Opinion and Perspectives

Quantum Mechanics Meets Cognitive Science: Explanatory vs Descriptive Approaches

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Abstract

We reflect on several aspects of the general claim that a quantum-like approach to Cognitive Science is advantageous over classical approaches. The classical approaches refer to the symbolic approaches including models using a classical (Kolmogorov) probability calculus. The general claim seems to be right from a descriptive viewpoint but not necessarily from an explanatory viewpoint. The explanatory perspective needs a more careful analysis since adding some additional arbitrary parameters (such as phase shift parameters in quantum probabilities) does not automatically increase the explanatory value of the approach; rather, it seems to decrease it. We argue further that there is another class of traditional models – the class of geometric models of cognition. These models have a much longer tradition than the symbolic models. Interestingly, quantum mechanics does not contradict the geometric models. Hence, real progress at the meeting between quantum mechanics and cognitive science could be made by unifying these geometric models with ideas from quantum theory.

Key Words: Quantum theory, interference effects, Jung, symbolic models, geometric models, quantum cognition

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> "With four parameters I can fit an elephant, and with five I can make him wiggle his trunk."
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> John von Neumann, according to Enrico Fermi, as quoted by Freeman Dyson (2004).

Current researchers of quantum cognition or quantum interaction are very optimistic concerning the question whether a quantum-like approach actually is advantageous over classical approaches (for relating this research to the idea of quantum minds, the reader is referred to Bruza, 2010). Unfortunately, the question is not easily answered, and in order not to fall into subjectivist speculations, idealistic daydreaming or unscientific promotion tours, let us start with stressing a silent assumption of modern cognitive science. This assumption concerns the view that a good cognitive theory has to be both *descriptive* and *explanatory* (e.g. Chomsky, 1995). Descriptive theories are theories about what a particular cognitive phenomenon – perception, language, or (cognitive aspects of) personality is like. They are theories about what tools we need in order to provide adequate descriptions of the phenomena. Explanatory theories, in contrast, are theories about *why* these phenomena are the way they are. Hence, theory building is definitely more than data fitting.

The history of connecting the quantum approach in physics to cognitive science is long and varied. Possibly, pioneer geneticist and evolutionary biologist J.B.S. Haldane can be seen as one of the first

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researchers who realized that quantum mechanics is linked to living systems and thought; cf. Tarlaci (2003). In one of his papers, Haldane (1934) points out that many characteristics of mind are comparable to those of atomic particles: both arise from dynamical systems, both exhibit a continuity and wholeness, both are at once localized yet spatially diffused. However, such analogies can be evaluated best as giving a hint for the descriptive adequacy of the framework. Analogies by themselves never tell us *why* they apply.

About ten years earlier, Carl G. Jung published his theory about psychological types (Jung, 1921) – after almost 20 years of practical experience and work as a specialist in psychiatric medicine. In this book Jung gave a careful analysis of the universals and differences of Human personalities. In Jung's theory there are no pure types. There is a set of psychological opposites, equally valuable but realized with different preferences for different personalities. Type preferences themselves are the bridge between the conscious and the unconscious. Jung's holistic picture of the Self is difficult to reconcile with classical ideas of physical symbol systems. Instead, it has been argued recently that a simple quantum mechanic model is sufficient to express the bulk of Jung's theory (Blutner and Hochnadel, 2010).

Though it is not implausible to assume that Jung (anticipating Haldane) felt that the mind and the Self are "resonance phenomena" that are associated with the wave-like aspect of atomic particles, he did not make any attempt to express his theory of personality by using the language of quantum mechanics. To develop logically stringent theories was not Jung's strongest talent, and this is perhaps one of the main reasons why Jung never was acknowledged as one of the big forerunners in unifying psychology, eastern thinking and quantum physics. Regrettably, Jung's cooperation with Nobel Prize winner Wolfgang Pauli didn't help to lift Jung's informal theory of personality onto a more stringent level. Instead, their common reflections were directed far beyond psychology and physics, entering into the realm where the two areas meet in the philosophy of nature.

Concerning Jung's theory of personality (Jung, 1921), there are many modern theorists who doubt its descriptive adequacy (for good overviews, see Eysenck 1967; Robins *et al.*, 2007). Special doubts come from the representatives of the "big five" personality theory (e.g. Goldberg, 1990; Hough, 1992). The recent reconstruction of Jung's theory in terms of Pauli's spin matrices (Blutner and Hochnadel, 2010) makes some shortcomings of the original formulation explicit and it provides the opportunity to find a descriptively more adequate solution. The solution is formulated in terms of a quantum probabilistic two qubit model.

