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Complementarity is a useful concept for consciousness studies. A Reminder

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Abstract We describe the concept of complementarity and argue that it is a useful concept for consciousness and other studies at the interface of conscious phenomena and physical reality. After outlining the history and source of the concept within psychology, we describe its place as a working hypothesis for the mind-brain problem. We then point out that generalized quantum non-locality could be of importance even for macroscopic objects. If this is so, complementarity would be the key-concept to understand EPR-like correlated systems.

Introduction

Implicit presuppositions are necessary albeit neglected preconditions of scientific thinking and human cognitive activities in general. Collingwood had argued already in 1940 [1] that at the base of any scientific endeavor are what he called absolute presuppositions. They stem from generally held beliefs about the nature of the world and the entities found and expected therein. These presuppositions, Collingwood argued, arise from the general zeitgeist, which is a distilled product of human cognitive, social, artistic, technical and scientific endeavors of societies. They define what are to be considered appropriate and inappropriate scientific questions; they describe the basic ontology and lay foundations for methodologies and the prevailing epistemology. They usually change slowly and not by a rational process, but the change processes are determined by complex social situations. Toulmin [2] pointed out that this concept of absolute presuppositions incidentally lies at the base of Kuhn's outlook on the scientific process.

In that sense, science in general has been dominated by a set of absolute presuppositions which might be termed materialist-localistic. Some important presuppositions which many scientists would subscribe to are the following:

- Basic entities in the universe are material, or: Matter is primary.
- Relationships between basic entities are outer relations, or: Complexity emerges out of combinations of primary, material entities.
- Change is either completely random or has an efficient cause.
- Causes are contiguous. Those events which cannot be analyzed in terms of contiguous causes will eventually be reduced to simpler events which in turn can be analyzed in terms of contiguous causes.

From these positions about basic physical states follows one relating consciousness:

- Consciousness as a complex phenomenon is likely to be analyzable in terms of simpler events.

It is worth noting that these propostions are nearly identical with the basic tenets of ancient atomism as propounded by Democritos [3]. Surely there are more propositions which are necessary to characterize a modern scientific stance. And there are certainly many scientists who do have more complex and in some aspects differing opinions. But in a very general sense these propostions seem to be at the base of a modern scientific world view.

This so-called "scientific" world view or outlook is a set of absolute presuppostions which are not amenable to direct empirical, experimental or philosophical tests of truthfulness but show their usefulness only in a broader context. It is a question of considerable importance whether this world view will in the end be able to explain consciousness, and at present it is an open question. It has been argued convincingly [4] that materialist positions are inherently problematic. This argument is so much the stronger as it has arisen out of a materialist position itself. The price to be paid is dualism, which has been shunned by scientists, as it violates the principle of economy.

We propose here to hold on to a monistic position, not to a materialistic one, however, but to a neutral one, with matter and consciousness as two complementary aspects. This proposal is not at all new. In a sense, formally it was Spinoza's idea [5, 6]. The difference is that complementarity, being a principle rooted in modern physics, affords a conceptual framework which is different from Spinoza's and which, by virtue of its importance for the quantum mechanical formalism and thereby for entanglement or EPR correlatedness, might offer a road to empirical or even experimental approaches to the problem. Moreover, complementarity as a way of looking at the world is much older. A case can be made that the dogmatic formula which was the result of the concilium of Chalcedon in 451 A.D. that Jesus Christ is man and God in one person is an early example of thinking in terms of complementarity in the West, and that from a developmental point of view complementarity as a way of looking at the world is a faculty which develops only after formal analytical thinking has been mastered [7–9].

Complementarity

Complementarity 1: Basic Property of Material Systems

Generally Nils Bohr is credited with having introduced complementarity as a necessary concept into the physics of our days [10]. He arrived at this notion when developing quantum mechanics together with Heisenberg, Pauli and others [11]. In its earliest form complementarity was introduced 1927 in Bohr's unpublished paper "The quantum postulate and the recent development of atomic theory"[12], pp. 91ff.], which was published in a somewhat altered version 1928 in "Nature." In this paper Bohr talks about the fundamental complementarity of causal and space-time descriptions:

"The very nature of the quantum theory thus forces us to regard the space-time coordination and the claim of causality, the union of which characterizes the classical theories, as complementary features

of the description of experience, symbolizing the idealization of observation and definition respectively." [12] p. 91

