On Quantum Nonlocality:
Using Prediction of a Distant Measurement Outcome

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Abstract

We assume that an event caused by a correlation between outcomes of two causally separated measurements is, by definition, a manifestation of quantum nonlocality, or superluminal influence. An example of the Alice-Bob type is given, with the characters replaced. The relationship between quantum nonlocality and relativity theory is touched upon.

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Introduction

A recent paper by Stapp [1] has breathed new life into the problem of quantum nonlocality, or superluminal influence. As a result, a controversy has been aroused [2-11]. Opinions differ widely: Quantum nonlocality exists and may be proved using counterfactuals; quantum nonlocality exists but the counterfactual proof is untenable; quantum nonlocality does not exist.

Our opinion is the second one, so that an existence proof of quantum nonlocality should be based on actual events. The aim of the present paper is to propose such a proof. It goes without saying that first and foremost a definition of quantum nonlocality or, to be more precise, of its manifestation should be given.

We assume that an event caused by a correlation between outcomes of two causally separated measurements is, by definition, a manifestation of quantum nonlocality, or superluminal influence.

Given this definition, there is no difficulty in constructing an existence proof. We choose that of the Alice-Bob type, replacing the characters. Other examples, which relate to Bell inequalities, are well known.

The relationship between quantum nonlocality and relativity theory (for this problem see, e.g., [12]) is touched upon.

1 Definition of quantum nonlocality via its manifestation

Nobody would deny that due to quantum entanglement there exists a correlation between outcomes of two causally separated measurements. But since the correlation does not imply superluminal signals, not all treat it as quantum nonlocality. In the long run, that is a matter of taste. Be that as it may, it seems reasonable to define quantum nonlocality via manifestations of the correlation.

By definition, we assume that an event caused by a correlation between outcomes of two causally separated measurements is a manifestation of quantum nonlocality, or superluminal influence.

Here the term ‘event’ has a standard relativistic meaning: An event is localized in spacetime.

2 Two civilizations

There are two civilizations: aggressive (A) and intellectual (I). The time distance between them is

\[ T \equiv T_{A-I-A}^A = T_{I-A-I}^I = \text{const} \]

where \( T^A \) stands for a time interval by A clock and \( A-I-A \) for a light signal from A to I to A.

A desires to destroy I. A can send a destroying light pulse with one of frequencies \( \Omega_i, \ i = 1, 2, ..., N, \ N \gg 1 \). I has N mirrors, \( M_1, M_2, ..., M_N \). The mirror \( M_i \) reflects the pulse \( \Omega_i \), so
that
\[
\text{combination } (\Omega_i, M_{i'}) \text{ results in destroying } \begin{cases} I \text{ for } i' \neq i \\ A \text{ for } i' = i. \end{cases}
\] (2)

The setting-up time for a mirror is
\[
T_{\text{setting}}^I = \frac{1}{2} T - \tau_I, \quad \tau_I \ll \frac{1}{2} T.
\] (3)

A is corrupt to the last degree. I has an excellent secret service.
A will send a pulse if \( \Omega_i \) is unknown to I: in view of \( N \gg 1 \), the risk is small.

3 An order

To get around the corruption and secret service, A decides that the choice of \( \Omega_i \) should be a random event. An order is given to a physical laboratory: At the time \( t^A_{\text{receiving}} \), a quantum system (A system) should be received in a mixed state with a statistical operator
\[
\rho^A = \frac{1}{N} \sum_i |Ai\rangle \langle Ai|, \quad \langle Ai| Ai'\rangle = \delta_{ii'},
\] (4)

where
\[
O^A |Ai\rangle = a_i |Ai\rangle.
\] (5)

At the instant
\[
t^A_{\text{measuring}} = t^A_{\text{receiving}}
\] (6)

the observable \( O^A \) will be measured with a result \( a_i \), and at the instant
\[
t^A_{\text{sending}} = t^A_{\text{measuring}}
\] (7)

a pulse \( \Omega_i \) will be send.

4 The order is fulfilled

Due to an operation by I secret service, the order is fulfilled as follows. At the time \( t^A_{\text{receiving}} \) A receives A system with \( \rho^A \) given by eq.(4), where
\[
\rho^A = \text{Tr}_I \rho^{AI},
\] (8)

\[
\rho^{AI} = |AI\rangle \langle AI|, \quad |AI\rangle = \frac{1}{\sqrt{N}} \sum_i |Ai\rangle \otimes |Ii\rangle, \quad \langle Ii| Ii'\rangle = \delta_{ii'},
\] (9)

\[
O^I |Ii\rangle = b_i |Ii\rangle.
\] (10)

I receives I system at the time \( t^I_{\text{receiving}} \) such that
\[
t^I_{\text{coming}} = t^I_{\text{receiving}} + \frac{1}{2} T
\] (11)

where \( t^I_{\text{coming}} \) stands for the instant of the pulse coming.
The result

The observable $O^I$ is measured at the instant

$$t_{\text{measuring}}^I = t_{\text{receiving}}^I$$

with a result $b_i$ corresponding to $a_i$. The mirror $M_i$ is set up by the time

$$t_{\text{receiving}}^I + T_{\text{setting}}^I = t_{\text{receiving}}^I + \frac{1}{2}T - \tau^I < t_{\text{coming}}^I.$$  

The aggressor $A$ is destroyed.

The event referred to in Sec. 1 is the impact of the pulse $\Omega_i$ on the mirror $M_i$.

We may say that $I$ has used the prediction that the outcome of the distant measurement of $O^A$ is $a_i$.

6 Quantum nonlocality and relativity theory

We would not say that quantum nonlocality contradicts special relativity: the situation is not so simple. Quantum nonlocality implies an additional structure of spacetime, which is absent in special relativity. The structure is this: The hypersurface of a quantum jump is that of a constant value of cosmic time [13].

Acknowledgement

I would like to thank Stefan V. Mashkevich for helpful discussion.

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