after establishing a horizon of expectations, e.g., as a result of additional experience, it may become possible to associate a spectrum to them and turn them into ordinary observables.

### 3. Observables and Epistemic Splitting

Weak quantum theory is a general theory applicable to all kinds of systems  $\Sigma$  that can be singled out from the rest of the world for the purpose of investigation. In the following we intend to apply weak quantum theory to the totality of the *unus mundus*. This is a problematic enterprise. A similar problem arises in quantum cosmology, where ordinary quantum mechanics is applied to the whole universe. The very notion of an “observable” indicates that the existence of an observer outside the observed system is presupposed. In both ordinary and weak quantum theory observables primarily apply to the description of systems as seen from an outside observer. In which way does it make sense to talk about the wave function of the universe or the state of the *unus mundus*?

First of all, it is always possible to enlarge a system  $\Sigma_1$  by inclusion of another system  $\Sigma_2$  originally outside  $\Sigma_1$ . For example, one may include the observer of a system  $\Sigma$  into a larger system and study the interaction of  $\Sigma$  with its observer within the enlarged system (possibly as observed by a “superobserver”).

In ordinary quantum theory, there exists a canonical tensor product construction for the Hilbert space of states and the algebra of observables of a composite system from the ones of its components. This is not at our disposal in weak quantum theory, but one can at least say (Atmanspacher *et al.* 2002) that the state space and the semigroup of observables of a composed system will contain the Cartesian products of the state spaces and observable semigroups of its components:



$$\mathcal{A} \supset \mathcal{A}_1 \times \mathcal{A}_2, \quad Z \supset Z_1 \times Z_2, \quad (2)$$

$$\mathcal{A}_1(Z_1) \subset Z_1, \quad \mathcal{A}_2(Z_2) \subset Z_2. \quad (3)$$

Just as important as the enlargement of systems is the possibility of analyzing systems by identifying subsystems within them, whose mutual relationship can be investigated. Such a decomposition into subsystems is a constitutive mental act. There are infinitely many ways to decompose a system into subsystems, and the kind of decomposition is not dictated by the system itself. Rather, the system as such remains unchanged after decomposition.

On the other hand, one can say that it is only by decomposition that subsystems come into being, which underlines the creative status of decomposition. Mahler strongly points out this twofold significance of decomposition (Gemmer and Mahler 2001, Otte and Mahler 2000), and speculates that this could constitute a point where consciousness might intervene in our world. In ordinary quantum mechanics, a decomposition is represented as a tensor product decomposition of the Hilbert space of states and the algebra of observables:

$$\mathcal{H} = \mathcal{H}_1 \otimes \mathcal{H}_2, \quad \mathcal{A} = \mathcal{A}_1 \otimes \mathcal{A}_2. \quad (4)$$

In weak quantum theory subsemigroups and subsets of states have to be identified in accordance with Equation (2). The decomposition of a system into subsystems can be considered as a symmetry breaking. It introduces distinctions which are not prescribed by the system itself.

In view of the twofold possibility of composition and decomposition or of synthesis and analysis, talking about the universe or the *unus mundus* as a system appears to be a reasonable extrapolation. This kind of extrapolation is, for instance, employed in quantum cosmology, where ordinary quantum theory is applied to the universe as a whole. In weak quantum theory, where no probabilities are attributed to measurements, the problem may even be alleviated somewhat, because the ensemble interpretation used in ordinary quantum theory does not apply.

The first and most important act of a decomposition of the *unus mundus* is the epistemic splitting, the inevitable starting point of any act of cognition separating an observer from what he or she observes. We already mentioned that the notion of an observable presupposes such an epistemic split. Moreover the epistemic split is intimately connected to the appearance of consciousness in however rudimentary form. It requires that some agent is set apart from the rest of the world, maintaining itself, gaining information about its environment and reacting to it. Higher levels of consciousness also involve a capacity to form a self-representation in a self-model as addressed in detail by Metzinger (2003). Observations in the technical sense will require such higher states of consciousness.

