Int Jr. of Mathematical Sciences & Applications
Vol. 13, No. 1, (January-December, 2023)

ISSN No: 2230-9888
www.journalshub.com

Quantum entanglement from Multidimensional Time

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Abstract: The successful series of tests supporting Bell's Theorem (BT) have been progressively reducing the chances for local realism to describe two particles A and B separated after an initial quantum interaction. We present the Multidimensional Time (MTD) as proper background for a final attempt to restore the local causality in Bell scenarios. The MDT would keep "timelike" the interval between A and B so that they could communicate through subluminal signals. Furthermore, temporal hidden variables could lead to the stunning conclusion that the particles A and B do not separate even if they are spatially distant. The MDT is compatible with the Connection across Constrained Colliders (CCC), another cutting-edge theory still escaping the BT.

MSC(2020): 46T12, 53B30, 53C27, 54B20, 57N16, 78A25, 78A40, 81V10, 83A05, 83E15

Keywords: Special Relativity, Quantum Mechanics, Bell's Theorem, local causality, hidden time variables, MDT, 6D, CCC.

1. Introduction

The Nobel Prize in Physics 2022 has renewed the interest in Bell's theorem (BT) and the related experiments measuring the polarization (or spin) of pairs of particles separated after an initial quantum interaction.

In this short note we do not discuss neither the mathematics of BT (Bell, 1964) nor the apparatuses arranged for Bell tests (Clauser & Horne, 1974; Aspect et al., 1981; Zeilinger, 1999). We also omit the formalism of Quantum Mechanics (QM) and the subsequent philosophical issues as irrelevant for our purpose.

We just focus on the settling topic raised by the opponents of the *non-locality* in QM (Einstein et al., 1935) in an oversimplified form: is it possible a *local* causality between two *distant* particles detected simultaneously?

In the standard four-dimensional universe (4D) the answer is *no*; in fact, according to the Special Relativity (SR), the space distance between two particles at the same time of measurement results in a "spacelike" interval ($ds^2 < 0$), preventing any mutual communication.

The assumption of a multidimensional time (acronym MDT) is aimed at restoring the local causality is such situation; namely, extra-time dimensions could keep a "timelike" interval ($ds^2 > 0$) albeit the particles are far apart from each other. Temporal hidden variables could lead to the further conclusion of a "null" interval ($ds^2 = 0$), i.e., the particles never actually separate.

Time is commonly considered *monodimensional*, but if its dimensionality should be proved greater than one, it would supply a deterministic description of the particles' entanglement (E=MDT).

Even Schrödinger's equation should be reformulated in MDT, confirming Einstein's claim of *incompleteness* about the wavefunction in QM.

The main candidate as MDT is the three-dimensional time in a 6D manifold, whose SO(3,3) symmetry has been widely explored (Bonacci, 1991–2018; Chen, 2005; Chester et al., 2020; Muchow, 2020; Rakotonirina, 2022).

An auxiliary consequence of a MDT is the *backward causation* which is the principal tool of the constrained retrocausal collider bias, another deterministic interpretation of quantum entanglement (E=CCC) that rejects the *statistical independence* of the measurement outcomes (Price & Wharton 2021, 2023).

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Although written for a general audience, this paper recalls some strong notions of SR and requires a basic knowledge of QM (Bonacci, 2020).

2. Dealing with the locality of interactions

We summarize the Principle of Locality from SR, focusing on the light cone of a spacetime event as derived by Hermann Minkowski (1907). Then we suggest the hypothesis of the multidimensional time (MDT) as a straightforward way to extend the *local causality* in regions forbidden by 4D superluminal constraints.

2.1 The light cone in Minkowski's 4D spacetime

The Minkowski's four-dimensional interval, between two spacetime events, is invariant in any inertial reference frames: $ds^2 = c^2dt^2 - dx^2 - dy^2 - dz^2$. The invariant interval is *timelike* ($ds^2 > 0$) if $v < c$, *null* ($ds^2 = 0$) if $v = c$, or *spacelike* ($ds^2 < 0$) if $v > c$.