"Nevertheless a complete account for the principal difficulties of satisfying the claims of causality within a space-time representation of atomic [microscopic] phenomena would seem to be offered only by the view that we are dealing here with complementary features of the description of nature." [12] p. 94

The general idea which Bohr expresses here is that a causal picture of the world which refers to a particle view of matter and a continuous picture which is built on the wave model of matter cannot be evoked simultaneously. "Wave" and "particle" are complementary aspects of matter. They cannot be operationalized in the same experimental setting. In his paper "Licht und Leben—Light and Life" he expressed this idea in the following words [all translations ours]:

"*The continuity of the propagation of light through space-time on the one hand, and the atomic character of the effects of light on the other hand, therefore, have to be considered as complementary in the sense that each one of them expresses important aspects of the phenomena of light, which even though incommensurable in terms of mechanics can never come into direct contradiction, since a thorough analysis of one or the other trait in the framework of mechanics calls for different and mutually exclusive experimental designs. -*

Die Kontinuität der Lichtfortpflanzung in Zeit und Raum einerseits und der atomare Charakter der Lichtwirkungen andererseits müssen daher als komplementär aufgefaßt werden, in dem Sinne, daß jede für sich wichtige Züge der Lichtphänomene zum Ausdruck bringt, die, selbst wenn sie vom Standpunkt der Mechanik aus unvereinbar sind, niemals in direkten Gegensatz kommen können, da eine eingehendere Analyse des einen oder anderen Zuges aufgrund mechanischer Vorstellungen verschiedene sich gegenseitig ausschließende Versuchsandordnungen erfordert." [13]

Bohr, thus, thought that complementarity is an irreducible and basic property of matter itself. This is what Fahrenberg [14], p. 54, had termed "Bohr 1": descriptions in the same category, in this case, in the category of matter.

Complementarity 2: Conceptual Framework for Pairs of Opposites from Different Categories

Later in his life Bohr seems to have expanded the concept of complementarity to apply to all situations, in which a pair of opposite or incompatible concepts is used to describe one fact or event. Rather vaguely he says that living or social systems show characteristic traits which call for complementary descriptions:

"...that regarding analysis and synthesis in other branches of science we find circumstances which remind of the situation in quantum physics. Thus, the integrity of living organisms and the traits of conscious individuals and cultural communities show traces of wholeness, whose description calls for a typically complementary language. -

...daß bei der Analyse und Synthese in anderen Erkenntnisgebieten Umstände vorliegen, welche an jene in der Quantenphysik erinnern. So weisen die Integrität lebender Organismen und die Merkmale bewußter Individuen und kultureller Gemeinschaften Ganzheitszüge auf, deren Beschreibung eine typisch komplementäre Ausdrucksweise fordert. [15] p. 7

Bohr was quite sure that with complementarity he had discovered a generally applicable and broad epistemic and philosophical concept. Thus he says that the way in which emotions and cognitions are used in order to describe psychological facts is reminiscent of complementary relationships in physics [13]. In that sense Bohr expanded his concept of complementarity to all descriptors of situations, events or facts which were mutually exclusive and yet necessary to describe completely the entity in question. "Bohr 2" [Fahrenberg, 1992, p. 54], thus refers to complementary descriptions which come from categorically different frameworks of descriptions.

It was in that sense that Fahrenberg [14, 16, 17], following v.Weizsäcker [18, 19], proposed the concept of complementarity to describe the relationship between mental and physical events in order to describe the unity "human being," a proposal which is akin to similar ones introduced later but independently by Kirsch [20] or Elitzur [6]. According to this view conscious or mental events are not reducible, supervenient to or emerging from physical or physiological events, as proponents of different strands of materialism, functionalism, emergentism or epiphenomenalism would have it, but they refer to different aspects of one [ontologically neutral] substance, which however is only accessible through two complementary and in a sense mutually exclusive descriptions. They are nevertheless both necessary to describe what seems to be most elusive and most obvious to us all: conscious embodied mind or mindful body. Bohr himself seems to have favored a complementary solution to the mind-body problem like the one later proposed by Fahrenberg. It is, however, not complementarity in the original sense of the word, which is relevant here, but complementarity in a broader sense, referring to two descriptions from two categorically different systems of language or descriptions.