In a nutshell, the two qubit model follows Jung in considering four psychological functions with the two basic attitudes *extraversion* and *introversion*. The four psychological functions consists of two opponent pairs: (i) sensing (S) and intuition (N) – related to two opponent ways of *perceiving* information, either directly by the senses or in a rather indirect way by the integration of large amounts of information; (ii) thinking (T) and feeling (F) – related to two opponent ways of *judging* information, either by reasoning or by evaluation.

In the present model, the first qubit represents the four psychological functions. In terms of Pauli spin matrices the opponent pair S/N is represented by $S = \sigma_x / N = -\sigma_x$ and the pair T/F is represented by $T = \sigma_z / F = -\sigma_z$. This choice is primarily motivated by Jung's idea of discriminating 8 basic personality types in dependence of one of four dominant psychological functions (T, F, S, N) and two secondary functions that correspond to the complementary pair, either S/N or T/F. The second qubit is used for representing extroversion/introversion.

Taking the product space we are able to represent the psychological functions in a certain attitude, *introversion* or *extroversion* or something in between. In discussing type dynamics, Jung stressed that each person realizes more than one psychological function, and he claimed that opponent psychological functions are realized with contrasting attitudes. In the two qubit model, this idea is expressed by entangling the attitudes with the psychological functions. For the details of the formal treatment it is referred to the original work (Blutner and Hochnadel, 2010).

Comparing the “big five” personality theory with the two qubit model, it is quickly observed that the latter position has a higher explanatory value than the former. To be sure, the “big five” approach has its origin in a behaviorist attitude. In contrast, Jung’s position – accepting archetypes to determinate identity perceptions – comes close to nativism. Whereas behaviorists typically ignore any inborn predispositions of personality types, for Jung both a careful analysis of the universals and differences of Human personalities matters. Jung thought that people were born with an inborn predisposition to type, perhaps at the quantum level (Meier, 1992), and that the positive combination of nature and nurture would see that predisposition expressed healthily.

In order to make the difference explicit consider the “big five” approach with its five factors ‘openness’, ‘conscientiousness’, ‘extroversion’, ‘agreeableness’, and ‘neuroticism’. Seeing these five factors as independent random variables within a Boolean network automatically leads to a stochastic model with 5 free parameters in the simplest case of dichotomous random variables. Unfortunately, it has been shown that the five factors of the model are not really independent of each other (Saucier 2002). This increases the number of parameter needed to give a full statistical description. Further, as Conte et al. (2007) has shown, Bell’s inequalities can be violated in case of describing personality statistics. Hence, several local models are needed to describe the full stochastic scenery in a more complete way. This can increase the number of arbitrary parameters even more dramatically. Obviously, a model with so many parameters cannot be very restrictive.

This sharply contrasts with Jung’s model (in the two qubit formulation) where the full distribution of three dichotomous random variables (‘thinking-feeling’, ‘intuition-sensing’, and ‘extraversion-introversion’) is described by three underlying parameters only. We can expect that this model is much more restrictive than the behaviorist-driven one.

Recently, a simple prediction of his model has been checked:

$$\widehat{E}(T)^2 + \widehat{E}(S)^2 \leq 1 \qquad (1)$$

where $\widehat{E}$ represents mean value, T represents the **T**hinking-feeling random variable (+1 for a clear thinking, -1 for a clear feeling), S represents the **S**ensing-iNtuition random variable (+1 for clear intuition, -1 for clear sensing). This prediction holds in the most general case allowing even for non-zero phase shifts in the underlying wave functions. Logically, it is possible that the sum in (1) is greater than 1 (it could be 2.0 at the maximum). However, investigating 51 subjects, we never found a statistically significant violation of the inequality (1). Of all cases, the sum on the right hand side of the inequality (1) was significantly smaller than 1 (p<0.05) in 47 of 51 cases, and in no case it was significantly greater than 1 (p>.2). This suggests that the constraints formulated by the two qubit approach really are satisfied by a sufficiently large population of personalities.