As an abstract mathematical entity, neither the algebra of observables of ordinary quantum theory nor the semigroup of observables in weak quantum theory contains observers. This notion only enters with the interpretation of the formalism, suitable for application to real systems. In the semigroup of observables attributed to the *unus mundus* in the above process of extrapolation, the epistemic split and the existence of observers are reflected in subsemigroups  $\mathcal{A}_i$  of observables pertaining to (conscious) observers and decompositions of the type of Eq. (2), with one of the factors associated to an observer.

Weak quantum theory has to explain how the material or physical world can be embedded into a supposedly larger system possessing also non-material features. This can actually be achieved by assuming that inside the large semigroup of observables there is a subsemigroup of material observables:

$$\mathcal{A}_{matter} \subset \mathcal{A} , \quad (5)$$

which has the rich structure of a  $C^*$ -algebra. A state  $z \in \mathcal{Z}$  gives rise to a positive linear complex-valued expectation value functional  $E_z$  defined on  $\mathcal{A}_{matter}$ :

$$E_z(\alpha A + \beta B) = \alpha E_z(A) + \beta E_z(B) \quad (6)$$

$$E_z(A^* A) \geq 0 \quad (7)$$

for complex  $\alpha, \beta$  and  $A, B$  in  $\mathcal{A}_{matter}$ . For observables  $A \in \mathcal{A}_{matter}$ , the spectrum  $spec A$  should be contained in the set of complex numbers.

This establishes the ordinary probability interpretation for quantum theory in the material world. Planck's constant  $h$  will play its usual role in  $\mathcal{A}_{matter}$ . Two states  $z$  and  $z'$  are called *physically equivalent*, if their associated expectation value functionals coincide:

$$z \sim z' \Leftrightarrow E_z(A) = E_{z'}(A) \text{ for all } A \in \mathcal{A}_{matter} . \quad (8)$$

The resulting equivalence classes should be called *physical states*. Matter observables  $A \in \mathcal{A}_{matter}$  will transform physical states into physical states. This is not expected to be true for other observables in  $\mathcal{A}$ . Starting from any physical state, a physical Hilbert space can be obtained by the GNS-construction (Haag 1992). As a linear operator on a Hilbert space and also as an element of a  $C^*$ -algebra, every observable  $A \in \mathcal{A}_{matter}$  will have a spectrum  $SPEC A$  that is identical with  $spec A$ , the spectrum of possible measurement outcomes.

Knowing  $\mathcal{A}_{matter}$ , it is natural to ask for its *commutant*  $\mathcal{A}'_{matter}$ , which consists of all those observables of the *unus mundus* that commute with all material observables:

$$\mathcal{A}'_{matter} = \{B \in \mathcal{A} \mid BA = AB \text{ for all } A \in \mathcal{A}_{matter}\} . \tag{9}$$

Primas (2003), in the framework of ordinary quantum theory, essentially identifies  $\mathcal{A}'_{matter}$  with the subalgebra of mental observables and assumes a decomposition of the Hilbert space and the observable algebra of the *unus mundus* of the kind

$$\mathcal{H} = \mathcal{H}_{matter} \otimes \mathcal{H}_{mind}, \quad \mathcal{A} = \mathcal{A}_{matter} \otimes \mathcal{A}_{mind} , \tag{10}$$

implying that matter observables and mind observables always commute.

We prefer a complementary relationship between matter and mind, in accordance with the intention of Pauli and Jung (Atmanspacher *et al.* 1995, Meier 2001). For instance, under the headings of “brain” and “mind”, one and the same system can be investigated in two different ways, either physiologically by physical observation and experimentation or psychologically by introspection, redirection of self-attentiveness and reporting about them. These two approaches will use complementary matter observables and mind observables, respectively:

$$\mathcal{A}_{mind} \cap (\mathcal{A} \setminus \mathcal{A}'_{matter}) \neq \emptyset . \tag{11}$$

#### 4. The Wheeler-deWitt Equation and Cosmological Time

In this section, we describe how time can be introduced into an originally timeless framework using a solution of the Wheeler-deWitt equation of quantum cosmology. We shall generalize this scheme to weak quantum theory in the subsequent section. The essentials of the principle can best be understood from a simple toy model.