Complementarity 3: A General Concept of Philosophy of Nature as a Supplement to Causality

It should be noted for the sake of completeness that Bohr took complementarity to also be a general principle of Philosophy of Nature, supplementing or complementing causality. He calls complementarity a "consequent generalization of the ideal of causality" [13], p. 26. Already in his early writings he always connects complementarity with the irreconcilability of a causal description of nature with a wave description. A causal description relies on particle formulations, since it is by real or virtual particles that causes are mediated. A continuous description on the other hand uses wave models and field concepts, which treat particles not as physical material entities but as ideal points. When Bohr says that complementarity supplements causality, he in fact implies that there is another way of actively relating to the physical world than that of efficiently causal influence. If causally mediated change is by virtue of contiguous, material causes—following Hume's analysis—then effects brought about by a complementary class of events should be direct and immediate changes, may be due to direct conscious influences. Bohr at no place explicitly says so, but following the thought to its end seems to lead to this conclusion. If this is true, complementarity plays an even more important role, since it would be a term referring to a hitherto neglected side of nature: to consciousness inasmuch as it is the complement of matter, not as a separate substance in the old sense but as a complementary and irreducible description of a class of events. And following Bohr in that sense we should expect another mode of consciousness relating to matter, namely one which Bohr called the natural consequence of causality. It could be the case that direct interactions between mental and material systems as researched and reported by parapsychologists [21–25] are a class of events belonging in this category and testifying to what Bohr might have had in mind as another class of interactions complementing causality.

Roots of Complementarity in Psychology

It is interesting to note at that point that Bohr probably used psychological sources to coin his concept. Plaum [26] has researched Bohr's sources and found out that Bohr had manifold contacts with psychologists who used concepts similar to complementarity. On the one hand the philosopher-psychologist Harald Höffding, who was a close friend of the Bohr family, might have introduced him to the thoughts of Kierkegaard, who might have stimulated his own thinking. On the other hand, Bohr was a close friend of the psychologist Edgar Rubin. He had participated in perception experiments of Rubin's. Rubin is famous for his teasing perceptual figures which can be seen in two ways—faces or vases, old witch or young girl—depending on our perception. Rubin called these perspectives "reciprocal." Furthermore, Bohr in an interview with the research team of Thomas Kuhn, Nov. 17, 1962, shortly before his death, conceded that he was introduced by Rubin to the work of William James who was the first to use the term "complementary" in the sense it was to be used later by Bohr. The locus classicus is from James' "Principles of Psychology," where he deals with what today would be called dissociative disorder [27]:

"It must be admitted, therefore, that in certain persons, at least, the total possible consciousness may be split into parts which coexist but mutually ignore each other, and share the objects of knowledge between them. More remarkably still, they are complementary. *Give an object to one of the consciousnesses, and by that fact you remove it from the other or others. Barring a certain common fund of information, like the command of langauge, etc., what the upper self knows the under self is ignorant of, and vice versa"[28] p. 204, italics added.*

We have here what probably is the first mentioning of "complementarity" in the sense that two perspectives have to be taken which are mutually exclusive and yet are both necessary to describe a situation. Plaum [26] voiced the suspicion that Bohr was so reluctant to name his sources because he wanted to keep physics free from "soft" sciences like psychology. And yet it seems that Bohr has exported a soft psychological concept into hard physics.

There is, in fact, one passage in Bohr, which is reminiscent of his purported psychological sources in that it explicitly mentions the term "reciprocal" which was used by Rubin. In his text "Wirkungsquantum und Naturbeschreibung" [12], p. 205 (orig., Naturwissenschaften, 17, 1929, 483–486] which was published in German, Bohr writes:

"We are acquainted with the necessity to seek out a complementary or better reciprocal description namely through psychological problems. In contrast the hallmark of the so-called exact sciences probably is the attempt to reach unequivocality by avoiding any reference to the perceiving subject. -

Mit der Notwendigkeit, zu einer in diesem Sinn complementären oder besser reziproken Beschreibungsweise Zuflucht zu nehmen, sind wir wohl besonders durch psychologische Probleme vertraut. Demgegenüber dürfte gewöhnlich das Merkmal der

sog. exakten Wissenschaften in dem Bestreben gesehen werden, Eindeutigkeit durch Vermeiden jeden Hinweises auf das betrachtende Subjekt zu erreichen." (p. 205, orig. 485)