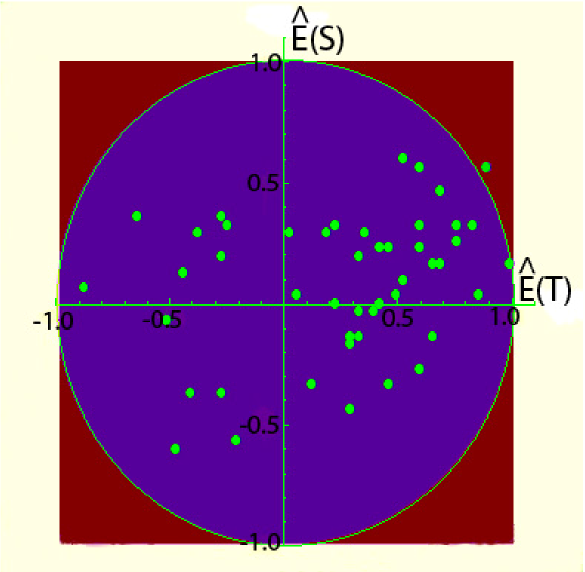

Figure 1. Checking inequality (1). The graph shows that the results of 51 subjects are in agreement with this hypothesis. Only a few subjects are situated slightly outside the unit circle; however, the deviation from the unit circle is not significant in these few cases.

Let us now shortly comment on the quantum interference effects found by Aerts (2009), Khrennikov (2006), Franko (2009) and several other authors. The existence of these effects in different cognitive and perceptive domains proves the descriptive inadequacy of standard models based on Kolmogorov probabilities, and it shows that the quantum approach is descriptively more adequate in these cases. However, it does not prove that these models are also adequate from an explanatory point of view. Quantum probabilities are simply more general than ordinary probabilities; they introduce extra phase shift parameters. What we need in order to see the explanatory power of this approach is an independent motivation or independent interpretation of these extra parameters. Are these phasing shifts introduced by spiking neurons? Or do these extra parameters refer to a different mechanism based on dendritic potentials and other dynamic quantities operating on the edge of chaos and order?

We add that a similar argumentation could be used in connection with Oaksford and Chater's (1991; 2007; 2009) recent Bayesian approach to propositional reasoning. The basic model only uses assumptions of the classical (Kolmogorv) probability theory and does not provide a very satisfying fit to the empirical data (it underestimates *modus ponens* and overestimates *modus tollens*). However, the introduction of only one additional free parameter (handling 'rigidity' violations) improves the data fitting considerably. Of course, proponents of quantum probabilities can argue that propositions in the context of real reasoning tasks do not longer form a Boolean algebra, and therefore Kolmogorov probabilities cannot be the last word. However, introducing quantum probabilities means introducing additional free parameters which can be fitted to the data. So far, we did not see any convincing argumentation that the quantum way to introduce new parameters is superior to Oaksford and Chater's more traditional way to handling the data. Hence, the difficulty of both the quantum model and the Oaksford and Chater model is to make visible the explanatory value of their respective approaches.

So far we have considered classical symbolic models including the Kolmogorov probability calculus. A final remark concerns the existence of another class of models called "geometric models". These models have a much longer tradition than the standard symbolic models. The basic idea is that understanding problem solving, categorization, memory retrieval, inductive reasoning, and other cognitive processes requires that we understand how humans assess *similarity*. Theories such as Torgerson's (1965) multidimensional scaling analysis of similarity and Tversky's (1977) analysis of features of similarity still provide the fundament for geometric approaches to meaning. Recently, Gärdenfors (2000) has argued that every natural property or natural concept is a convex region of a domain in a conceptual space.

Interestingly, this sheds a new light on the algebraic structure of the inner world of ideas, concepts, and propositions. Boole and other great logicians of the 19th century assumed that thinking is like doing regular algebra in following strict rules exhibiting associative, distributive and commutative properties. These are the same rules we can observe when we consider the construction of sets by using union, intersection and complementation. However, if natural concepts are based on prototypes, and as such, natural concepts are geometrical concepts that best can be represented by convex sets, then the underlying algebra is different from a Boolean algebra. Surprisingly, it comes close to the orthoalgebra quantum mechanics is based upon (Primas, 1982). Hence, quantum mechanics conforms to the spirit of geometric models. Moreover, closely related research on geometric algebra has found useful applications in computer vision, biomechanics and robotics (e.g. Dorst, Fontijne and Mann, 2007). This strongly supports a view taken by Conte (2010) that the basic features of quantum mechanics are consistent with the logic formulation introduced by using Clifford algebra. Conte's reformulation and justification of von Neumann's processes I & II in terms of Clifford algebras is an essential aspect of increasing the explanatory power of this integrative framework (for different but related ideas, see Primas, 2000).

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