Complementarity of Phenomenal and Physiological Observables

Hartmann Römer

Physikalisches Institut der Universität Freiburg
Hermann-Herder-Str.3, 79104 Freiburg
e-mail: hartmann.roemer@physik.uni-freiburg.de

Harald Walach

University of Northampton
School of Social Sciences
& Samueli Insitute, European Offe (www.siib.org)
Boughton Green Rd
Northampton NN2 7AL, UK
e-mail: harald.walach@northampton.ac.uk

1. Introduction

To all of us introspection provides a privileged access to our own state of mind, open at any time and on any occasion. Moreover, access to other people's minds is given by interpreting their utterings under the overwhelmingly plausible hypothesis, that not only their bodily appearance but also their mental organisation is very similar to ours.The huge body of cultural knowledge of mankind about its own interior life almost exclusively flew from this single source. Adopting a philosophical term we shall call all knowledge coming directly or indirectly from introspection *phenomenal data.*
Only very recently as seen from a historical perspective, these phenomenal data on the human mind have been supplemented by *neurophysiological data* on the neuronal activity in our brain.The first device for obtaining neurophysiological data was the EEG (electroencephalogramm) giving spacially and temporally moderately localised signals of the neuonal activity in various parts of the brain. Even more recently, more detailed signals can be gathered by fMRT (functional magnetic resonance tomography) and PET (positronium emission tomography). In addition, information on the activity of individual neurons is accessible by means of precisely placed microelectrodes.
Although the contribution of neurophysiological data to our vast corpus of knowledge and experience concerning the human mind is very small indeed, particular epistemological dignity and significance is attributed to them in the spirit of the prevailing reductionist scientific world view. This high esteem culminates in what might be called the *strong neuroreductive credo:*

All features of the human mind can (at least in princible) be reduced to and understood in termes of neurophysiological data.

At present, most scientists in the western world would probably suscribe to this credo.
In this study, we should like to investigate about the mutual relationship of phenomenal and neurophysiological data and argue, that in many cases it will be complementary in a quantum theoretical sense[1]. Such an argument requires a theoretical framework, which (a) comprises essential features of physical quantum theory and (b) allows to treat self

observation and neurophysiological data taking on an equal footing under a notion of generalised measurement.
Such a formal framework is really available under the heading *“Weak Quantum Theory”* or *“Generalised QuantumTheory”*(GQT) [2].
This is a generalisation of physical quantum theory, applicable to systems of most general kind. In GQT quantum concepts like complementarity and entanglement are formally well defined and applicable notions. GQT will be the framemework of our considerations. We shall proceed as follows: The next section contains the necessary minimum of GQT for making this presentation reasonably self sustained. In section 3 the problem of complementarity between phenomenal and neurophysiological observables will be described, and in section 4 our arguments in favour of complementarity will be given.

2. Basics of Generalised Quantum Theory

Generalised Quantum theory arose from physical quantum theory in algebraic formulation by weakening or omitting axioms. Thus an enormous widening of the range of applicability was achieved. Notions taken over from physical quantum theory are:

System: A *system* is everything which (at least in priciple) can be separated from the rest of the world and be turned into the object of a study. It may be possible to identify *subsystems* within a system.
State: A system can reside or can be thought to reside in different *states* without losing its identity as a system. The notion of states contains an epistemic element, because it also expresses the amount of knowledge about a system. One may further decide between *pure states,* which correspond to maximal attainable knowledge about the system and *mixed states,* in which maximal knowledge is not given. In contradistinction to quantum physics, in GQT the set Z of all states z need not be describable in terms of an underlying vector space.
Observable: *Observables* correspond to all features of a system, which can be investigated in a (more or less) meaningful way. If a system has subsystems, one may decide between *global observables* pertaining to the system as a whole and *local observables* pertaining to subsystems.
Measurement: A *measurement* of an observable A is done by really performing the investigation which belongs to A and arriving at a result α , which can claim the status of a fact. How this has to be done depends on the detailed description of the system. The set of all possible results α of a measurement of the observable A is called the *spectrum of A* and denoted be specA. The result of a measurement of A will depend on the state z of the system but will in general not be completely determined by z.