In this passage Bohr explicitly acknowledges that it is especially with the conscious subject, or with consciousness in general, that complementarity becomes an issue. It is only with the interaction of a conscious observer with physical reality that the paradoxicalities arise quantum mechanics has become so famous for. It is with subjective consciousness that complementarity comes into play. Bohr seems to have intuited the fact that the ambiguity in the perception of flipping images, of delineating boundaries of personalities, and other observations of psychology, in short that the fact of consciousness introduces a situation which calls sometimes for complementary descriptions. It seems an extraordinary fact of the history of science that psychology with its reference to subjectivity as opposed to objectivity, soft as opposed to hard facts, has provided a conceptual tool for understanding matter. The tool is complementarity, and it was introduced at the price of vagueness and paradoxicality in the description of nature. And at the same time the concept of complementarity seems to be a bridge between material phenomena and conscious events. The difference is that while in psychology and what has been termed Bohr 1 and Bohr 2 "complementarity" is used metaphorically, while in physics/Bohr 1 the term has a rigid definition. It was, incidentally, the firm belief of the physicist Wolfgang Pauli, who was one of the leading figures in the development of the so-called Copenhagen interpretation of quantum mechanics [11, 29, 30], that physics would have to be complemented by psychology in order to reach a full understanding of matter. He had repeatedly expressed that fact in his letters to the psychiatrist Carl Gustav Jung with whom he had an intense exchange of ideas [31]. This exchange cumulated in the joint publication of a book entitled "Naturerklärung und Psyche—Explanation of Nature and Psyche" [32, 33]. This interesting dialogue which has only recently become available to a broader public and found some scientific interest [34] has to be left aside at that point. Suffice it here to note that complementarity is at the very root of this dialogue: complementarity between psychology and physics, mind and matter, causality and synchronicity. It makes the proposition historically even more plausible and factually clearer: Complementarity is, at its deepest meaning, probably a concept relating conscious and material events in some regular way which we do not yet understand. This proposition seems to already have been in Bohr's mind when he introduced complementarity into physics. And this background is responsible for the fact that apart from a quite operational description of the term complementarity in the first sense of Bohr, it is not a well defined concept and its meaning changes depending on the level of generality it is used for. Therefore, an attempt at defining it is now in place.

Attempting to Define Complementarity

It is in itself an interesting fact that Bohr never gave a clear definition of complementarity. He gave descriptions in ever changing fashion, which somehow seem to contradict each other. This is due to the fact, as Fahrenberg [14] p. 54, has pointed out, that the term was used in the above described three senses. Atmanspacher [35] has mentioned the following three elements of complementarity.

1. A fact or situation is complementary if one needs an algebra of non-commuting operators to describe or formalize it, as it is the case with quantum mechanics. That is: depending on the sequence of measurements or applications of the operators the result is different. This is a more technical expression for what is commonly known by Bohr's expression that different experimental procedures are necessary to measure complementary aspects of a quantum object, and they cannot be performed simultaneously [36]. Classical examples are the operators of momentum and place which cannot give arbitrarily sharp values for the same particle at the same time. This is the essence of Heisenberg's uncertainty relation. But it can be extended to any pair of observables which are not indifferent to the sequence of measurements. Another way of stating this is that complementary statements describe different contexts of one and the same object. In each of these contexts observations and measurements can be made, which are not available in the other contexts. In each context there is a perfect definition and clear measurement values. But the full view of the object, all possible perspectives at once, can only be achieved by serially changing contexts.
2. Complementary terms are not just contradictory like a and not-a, but they are incompatible. They denominate descriptions which are mutually exclusive. If one description is used the other one is, at the same time, not available. Therefore,
3. Such relationships are formalizable only by a non-Boolean logic. A simple negation like "a particle is not a wave" is a statement which can be expressed by Boolean terms. Complementary formulations like "x is a particle and a wave depend-

ing on the measurement apparatus" can only be expressed by non-Boolean logic.