Consider a system in ordinary quantum theory, whose algebra of observables is generated by two observables  $X$  and  $Y$  together with their conjugates  $P_X$  and  $P_Y$ . The fundamental commutation relations are just the commutation relations for position and momentum of a point particle in two-dimensional space:

$$[X, Y] = [P_X, P_Y] = [X, P_Y] = [Y, P_X] = 0 \tag{12}$$

$$[X, P_X] = [Y, P_Y] = i \frac{\hbar}{2\pi} \mathbb{1} \tag{13}$$

In a basis of simultaneous eigenstates  $|x, y\rangle$  of  $X$  and  $Y$ , state vectors of the system are given by functions  $\psi(x, y)$ . Assume now that the state function obeys an equation

$$\left( \frac{\partial^2}{\partial x^2} - \frac{\partial^2}{\partial y^2} \right) \psi(x, y) = 0 \tag{14}$$

In our simple example it is possible to give the general solution of Eq. (14) as

$$\psi(x, y) = f(x - y) + g(x + y) \quad (15)$$

for arbitrary functions  $f$  and  $g$ . In general, the solution Eq. (15) does not factorize into a function of  $x$  and a function of  $y$ , although there are, of course, special factorizing solutions such as

$$\psi(x, y) = \sin(kx) \sin(ky). \quad (16)$$

Generically, the solution of Eq. (14) does not factorize but is entangled with respect to the observables  $X$  and  $Y$ . Entangled solutions can only be represented as superpositions of factorizing solutions. Now, in contrast to a factorizing solution like Eq. (16), for an entangled solution the distribution of the values of  $y$  depends on the value of  $x$ . In this sense,  $x$  controls the knowledge of  $y$ . In the extreme case,

$$|\psi\rangle = \int dx c(x) |x, y(x)\rangle, \quad (17)$$

and the value of  $x$  determines  $y$  completely; the other extreme is given by factorizing solutions like Eq. (16).

This allows us to interpret the controlling variable  $x$  as a time variable, where a factorizing solution would describe a time-independent situation. For a hyperbolic equation like Eq. (14), the time-like variable  $x$  shares another feature of time as it is normally understood in physics. Prescribing the initial values for  $x = 0$  by

$$\psi(0, y) = a(y), \quad \frac{\partial}{\partial x} \psi(0, y) = b(y) \quad (18)$$

fixes the solution of the state equation (14) for all values of the time  $x$ . This means that the hyperbolic character of Eq. (14) leads to a deterministic time-development with respect to  $x$ .

The Wheeler-deWitt equation (Wheeler 1968) is an equation for the wave function of the universe in quantum cosmology, which can be conceived as an enormous upgrading of our toy model Eq. (14). It contains an infinity of pairs of conjugate variables rather than just two, such that the variable  $X$  is replaced by the spatial metric  $h_{ab}$  of the universe, and  $Y$  corresponds to an infinity of observables  $\varphi$  pertaining to matter fields in the universe. The derivatives in Eq. (14) are replaced by functional derivatives with respect to  $h_{ab}$  and  $\varphi$ . The wave function  $\psi(x, y)$  is replaced by a functional  $|\Psi[h_{ab}, \varphi]\rangle$  depending on the spatial metric and the matter fields. The Wheeler-deWitt equation is a direct consequence of the invariance of general relativity theory under arbitrary coordinate transformations. It has a structure similar to Eq. (14), which we give for the benefit of the reader with some familiarity in quantum field theory:

$$\left\{ -\frac{1}{2m_P^2} G_{ab,cd} \frac{\delta^2}{\delta h_{ab} \delta h_{cd}} - m_P^2 \sqrt{h} R^{(3)} + H[h_{ab}, \varphi] \right\} |\Psi[h_{ab}, \varphi]\rangle = 0. \quad (19)$$

Here,  $m_P$  is the so-called Planck mass,  $h$  is the determinant of  $h_{ab}$ ,  $R^{(3)}$  is the scalar curvature associated to  $h_{ab}$  and  $G_{ab,cd}$  is a metric in the infinite dimensional “superspace” of spatial metrics and given by

$$G_{ab,cd} = \frac{1}{\sqrt{h}} (h_{ac} h_{bd} + h_{ad} h_{bc} - h_{ab} h_{cd}) . \quad (20)$$

$H[h_{ab}, \varphi]$  is a term depending on the metric and the matter fields, whose precise form depends on the model for the matter fields.

