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How human and nature shake hands: The role of no-conspiracy in physical theories

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ABSTRACT

No-conspiracy is the requirement that measurement settings should be probabilistically independent of the elements of reality responsible for the measurement outcomes. In this paper we investigate what role no-conspiracy generally plays in a physical theory; how it influences the semantical role of the event types of the theory; and how it relates to such other concepts as separability, compatibility, causality, locality and contextuality.

1. Introduction

As the old *bon mot* has it, in experiment human and nature shake hands. This portrayal of the experiment as the celebration of a good business pact between two parties highlights two features of experimentation, namely that both human and nature are equally contributing to its success and that both parties are being independent. This independence is the topic of the present paper.

In the foundations of quantum mechanics probably the most significant research project has been for decades to precisely identify and conceptually analyze those assumptions that go into the derivation of the Bell inequalities and can be made responsible for their violation in the EPR scenario. Locality, factorization, Common Cause Principle, determinism—these were the main concepts and principles on the table. There was, however, one additional premise which, though being indispensable in the derivation of the Bell inequalities, remained much more obscure concerning its status, meaning and relation to the other premises.

The palpable evidence for this embarrassment around this assumption is that there has not even been coined a name for it. It has been referred to by many names such as (no) “conspiratorial entanglement” (Bell, 1981), “hidden autonomy” (Van Fraassen, 1982), “independence assumption” (Price & Arrow, 1996), “free will assumption” (Tumulka, 2007), “measurement independence” (Sanpedro, 2013), (no) “superdeterminism” (Price & Wharton, 2015), and—probably in its most well-known form—“no-conspiracy” (Hofer-Szabó Rédei and Szabó, 1999; Placek & Wroński, 2009). This latter is the phrase we are going to use in this paper.

The fact that no-conspiracy has been used by so many names attests that there is a wide range of topics which it can be related to. It has been explicitly addressed by Bell in his 1981 paper and its rejection has been qualified as “even more mind boggling than one in which causal chains go faster than light” (Bell, 1981, p. 57). No-conspiracy made its way into the philosophy of physics via Van Fraassen's (1982) careful analysis of the assumptions leading to the Bell inequalities. Ever since then no-conspiracy has been given some attention in the philosophy of science. A topic gaining probably the greatest philosophical interest was that how no-conspiracy is related to free will. The first to identify conspiracy as a lack of free will was Bell (1977, 1981) himself and has been followed by many others (Price & Arrow, 1996; Conway & Kochen, 2006; Tumulka, 2007; Price & Wharton, 2015).

The present paper does not concern any of the topics mentioned above: neither free will, nor EPR, nor Bell inequalities. It does not investigate no-conspiracy at the level of the specific scientific theories such as quantum mechanics, quantum field theory, etc. (For this see Bell (1977, 1981), Butterfield (1995), Sanpedro (2013, 2014), Hofer-Szabó, Rédei and Szabó (2013) and Price and Wharton (2015)). Our aim is more general: to investigate what role no-conspiracy plays in a physical theory. To this aim in

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Section 2 we will first unfold a general scheme of the ontology of a physical theory. We will discern two event types making the ontology: measurement event types and elements of reality. Measurement event types can be of two types: measurement settings and measurement outcomes. We will clarify how measurement settings and measurement outcomes provide semantics for a physical theory. To illustrate the general scheme we introduce a toy model in Section 3 which will then be used throughout the paper. No-conspiracy enters in Section 4. Here we show how the presence of no-conspiracy can deprive measurement settings and measurement outcomes of their semantical role and directs them into pragmatics. In Section 5 some examples will be given for situations when no-conspiracy is violated. In Sections 6 to 10 we will investigate in turn the relationship of no-conspiracy to such concepts as separability, compatibility, causality, locality and contextuality. We conclude with a discussion in Section 11.

This paper is written in the down-to-earth physicalist philosophy of László E. Szabó to whom I dedicate it.

2. The ontology of experiment

In this Section we expose the main philosophical ideas lying behind our approach in a concise manner. In the following Section all these general considerations will be made concrete on a simple toy model. The approach we are following here is a strict actualist approach where the key concepts such as causality, probability, etc. all supervene on particulars instantiating certain event types in a Humean manner. This framework is certainly not necessary to address the question of no-conspiracy; I presume that most claims of the paper also hold in other metaphysical frameworks. I follow this approach simply because the present paper is part of a larger research project aiming to explore how far one can get in understanding physical theories and especially quantum mechanics within a Humean framework.