In that sense, we could attempt to define complementarity in the following way: Complementary statements are characterized by the fact that the measurements, observations or procedures necessary to form them cannot take place simultaneously, or that the properties described by these expressions cannot be realized jointly, and that the sequence of measurements or observations is decisive for the final result. A simpler way of stating this would be that complementary propositions have the same referent although they make at least two incompatible statements about it. Note that with complementary statements it is necessary to have at least two statements which are incompatible to characterize the referent, but possibly there could be more.

Complementarity in Consciousness Research

It was in that sense that Fahrenberg [14, 16, 17] used the term complementarity. He proposed to view complementarity as a general principle which prohibits simple reductionist approaches in empirical research in psychology or psychophysiology. In his formulation conscious events and physiological events are not in either way reducible to each other but simply given facts which characterize the living being. They are complementary in the sense that they are both necessary to describe the living being, not reducible to each other, and delineate different empirical approaches: a hermeneutical-ideographic and an objective-nomothetic approach. Each one of the approaches has its own criterion of truth which belongs to its own categorical system. Neither of the categories is reducible to the other, easily translatable or superfluent. This is a proposal which in its consequence leads to a multi-methodological approach which has become if not standard then at least ideal in psychophysiological empirical research, at least in Germany [37]. But it could also be a guiding heuristic principle in that it prevents researchers from rushing at shortcut solutions to the mind-body problem which are fashionable because they seem so easy. Complementarity as a research metaphor for consciousness research would make the apriori assumption that mental and physical events are indeed in some sense related or even pertain to the same "substance," but need maximally incompatible procedures and propostions for their characterization, and therefore the attempt at explaining one (usually mental event) by some formulation of the other [usually physical events) is doomed to failure.

If this were the only reason for talking about complementarity within the realm of consciousness research, this would be a somewhat general and imprecise exhortation without much concrete consequence. There is, however, a sense, in which complementarity comes directly into play and which might be even experimentally relevant, which we now turn to: the generalization of quantum EPR-entanglement. This ascribes a central role to complementarity.

Fundamental Nonlocality and the Generalization of Quantum Entanglement

It is well known that at a very basic level material entities behave holistically no matter how separate they are in space and time. This so called quantum entanglement or EPR-correlatedness refers to the fact that quantum mechanics treats material systems before any measurement is made as a whole with a multiplicity of possible states. Only when a measurement is made the wave function collapses, and the system exhibits definite properties. These properties are fixed at the instant of measurement. Observables that belong to the same quantum system exhibit correlatedness when measured, no matter how spatially distributed the system is [38, 39], producing nonlocal effects. This also applies to the temporal distribution of systems [40, 41]. While for the latter empirical tests are still awaiting their realization, for spatial EPR-correlatedness empirical tests have been carried out thanks to the pioneering work of John Bell, who by formulating his famous inequality laid the foundations for the operationalization of such a testing [42]. This test has been repeatedly carried out and proven quantum mechanics to be correct [43–46]. Nonlocal entanglement is the primary situation [47–50], at least for material quantum systems. Normally this entanglement is only visible after delicate experiments. Historically this is an unprecedented situation. For the first time in history a metaphysical question has been answered by empirical means [51]. Reality, before any conscious mind looks at it, is nonlocally entangled and a whole. Single entities, material objects (and perhaps single minds?) are secondary to that situation. They are created by what is called "measurement": the taking notice of specific qualities.

Most people and scientists seem to think that this basic EPR-entanglement is irrelevant for our macroscopic world of minds and actions. Those who advocate a place for quantum mechanical processes in consciousness research either adhere to an interpre-

tation of quantum mechanics which makes consciousness primary, or they look to the many-worlds-interpretation as an alternative [52], or they point out that at very basic levels of neurobiochemistry dimensions are so small that the quantum formalism has to be taken into account [53–56].

While this could be true, we do not want to follow these traces of thought. Although these approaches try to exploit quantum mechanical ideas for macroscopic phenomena, they still stick to the conventional compartmentalization according to which quantum mechanics has to do with the very small and subatomic realm, while classical approaches cover the regions above the Planck constant in space and time. What is even more interesting is a fact which seems to have gone rather unnoticed and which has been pointed out by Primas recently [57]: Landau [58] (as quoted by Primas [57]) has shown that EPR-correlatedness is generalizable. That is to say that entanglement need not be confined to microscopic systems but could come into play in systems of any size and make-up provided three conditions hold jointly:

1. There exist two systems which are kinematically independent.
2. Each of the two systems is well defined.
3. In each of the systems there is a pair of observables which demand, for their description, an algebra of non-commuting operators.