GQT is defined by a set of axioms, for whose precise form we refer to the original publications cited under [2]. Here we only point out the most salient features:
Observables A can be identified with functions associating to every state z a state A(z). In general we have $z \neq A(z)$. In classical systems this is only true for mixed states, because a measurement will increase our knowledge of the system, whereas pure states well remain unchanged by measurement. In quantum like systems we generically have $z \neq A(z)$ even for pure states. Observables A and B can be concatenated by applying A after B to states z: $AB(z) = A(B(z))$.
Observables A und B are called *compatible,* if AB = BA und *incompatile* oder *complemenary,* if $AB \neq BA$. Observables A and B are compatible if and only if the corresponding measurements are interchangeable. Complementarity of observables is a

genuine quantum feature and does not occur in classical systems. In a more general setting byond quantum physics complementarity will arise whenever a change of the state z by a measurement is inevitable. This is true in an exemplary way for systems containing conscious individua with the ability of self observation, because self observation necessarily changes our state of mind.
Entanglement is to be expected, when a global observable A is complementary to a local observable B and if the state z of the system is an *entangled state* z, for which $AB(z) \neq BA(z)$.

Propositions are special observables P with $PP = P$ and $specP \subset \{yes,no\}$. They simply correspond to yes-no questions about the system. For every proposition P there is a negation $\neg P$ compatible with P. For compatible propositions P_1 and P_2 there exists a *conjunction* $P_1 \wedge P_2 = P_1 P_2$ and an *adjunction* $P_1 \vee P_2 = \neg(\neg P_1 \wedge \neg P_2)$. The laws of ordinary proposition logic are assumed to hold for compatible propositions.

For the arguments to be presented in section 4 we have to mention some axioms of GQT referring to propositions

If z is a state and P is a proposition, and if a measurement of P in the state z gives the answer "yes" then P (z) is a state for which P is true with certainty. This emphasizes the constructive nature of measurement as 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_α .which is just the proposition that α is the outcome of a measurement of A. Then

$$A_\alpha A_\beta = A_\beta A_\alpha = 0 \quad \text{for } \alpha \neq \beta,\ \alpha, \beta \in specA, \tag{1}$$

$$AA_\alpha = A_\alpha A, \qquad \bigvee_{\alpha \in specA} A_\alpha = \mathbb{1} \tag{2}$$

where 0 and 1 are just the trivial propositions which are never and always true respectively. Moreover, an observable B commutes with A if and only if all B_β commute with all A_α . The sets of projectors { A_α } or { B_β } are called *complete sets of commuting propositions.* If the proposition A_α yields the answer "yes" in the state z , the state $z_\alpha = A_\alpha z$ is an *eigenstate of the Observable A with eigenvalue* α, a state for which a measurement of A will give the result α with certainty

GQT has found a considerable number of applications, for which we refer to ref.[1] and to [3, 4, 5, 6, 7, 8] .

3. Statement of the Problem

Neurophysiological and phenomenal data of the human mind differ so much that they almost seem to come from different worlds.
Neurophysiological data belong to the realm of pysics. They are obtained by an external observer at the end of a chain of devices and causal relationships and they are explained mainly in terms of causality notions like e.g. stimulus and response.