A *physical theory* can be reconstructed as a formal system plus a semantics connecting the formal system to the world. The *formal system* consists of a formal language with some logical axioms and derivation rules, some mathematical and physical axioms. The *semantics* provides an interpretation for the formalism; it connects the formal system to reality. Note that here 'semantics' does not mean a connection between the formal system and some models of the system as in model theory; here semantics means a down-to-earth physical interpretation of the formal system. We stress again that the semantics is an indispensable part of a physical theory. A formal system in itself is *not* yet a physical theory (Szabó, 2011).

The *semantics* settles the ontology of the theory. This can be done in many ways but typically the semantics fixes the ontological *types* or *categories* out there in the world and provides some means to decide when a certain *token* falls in the category of a given type making a certain sentence of the theory true. The types and tokens which we will be interested in here are *event types* and *token events*. The ontology of a physical theory is an *event algebra* constructed from these event types. Note that concerning the ontology of the types our approach is not committed metaphysically either to the realist nor to the nominalist camp.

Physical theories are verified by *experiments*. The rough picture of an experiment is the following. An experimenter performs a procedure by setting a measurement apparatus in a certain way, obtaining a measurement outcome and repeating this procedure many times. The two essential ontological categories of an experiment are the *measurement settings* and the *measurement outcomes*. These categories are event types just as the other ontological types of the theory. The token events are the *instances* of these event types in the different runs of the experiment. Sometimes I will simply refer to these token events as the *runs* of the experiment.

Measurement settings and measurement outcomes do not appear directly in the textbook form of a theory but they are indispensable part of the semantics (not of pragmatics!): without them the theory cannot be linked to reality. More than that, these two types are the only types an experimenter has direct empirical access to. Everything else posited by the theory has to ultimately boil down to some relations between these observable categories. To be more specific, any deductive or inductive relation between the ontological types of the theory has to be accounted for in terms of *correlations* between the token events falling in the category of measurement settings and measurement outcomes. As the empiricist thesis teaches, one has no other access to physical reality than via observation.

Correlations between measurement settings and measurement outcomes can be accounted for in terms of *probabilities*. In our actualist framework the probability of an outcome type is understood as the *long-run relative frequency* of those runs of the experiment which fall in that type if the experiment is repeated appropriately many times. Specifically, the probability of an outcome *given* a certain measurement setting is simply the number of those runs which fall in both the type of the outcome and the setting divided by the number of those runs which fall in the type of the setting. More importantly, *any* probability assignment to any ontological type to which we have no direct empirical access must be based on *type assignments* to the individual runs of the experiment in the long-run frequency sense: the probability of a given type is p only if the relative frequency of the individual runs (instances) falling in the type in question is p. Probability supervenes on the Humean mosaic of token events.

In order to account for the observable measurement outcomes physical theories typically introduce a further, not directly accessible event type, which we will call *elements of reality*. In this sense our approach is scientifically realist. Elements of reality come in two sorts: they can either determine the measurement outcomes for a given measurement setting *for sure*, or they can fix only the *probability* of the measurement outcomes. We will call the first event type *property* and the second event type *propensity*. Whereas measurement outcomes are clearly causally influenced by and therefore probabilistically dependent on the elements of reality, it is not a priori clear what the relation between the measurement settings and the elements of reality should be. This is what we are going to analyze in what comes.

3. A toy model

Let us make these abstract considerations more concrete on a simple model. (For a general scheme of a physical theory see the Appendix.) Consider a box containing colored dice (Szabó, 2008). Let us try to develop a physical theory of this system. Whatever theory we develop, the semantics of the theory has to minimally specify the measurement settings and measurement outcomes. These are the categories which are directly accessible for an experimenter. Suppose that the measurement settings are the following:

a_1: drawing a die from the box and checking its *color*
a_2: drawing a die from the box, throwing it and checking the *number on its upper face*

Suppose furthermore that the measurement outcomes are

A_1^i: the color of the die is *black* (A_1^1) or *white* (A_1^2)
A_2^j: the number on the *upper face* of the die is j ($j = 1 \ldots 6$)