The last condition could somewhat loosely be reformulated into:

3a. Each of the two systems contains at least one set of observables which are complementary to each other in the sense that their descriptions are maximally incompatible with each other and require mutually exclusive experiments or empirical procedures to measure or verify them.

Primas [57] has pointed out that the algebraic formulation of Landau [58] does not presuppose that the two systems have to be material. Following a footnote of Jung's [32], p. 85, note 7, in which Jung states that the relationship of mind and body could be what he called a synchronistic one, Primas [57] speculates that the generalized formulation of the EPR-correlatedness also allows for two different systems, a material and a non-material system, to be related.

We would like to point out that possibly even 3b holds:

3b. Each one of the subsystems contains one half of the pair of incompatible observables.

In that sense complementarity comes into play again in a different sense. Two systems which together can be characterized by, or jointly contain, a set of incompatible or complementary variables are EPR-correlated, if they are kinematically independent and well defined. While all these terms are quite well understood in a physical sense, relating to physical systems, it is not known what this would mean on a more macroscopic level, pertaining to biology or psychology. While some authors have already speculated that quantum-entanglement might have been used by biological systems in the course of evolution in order to maximize their evolutional gain [59], and while there are some general statements that EPR-correlatedness probably has some impact also in macroscopic systems [60, 61], there is no systematic research which has followed along the lines suggested by Landau [58] or Primas [57].

One serious problem pertains to the fact that while in quantum mechanics everything is well defined and a precise mathematical formalism is available, no such precise formulations are available in "softer" sciences like psychology or consciousness research. Thus, we do not know what it means for two macroscopic systems to be well defined, or to be kinematically independent, let alone to contain a set of observables requiring formalization in terms of an algebra of non-commuting operators. Thus only a few speculations can be made at this point.

Speculations and Tentative Exemplifications

In the polarization experiment to test EPR-entanglement there is one system with two separate subsystems, each of which can be described, e.g. by spin directions which are mutually exclusive, or complementary in the adopted terminology. In analogy, the human being could be viewed as the system comprised of two separate, but entangled subsystems. Entanglement would be active until a "measurement" is performed at which both systems are found to be in corresponding states. This so far is not more, nor less, than a rediscription of Leibniz' famous examples of two clocks going in harmony or preestablished harmony of inner and outer processes [62] 65f.:

"Souls follow their own laws,..., while bodies follow theirs, namely the rules of motion. Nevertheless, these two entities of completely different kind meet and are coordinated like two clocks, which have been perfectly set in the same way, although they may be of totally different making. It is exactly this which I call preestablished harmony.

– Die Seelen folgen ihren eigenen Gesetzen, ... während die Körper ihrerseits ebenfalls den ihrigen, nämlich den Regeln der Bewegung, folgen. Trotzdem treffen diese beiden Wesenheiten von gänzlich verschiedener Art zusammen und entsprechen einander wie zwei Uhren, die wollkommen in derselben Weise reguliert worden sind, wenngleich sie vielleicht von gänzlich verschiedenem Bau sind. Eben dies aber nenne ich die prästabilierte Harmonie."

The difference is that in the case of generalized EPR-correlatedness there is a more basic principle at work which, at least generally, is amenable to empirical research and testing. The principle is that in both systems sets of non-commuting observables, which we translate into complementary variables, are regulating this coordinated behavior. The problem is that we do not know what this could mean, apart from the known quantum mechanical formalism. One line of thought could be to analyze all organismic processes in terms of different sets of complementary terms—"complementary" for the time being taken in the loose sense as described in this paper. For instance, every single organismic process can be characterized in terms of individuality or singularity and connectedness. No matter whether we look at molecular processes, at the cellular or organ levels, all processes can be described on the one hand as singular, individual events. But all these singular, individual events are at the same time regulated by top-down principles which restrict and channel these events. A neuronal event, for instance, can only be seen in its direct connection to the whole nervous system. The same is true for immunological processes. They always have to be analyzed in terms of single events on the one hand, which are events within a larger system on the other hand. Thus "individuality" and "connectedness" could be a pair of general terms which could apply to many systemic levels exemplifying a set of "complementary" variables.