On the other hand, phenomenal data are immediately available to an internal "observer" by introspection: One instance of the human mind has direct access to other parts. In addition, notions of externality, referentialiy, intentionality[9] and emotionality, alien to physcal data are vital for understanding phenomenal data, which will always refer to something else, usually outside the human mind, are often coloured by and related to intentions, plans and desires and go along with emotional validations. The inner perspective of an internal "observer" is often called the *first person perspective* as opposed to the *third person perspective* of a physical observer.
There is another very important difference between neurophysiological and phenomenal data. Viewed as a pysical system, the human brain is almost certainly to be described by classical physics, and quantum physics should not play an important role for understanding it. There are, however, minority claims that the human brain and consciousness should be understood in terms of quantum physics[10, 11]. In these attempts, quantum processes are located either in the synapses between the neurons or in the microtubuli inside the neurons. But quantum physics almost exclusively rules the microworld, and if these quantum approaches are to produce more than just some small random noise, macroscopic enhancement mechanisms of very low plausibility have to be invoked[12].
On the other hand, as already mentioned in the previous chapter, the human mind as seen from an internal first person perspective is a paradigmatic case of quantum behaviour in the sense of GQT, because an introspective registration af the state of mind will inevitable alter it. Of cause, the reason for this quantum like behaviour of the human mind is not quantum physics but a partial structural analogy with quantum physics in the sense of GQT. In fact, GQT is a general phenomenological theory for systems of all kind incorporating both classical and quantum mechanics as special cases but mainly devised for macroscopic system with quantum analogue behaviour. The uncertainties of the outcome of a measurement in GQT need not be genuine quantum indeterminacies. In many cases they are of more innocent origin like incomplete knowledge and inevitable perturbations by measurements. In ref [7] it is shown that even systems of classical mechanics can show quantum features of GQT like complementarity after suitable "coarse grained" partitions of the state space. This remark will be important in the next section. In contradisdinction from quantum physics, the general formalism of GQT does not allow for a derivation of "no go" theorems for the existence of underlying classical "hidden variable" systems in the way Bell's inequalities[13] rule out local hidden variables and the Kochen-Specker theorem[14] rules out context free hidden variable theories. A quantum like system of GQT may in some cases have a classical mechanical refinement.
We want to clarify the reationship between neurophysiological and phenomenal data in the framework of GQT. For doing so, a little obstacle has to be overcome: The very notion of an observable requires the existence of an observer, and observables can only be compared if they pertain to the same system and the same or at least equivalent observers. Now neurophysiological and phenomenal data are taken by different observers, an external one in the first and an internal one in the second case. But phenomenal data can be communicated to the same external observer who also takes the neurophysiological data without complete loss of their salient features. In this sense, we can speak of a human being as a system of GQT with both neurophysiological observables N_1 , N_2 , N_3,... and phenomenal observables P_1 , P_2 , P_3,... .In quantum theoretical language, the external observer takes over the role of a *superobserver*, who observes a measurement of an internal observer. (In the exceptionary case that a person registers his own

neurophysiological data there is also the possibility to "internalise" these data. We shall not elaborate on this situation, which is largely analogous to the more important situation described before.)

The main problem we have to deal with in applying GQT can be stated as follows: The human brain is a classical system, and for such systems all observables are commuting and compatible without any chance for complementarity. Now the strong neuroreductive credo spelled out in the Introduction claims that every feature of the human mind can be described in terms of neurophysiological data. This seems to imply that every phenomenal observable is a function of neurophysiological observables, symbolically:

$$P = f(N_1, N_2, N_3, \ldots)$$

If this is true, then also all phenomenal observables have to commute with one another and with all neurophysiological observables. On the other hand, we have argued that complementarity is typical for phenomenal observables, and we want to show, that nerophysiological and phenomenal observables will often be complementary.

One way out is of cause to question the strong neuroreductive credo, but, although we have strong doubts about the credo we shall try to develop stronger arguments which work without this step. In one of the arguments to be given in the following section we shall even use a weak version of the neuroreductive credo which follows from the strong version without implying it. We should like to call it the *weak neurorductive credo* (WNC):

Every state of the human mind has a neuronal correlate and different states have different correlates.

We see no reason to exclude the possibility that the same state of the human mind may have different neuronal correlates.

4. Arguments for Complementarity

To be able to argue in favour of complementarity for two observables A and B we need a convenient criterion for complementarity. The axioms quoted at the end of section 2 suggest that the existence or noexistence of joint eigenstates of A and B should be decisive. In section 2 we already saw that two observables A and B are compatible if and only if the associated complete sets of compatible propositions $\{ A_\alpha \}$ and $\{ B_\beta \}$ commute with one another. This implies that A and B are compatible if and only if there is a complete set $\{ A_\alpha B_\beta \} = \{ B_\beta A_\alpha \}$ of joint compatible propositions. Starting from these propositions we can construct states $z_{\alpha\beta} = A_\alpha B_\beta (z) = B_\beta A_\alpha (z)$, which are simultaneously both eigenstates of A with eigenvalue α and of B with eigenvalue β . As a corrolary we can state that the observables A and B are complementary if and only if there is at least one α in specA for which no common eigenstate $z_{\alpha\beta}$ exists. A forteriori A and B are certainly complementary if they do not possess any common eigenstate. In the following we give three arguments for the possibility of complementarity between phenomenal and neurophysiological observables which make use of this criterium.