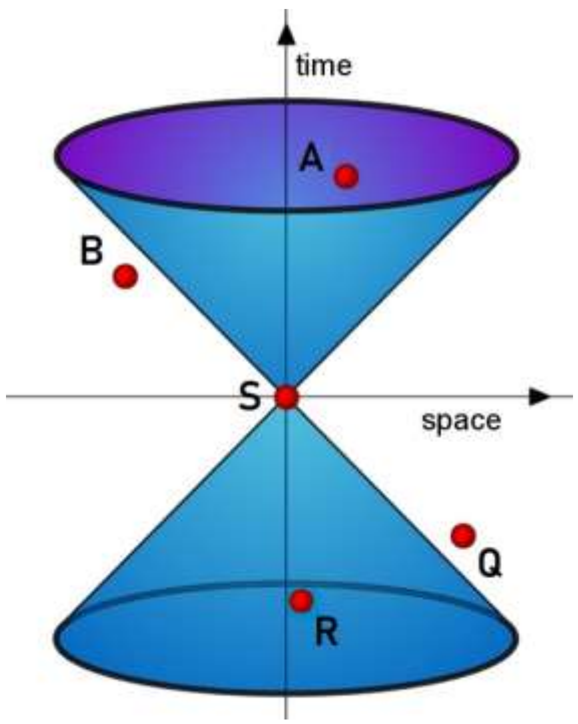

Figure 1. Representation of the standard light cone of S.

Spacelike separated events are causally disconnected. Only timelike or lightlike separated events can be causally related ($ds^2 \geq 0$).

The light cone $c^2t^2 = x^2 + y^2 + z^2$ associated to an event S (Fig. 1) consists of two parts: *forward* ($t > 0$) and *backward* ($t < 0$). The event S can influence A (forward) and could be influenced by R (backward) because A and R lie in the interior or on the surface of the light cone.

The events B and Q are causally disconnected from S for they lie outside the light cone, *elsewhere* in the "spacelike" region. An eventual interaction among these events would require a signal at velocity $v > c$.

2.2 Restoring the local causality via MDT

How could we bring the event B in the *causal future* of S and the event Q in the *causal past* of S?

We should *enlarge* the light cone (Fig. 2), reducing the "spacelike" region, by adding at least a time coordinate τ in the light-cone's equation as follows:

(1) $c^2t^2 + c^2\tau^2 = x^2 + y^2 + z^2$

We are assuming a multidimensional time (MDT) instead of the standard 1-dimensional t.

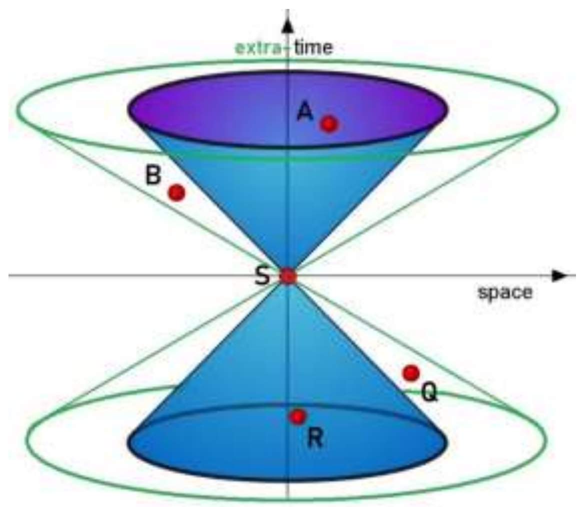

Figure 2. Representation of the enlarged light cone of S.

2.3 Plausible features of the MDT

A valid framework for the MDT is a 6D spacetime where an event $E(x, y, z, t, \tau, \theta)$ is characterized by three spacelike $S(x, y, z)$ and three timelike $T(t, \tau, \theta)$ dimensions (Bonacci, 1991–2018; Chen, 2005; Chester et al., 2020; Muchow, 2020; Rakotonirina, 2022).

The coordinate invariance for topological reasons ($\Delta\tau = \Delta\theta = 0$) could macroscopically hide two temporal dimensions out of three, letting us perceive time passing only as t (Bonacci, 2022a, 2022b, 2022c); the time extra-dimensions τ, θ would show up when particles are tested at quantum level.

Therefore, two 6D events involved in Bell experiments $E_1(x_1, y_1, z_1, t_1, \tau_1, \theta_1)$ and $E_2(x_2, y_2, z_2, t_2, \tau_2, \theta_2)$ could have $\tau_1 \neq \tau_2$ and $\theta_1 \neq \theta_2$ and their interval would be much more time-oriented than in 4D:

(2) $\Delta s^2 = c^2\Delta t^2 + c^2\Delta\tau^2 + c^2\Delta\theta^2 - \Delta x^2 - \Delta y^2 - \Delta z^2$

The stunning conclusion is that spatially distant events in 6D ($\Delta x^2 + \Delta y^2 + \Delta z^2 > 0$) could be considered "not separated" ($\Delta s^2 = 0$) if there is enough time to compensate the space between them, as follows:

(3) $c^2\Delta t^2 + c^2\Delta\tau^2 + c^2\Delta\theta^2 = \Delta x^2 + \Delta y^2 + \Delta z^2$

2.4 Problems and opportunities about the MDT

A multi-dimensional time could bridge the chasm between Relativity and Quantum Physics starting from the local interpretation of the entanglement (E=MDT).