"Individuality" and "connectedness" both fulfill at least at first appearance some requirements for terms standing in a complementary relationship with each other:

1. They cannot be "measured" or seen in the same experiment or measurement. In order to measure individuality, one has to analyze an event as single, thereby stripping it of its connections. In order to look at connectedness, one would neglect individuality and synthesize single elements to a larger compound.
2. Depending on the sequencing, results are different. Any individual seen first and foremost in its role as individual is and appears differently from the same individual taken as an element in an interconnected system. This is so, because in an interconnected system the complex relationships form and change any part of it continually, thereby introducing an irreversible temporal order. Therefore, every individual is different from moment to moment. This is a striking resemblance to the fact that the generic definition of non-commuting observables is the difference in mathematical results depending on the sequence of measurements.
3. They also seem to fulfill one criterion mentioned above: They are incompatible at first glance, and yet they are needed to describe any living system completely. There is no single system in the whole universe which is disconnected from its surroundings and thus a true individual (except perhaps the whole universe). Individuals only make sense and take shape in connection with other individuals. On the other hand it is utterly senseless to talk about the connection of everything with everything, or totality, or wholeness, unless it is specified what parts a whole or totality exists of. Individuality and connectedness are not just contradictory terms. They are mutually exclusive, and yet necessary to describe any system.
4. It is of considerable interest that these terms are so general that they need not be confined to material systems or entities in the strict sense. They could also refer to mental systems, like semantic, semiotic, or social systems.

In other frames of reference one would probably opt for different notions to describe a unit of analysis, like a human being, or a group: They could also be termed "individual" and "society" when referring to sociological or social-psychological systems, or "freedom" and "responsibility," when considering the realm of moral philosophy and ethics. The same basic relationship seems to be at work in many domains: In personality theory there is a long-standing debate about the primacy of traits, representing the individual, and states, representing the environment, in which the individual is embedded [63]. In genetics the debate is about the primacy of genes and the modification of their expression by a given environment [64].

If this is plausible, then we have a set of complementary variables in each system. For these two elements are present in every system, specifically in the human organism and in consciousness. All physiological processes, whether they are metabolic, immunological, hormonal or neural signaling processes, depend on this relationship that single individual events are necessitated and modified by the

organic whole of the organism which they in turn change and modify. Thus, the individual process is determined by and at the same time determines the whole. The same is true for the first-person account of consciousness. Single qualia always are qualia of a certain specific perception, which is a perception only by virtue of its embeddedness in the whole cognitive structure.

In a broader sense, complementarity as envisaged by Fahrenberg holds also between the mental and the physical systems. These two systems are in a complementary relationship, too. They are both maximally incompatible descriptions of the living human being. One has to use different and in a sense mutually exclusive experimental or empirical approaches, in order to "measure" them. Thus, the human being in totality can be characterized as a system containing a set of complementary "variables" or "observables," the mental and physical system.

One prediction resulting from this analysis would be that we should observe EPR-like correlated events in any subsystem which is temporarily or otherwise connected to a human being to form a higher order system, and the other way round. This could happen if the other is also a system describable in terms of complementary variables, the boundaries between the two systems are temporarily suspended, and thus two sets of complementary variables are present. This would be the case, for example, when two human beings enter any sort of relationship, which delineates the dyad against the outside as one system. It is one of the purposes of rituals to draw a distinction between inside and outside thus delimiting, at least temporarily, a higher order system. The prediction would be that whenever human beings meet within such a ritualistic context, which joins at least two persons into a supersystem, they are EPR-like correlated, and entrainment ensues [65, 66]. This could be the basis for the well known but little understood phenomena of transference in the psychotherapeutic, especially psychoanalytic setting, for ritualistic or placebo healing, and possibly for experimenter effects in science.