The Wheeler-deWitt equation (19) does not contain any reference to time, but, depending on the nature of its solution, a time variable can be introduced in a way completely analogous to our toy model. The metric  $G_{ab,cd}$  is of hyperbolic character, and this opens up the possibility to interpret one combination of the variables  $h_{ab}$  as a time variable monitoring a deterministic development of the other variables if the solution of Eq. (19) is not factorizing (Kiefer 2000).

Which variable assumes the role of time depends on the solution of Eq. (19). Models have been constructed whose solution corresponds to an expanding universe. In these models the determinant function  $\sqrt{h}$  assumes the role of a time variable. The quantity  $\sqrt{h}$  is directly related to the radius of the universe, which in an expanding universe serves as a measure of time. The fact that time is normally treated as a classical parameter rather than a quantum observable is explained by a mechanism of *decoherence* (Giulini *et al.* 1996). Since the time operator  $\sqrt{h}$  interacts with infinitely many other degrees of freedom, it is effectively measured continuously, and the state of the universe becomes indistinguishable from an incoherent superposition of states with different values of the time observable.

## 5. Emergence of Time in Weak Quantum Theory

The core of the argument of the preceding section on the emergence of time in quantum cosmology can be transferred to the case of the *unus mundus* treated in terms of weak quantum theory. We do not expect the formalism of ordinary quantum theory to be applicable at this level of generality. The basic idea is to locate time primarily in individual consciousness and to assume entanglement correlations as the decisive mechanism for time synchronization. This approach is motivated by (i) a neutral monistic attitude towards the mind-matter problem, (ii) the notorious difficulty of reducing psychological A-time to physical B-time, and (iii) the observations that internal time is intimately related to our

mode of existence as conscious individuals and that it shows a high degree of correlation with both the internal time of other individuals and changes in the material world. This suggests that the state of the *unus mundus* is strongly entangled. In detail, our scenario for the emergence of time consists of the following points:

1. As mentioned in Section 3, individual consciousness, at least at some low level, is intimately related to the epistemic split isolating an observing subject from the rest of the world. The distinction between mind and matter requires such an epistemic split. As explained in Section 3, this means that subsemigroups  $\mathcal{A}_i \subset \mathcal{A}$  of the semigroup of observables of the *unus mundus* must be established and identified, which correspond to conscious individuals, and will have a nonvanishing intersection with  $\mathcal{A}_{mind}$  of Eq. (11). Moreover, the relationship between  $\mathcal{A}_i$  and  $\mathcal{A}_{matter}$  will be complementary.
2. The *unus mundus* itself is timeless, but the epistemic split allows us to identify observables  $T_i \in \mathcal{A}_i$  which, similar to the situation of the Wheeler-deWitt equation, assume the character of time, monitoring other observables via entanglement correlations, since the state of the *unus mundus* is entangled. Our mode of existence reveals that  $T_i$  will have the quality of an A-time in the sense of McTaggart (1908). The quality of A-time is expected to depend on the level of consciousness. For simple organisms the notion of “now” will be the predominant feature, and a faint notion of past will be able to incorporate the results of learning from the environment. At higher levels, the notion of past will be more elaborate, and a self-model (Metzinger 2003) will allow us to plan actions and to develop a differentiated notion of future. The spectrum  $specT_i$  will contain at least an element “now” and, depending on the level of consciousness, a simple or elaborate set of labels pertaining to the more or less remote past and future. Such a gradual unfolding of personal A-time can also be observed in human development from birth to adulthood.
3. The scenario outlined in the two previous points describes how internal personal A-time emerges as the primary time-like quality from an originally timeless *unus mundus*. It must be emphasized that  $T_i$  assumes the quality of time only through entanglement correlations. Unlike the situation for the Wheeler-deWitt equation, we do not expect any strict property of hyperbolicity to hold, because this would lead to a deterministic dependence on  $T_i$ , which is highly implausible at this level of generality and for the primarily individual A-time  $T_i$ . In the following two points, we are going to elucidate the nature of the entanglement correlations of a given A-time observable  $T_i$  with other observables.