A) As described in section 3, a “measurement” of a phenomenal observable A is first performed by introspection, and the result is subsequently communicated to an external observer, who may also measure a neurophysiological observable B. Both with respect to A and B the external observer is in the position of a superobserver taking measurements at a system, inside which a measurement is done. Now, if a person performs a measurement of the phenomenal observable A, the very act of self observation and conscious registration of its result will inevitable change the mental state of this person. By the weak neuroreductive credo this change of the mental state will be accompanied by a change of the neurophysiological state which is registered by the external observer. Hence, a measurement of a phenomenal observable always goes along with a change of the neurophysiological state which is measured by the observable B. On the other hand, a common eigenstate $z_{\alpha\beta}$ of A and B is unaffected by a measurement of A or B. This means that there is no common eigenstate of the phenomenal observable A and the neurophysilogical observable B and the relationship between A and B is complementary.
B) The difference between substance ontology and process ontology is a recurrent subject of contemporary philosophy. Ref. [4] contains a detailed discussion in terms of GQT. Substance observables pertain to properties of stable substances, whereas process observables refer to changes and transitions. Typically, substance propositions are expressed by nominal sentences and process propositions by verbal sentences. In ref [4] we argue that substance observables should be complementary to process observables. The reason is a vital difference in their relationship to a time observable T. Substance observables commute with T, and an eigenstate of a substance observable can be assumed to be an eigenstate of T, too. In sharp contrast to this, process observables do not commute with T and will change the value of T. This means that there are no common eigenstates of substance and process observables and implies complementarity between them. A neurophysiological state is described by the states of neurons, and a little thought teaches us that neurophysiological observables are substance observables. On the other hand, phenomenal observables as often as not are process observables. Hence, we have at least to expect complementarity between neurophysiological observables and a large class of phenomenal observables.
C) The third argument employs the notion of complementary partitions as introduced in ref [7]. The human language is not rich enough for a complete description of all phenomenal states of the human mind, and every characterisation in terms of phenomenal observables contains an inevitable element of vagueness. A complete description of the neurophysiological state of the human brain is impossible, because it would consist of a description of the states of roughly 10^{12} neurons. The state of a few neurons gives a very incomplete description of the total neurophysiological state an even the most modern imaging procedures have a special resolution orders of magnitudes above the distance of two neighbouring neuron. In addition, the temporal resolution is poor compared to typical neuronal time scales. Thus, imaging procedures yield only rough space-time averages. One should also keep in mind that neurophysiological states are frequently characterised by referring to phenomenal observables with their inherent fuzziness. So, phenomenal and accessible neurophysiological observables only give coarse grained partitions of the full set of states.
Moreover, the topologies of phenomenal and neurophysiological states are quite different. Two clearly separable phenomenal states may correspond to very similar neurophysiological states, whose difference cannot be resolved by realisable neurophysiological observables. Vice versa clearly different neurophysiological states may give rise to very similar phenomenal states. In such a situation, an eigenstate of a neurophysiological observable will imply indeterminacies of phenomenal observables and an eigenstate of a phenomenal observable will be beset with indeterminacies of

neurophysiological observables. In this case there will be no common eigenstates of certain phenomenal and neurophysiological observable, and the criterion for complementarity will be fulfilled. Of cause, this situation of complementarity is not always realised. It is not expected to hold for sensomotoric phenomena or for dispositional states like hunger or sexual arousal, which are associated to clearly distinguishable neuronal excitation patterns. For instance, different parts of the retina are mapped onto distinguishable regions of the visual cortex, and different parts of the human body correspond to different regions of the parietal somatosensoric cortex. In these cases, the complementarities described under the points A) and B) are irrelevant in the same sense as complementarity in quantum mechanics is negligible as long as classical mechanics is a valid approximation. Indeed, a visual excitation pattern or a state of hunger are not essentially changed by becoming conscious.
In other situation, however, partitional complementarity will be of decisive importance. For example, this will be the case for the subtle and highly unstable stream of consciousness, which is redirected by every act of conscious registration. Just to mention two direct consequences of this complementarity between phenomenal and neurophysiological observables:

- Detailed "thought reading" by means of neuronal imaging is impossible
- Even if the strong neuroreductive credo holds true, it refers to an unrealisable situation. Because of their complementarity to realisable neurophysiological observables, phenomenal observables are indispensable for a full description of the human mind in the same sense as in quantum mechanics it is impossible to dispose of spacial observables in favour of momentum observables.

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