"Transference" denotes the simple fact that in a psychotherapeutic context the therapist [and the client or patient] experiences emotions, body feelings, and trains of thought, which are not "his" or "hers" but his or her patient's. It is part of the therapeutic training, at least in the traditions deriving from psychoanalysis, to learn to discriminate between personal and other contents, and to use the "transferred" material accordingly. In the classical psychoanalytic setting the material is used for interpretation. It is fed back to the patient as the patient's own, not yet acknowledged, feelings, affects or thoughts, thus enabling the patient to own the material. While this process is practically well understood and frequently used, it is not at all clear theoretically. Usually one would invoke subliminal signals or perception of hidden cues to understand how such transferences arise. This does not seem to be a sufficient explanation for seemingly absurd, unfitting and spontaneous mental events, which are frequently experienced within the context of psychotherapy. An analysis along the lines proposed in this paper would be more fitting to the empirical phenomena.

Ritualistic and placebo healings have been reported repeatedly. While some can be understood along conventional lines by expectancy effects [67, 68], there are strange phenomena which defy explanations by known psychological mechanisms: Prayer healing sometimes seems to be effective also in a double blind setting, where both groups had the same expectation [69–71]. In clinical drug trials across several diseases, therapeutic effects in the placebo group are highly correlated ($r = .59$ to $r = .89$) with therapeutic effects in the drug group [72, 73]. While the traditional model would predict that this correlation between drug and placebo-groups reflects the expectancy effects, we could in our own research find no correlation whatsoever between a measure of expectancy and therapeutic effects in the placebo and drug groups [74]. It might be promising to analyze these effects in terms of correlatedness as advocated here.

Finally, experimenter effects are well known in behavioral science [75]. They refer to the fact that experiments sometimes are biased in the way experimenters expect results. In the traditional analysis they are taken to be due to insufficient blinding, such that experimenters know about the desired outcome and subliminally convey this knowledge to the participants, who perform in the socially desired way. While this is certainly a good way of describing experimenter effects in unblinded research, it is difficult to understand such effects in double-blind experiments, where no one has a cue. There have been occasional reports of experimenter bias even in double-blind drug experiments. A classic in that sense are the two studies of Uhlenhuth [76, 77], in which blinded doctors had different results with a drug and a placebo according to their belief, although they could not have known which patients were treated by which substance. We found in a blinded experiment of dowsing that, although on average volunteers were unable to discern poison from water by dowsing, they were significantly more often to do so when instructed by a particular, but blind experimenter [78].

These and probably many more anomalies could be analyzed as instances of generalized EPR-correlatedness, in which a system exhibiting complementary

variables—here: a mental and a physical system—is entangled with another system—here: another human being—by virtue of a systemic boundary which is temporarily erected by a ritualistic context, such as a formal trial, an experiment or a therapeutic setting. This would also make plausible when and how anomalous correlations between consciousness and material systems, as researched by parapsychologists, can occur, without violating any known physical laws and without running contrary to scientific orthodoxy.

What we have proposed so far is a general model, which is neither new nor our genuine invention. This is why it is called a reminder. We suggest that the model could be a useful metaphor and framework, and we have elaborated into a few directions how it could be fruitful. It is, however, a future task to operationalize and make concrete the very general predictions and to test these predictions in empirical research. It could well be that this framework could be useful for understanding consciousness-matter interaction of any degree and two-system-interactions in general, without having to resort to reductionist approaches, and without getting stuck in pure dualism. Complementarity seems to be a notion of considerable theoretical, predictive and explanatory power, when set free from its quantum mechanical technical domain and expanded from there to where it originated: to psychology and the study of conscious phenomena. It affords a redescription of well-known positions in the reflection on the mind-body-relationship in a more adequate, modern language.

In sum: The proposition made here is to analyze the relationship of conscious mind to living body in terms of generalized EPR-correlatedness. This predicts that the two systems, which are well described, kinematically independent and yet belonging together, are EPR-correlated, if they contain or exhibit each a set of complementary variables. We have proposed to take individuality/ singularity and connectedness as general categories of physical and mental systems. If this analysis is accepted then mind and body, following a suggestion of Jung and Primas [57], can be seen as two entangled systems. Extrapolating from there, every human being can be seen as a system containing two complementary variables - mind and body, consciousness and physical system. If this is so, the same applies for two (or more?) human beings joined together by any system-generating mechanism, and probably also for human beings and physical systems, as long as these physical systems also exhibit signs of complementarity. While not subscribing to reductionist approaches, this proposal can enlarge our understanding how seemingly not causally related systems can nevertheless be in intricate communication.

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