4. For well-separated different individuals we can expect their time observables to commute:

$$T_i T_j = T_j T_i . \quad (21)$$

We know that the time observables of different individuals are at least loosely correlated. Hence, we have to expect entanglement correlations between different time observables  $T_i$  and  $T_j$  giving a rough synchronization between them.

5. Entanglement correlations will also exist with material systems. These correlations will be particularly strong for “clock-like” systems, for instance particular astronomical systems. The observable semigroup  $\mathcal{A}_I$  of these systems will contain clock observables  $T_I$  which show particularly strong entanglement correlations among each other and with the variables  $T_i$ . Again, we expect commutativity:

$$T_I T_J = T_J T_I, \quad T_i T_I = T_I T_i . \quad (22)$$

These strong correlations make it possible to import a notion of time into material systems. However, the A-character of time will be lost in this operation, and  $T_I$  will rather look like a B-time. With a directed A-time as a primary notion, the second law of thermodynamics can now be understood in the usual way (Zeh 2001), as an effective loss of information about the microscopic state by conversion into inaccessible correlation information. In this way, the circular relationship between information loss and a psychological time arrow, indicated in Section 1, can be avoided.

6. Such processes of translation and identification can be used to construct a more and more universal and operationalized B-time by taking into account more and more entanglement correlations and by choosing and redefining time observables such as to maximize their entanglement correlations. Such a process of purification and operationalization can be observed in the development of the notion of time in human thinking in general and in the development of science in particular, eventually leading to the concept of physical B-time from internal A-time. With respect to this B-time, physical determinism holds, at least to a very good approximation and with respect to  $\mathcal{A}_{matter}$ . The process leading to a clear and sharp notion of a linear B-time requires human consciousness at its highest level. The same holds for a manifold of other variants of A-time like cyclic time or mythological time, which have been developed in various human societies.

The redefinition of an observable can easily be formalized in the framework of weak quantum theory: Let  $A$  and  $B$  be observables and take a function

$$f : \text{spec}A \longrightarrow \text{spec}B . \quad (23)$$

Then we say that  $B = f(A)$  if the following relations hold for the associated projectors  $A_\alpha$  and  $B_\beta$  of Eq. (1):

$$B_\beta = \bigvee_{\alpha \in \text{spec}A, f(\alpha)=\beta} A_\alpha . \quad (24)$$

As in the previous section, decoherence mechanisms explain why physical time is normally experienced as a classical quantity with a sharp value. As compared to ordinary quantum theory, the situation might be more favorable in weak quantum theory, because, due to the absence of a probability interpretation, the notion of a collapse of states is not a part of weak quantum theory.

7. During the course of generalization and objectivation, time loses more and more of its original qualities as A-time. Some steps along this way lead from internal A-time to directed B-time and to an undirected B-time of time-reversal invariant physics. In contemporary physics, this process has even proceeded further. In parts of string theory, as well as in quantum cosmology, timeless equations like the Wheeler-deWitt equation have been formulated in which time has disappeared altogether. Using a term employed by Ruhnau (1997) in a rather different context, one might talk about the *deconstruction of time* as one of the effects of the collective effort towards an increasing refinement and purification of the notion of time. One might interpret this whole process as yet another attempt by man to overcome the limitations of his time-bound mode of existence.

At this point, let us briefly compare our approach with the recent work of Primas (2003) who tentatively applies ordinary quantum theory to the *unus mundus*. A first symmetry breaking leads him to the decomposition into (collective) mind and matter of Eq. (10). Unlike in our approach, matter and mind observables are considered as commuting rather than complementary. Time has its origin in a one-parameter symmetry of the timeless *unus mundus* and, after the decomposition into matter and mind, appears with the representation of the symmetry group in the collective mind sector. Synchronization with and transfer to the matter sector is achieved by entanglement correlations, which are a consequence of the original symmetry of the *unus mundus*. It is reassuring and adds to the



cogency of the overall picture to see the importance of entanglement correlations highlighted from different perspectives.

After the decomposition of the *unus mundus* into the commuting sectors of mind and matter, the scenario by Primas has much in common with Leibniz' view of a world governed by pre-established harmony, whereas we keep closer to the picture of Jung and Pauli (Atmanspacher *et al.* 1995, Meier 2001). A further difference is that in Primas' scheme B-time is created in one step, while we try to investigate the process of its stepwise emergence. Using ordinary quantum mechanics and the representation theory of groups in Hilbert spaces, Primas derives a large number of interesting results and notions relevant for the concept of time. He makes important remarks about the origin of the directedness of time, which for us is present from the beginning, and about the synchronization of the time arrows, even for non-interacting systems, by entanglement. In describing features of time in the mind sector he uses the notion of a forward expanding Hilbert-space K-structure, which describes learning and the filling up of a memory storage by the accumulation of experience. Once time has been established along the route described above in points (1)–(7), the related notion of an increasing sequence of propositions can easily be incorporated into weak quantum theory. A family of propositions  $(P_\tau)_{\tau \in \mathbf{R}}$  can be called increasing if

$$P_\tau P_\sigma = P_\sigma P_\tau = P_\sigma \text{ for } \sigma \leq \tau . \tag{25}$$

## 6. Remarks, Questions, Speculations

Following the main body of this paper, let us finally address some issues that lie somewhat off the main line of our argument.

- First of all, one should not forget that even the pervading importance of time has its limits. There are many observables, for instance observables pertaining to logical questions or to issues of sense and meaning, which are unrelated or complementary to time. There will be many observables  $A$  with

$$AT_i \neq T_i A . \tag{26}$$

- Energy is a particularly clear and important example of such an observable. In ordinary quantum theory, the energy operator is conjugate to time and generates time translations. The operator for a translation in time by an amount  $\alpha$  is given by

$$U_\alpha = e^{2\pi i \alpha H / h} , \tag{27}$$

where  $H$  is the energy operator. The question now arises, whether the concept of energy can be generalized in a sound manner, so as to apply beyond the realm of ordinary physics. Given a sufficiently universal time observable  $T$ , one can define an operator  $U_\alpha$  fulfilling a relation like

$$U_\alpha T U_\alpha^{-1} = T + \alpha , \quad (28)$$

as is well-known for chaotic systems or K-flows (cf. Atmanspacher 1997). There is an intuitive notion of energy in everyday language, and the notion of energy in physics has arisen from it by a process of refinement and operationalization similar to the one described above for time. In a very vague sense, this notion is related to the capability to give rise to changes. Associated with the intuitive notion of energy is an element of will and desire that is one of the features that have disappeared in the operationalization process leading to physical energy. A version of Eq. (28) may be able to capture some features of the intuitive notion of energy.

Quite generally, energy should be related to any kind of transition, a key topic in process philosophy. Normally, descriptions of the operation of the human mind focus on a discussion of concepts, notions and categories corresponding to more or less stable mental states. However, one may shift the emphasis to transitions between categories, i.e. to so-called acategorical states (Atmanspacher and Fach 2004). A generalized energy observable could be related to such acategorical features of the human mind. This mental aspect of energy need not be completely disjoint from its material side. In fact, it has been argued (Bekenstein 1981, 2001, Bekenstein and Schiffer 1990) that every exchange of information is associated with a, however tiny, exchange of energy.

- As emphasized several times, the epistemic split is of paramount importance for every act of cognition. The very notion of an observable presupposes it, and the semigroup of observables is contextual and depends on the observer. Assuming that the observer is a conscious individual, and that A-time is intimately related to the form of existence of conscious individuals, it would not be surprising to find temporal features in any semigroup of observables. This is indeed the case. The composition of observables contains an embryonic element of time in as far as  $AB$  means “ $A$  applied after  $B$ ”, where “after” expresses temporal order.
- Time also enters in another way into the semigroup  $\mathcal{A}$  of observables. The state of the observer will change, not least as a result of the observations he makes. The observer-dependence of the semigroup of observables will thus render it time-dependent as well. This change

may result in adding or modifying observables and in the transformation of preobservables, as described at the end of Section 2, into full-fledged observables.

- Finally, having discussed time at considerable length, one might wonder about space. We expect that space, as time, arises only after the epistemic split. As opposed to time, it will have its origin in the material component  $\mathcal{A}_{matter}$  of the *unus mundus*. This corresponds closely to Descartes' attribution of space to *res extensa* and with the way in which Kant interprets time as the form of an outer rather than an inner sense. These questions certainly deserve a study of their own.

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