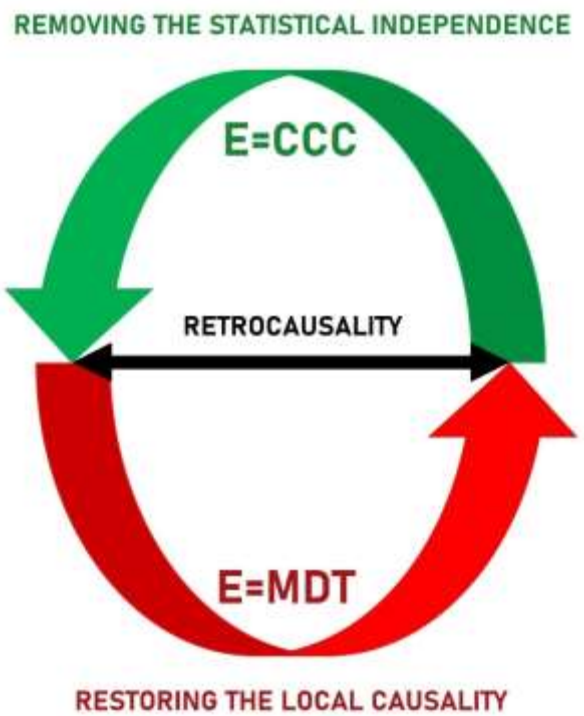

Figure 3. Link between E=MDT and E=CCC.

Despite its huge potential, the MDT is still a niche conjecture for being associated to paradoxical phenomena such as the symmetry of causation along timelike curves.

Nevertheless, a novel idea of entanglement, known as Connection across Constrained Colliders (CCC), is based on *retrocausality* (Price & Wharton 2021, 2023).

Both the approaches E=MDT and E=CCC reevaluate the role of time in physical description (Fig. 3).

3. Testing Bell-type inequalities

Let us consider the photon pair A&B emitted from a single quantum event S, defined by a wavefunction, towards opposite detectors (Fig. 4). Each photon crosses a two-channel polarizer whose orientation can be set by the experimenter also *during* the flight of A and B.

The photons are in a superposition of linear polarized states until the polarization measurement collapses the wavefunction into one state (vertical or horizontal).

The measurement outcomes are sent to a monitor counting the number of *coincidences*; a result greater than two infringes the CHSH inequality (Aspect et al., 1981) confirming the quantum correlation between A and B.

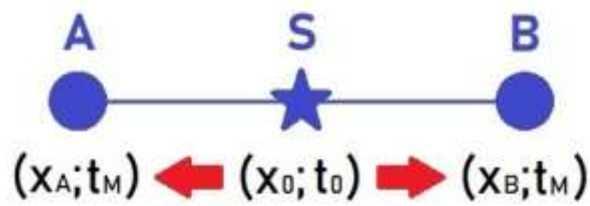

Figure 4. Polarization-entangled photons in 4D.

3.1 The non-locality in 4D

In any *deterministic* mechanism, reproducing the measurement outcomes, the setting of one measuring device would influence the reading of the other instrument, however remote, through a signal propagating *instantaneously* (Bell, 1964).

In the accepted four-dimension universe it is impossible because, at the time of measurement t_m, between A and B there is a "spacelike" interval:

$\Delta s^2 = c^2(t_m - t_m)^2 - (x_B - x_A)^2 = -\Delta x^2 < 0.$

It hinders any interaction between the particles since the backward cones of A and B do not overlap (Fig. 5).

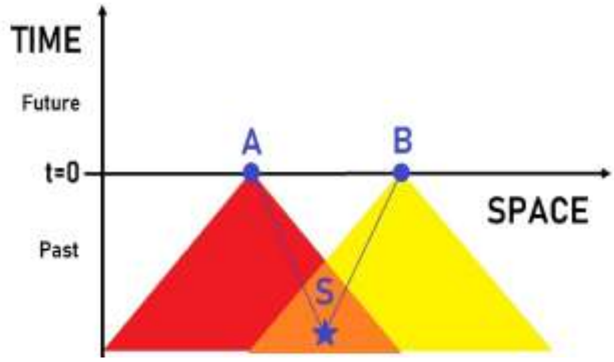

Figure 5. Backward light cones not overlapping in 4D.

3.2 Restoring the locality via MDT

From the Eq. 1, we know that an extra-dimension τ could keep the interval "timelike" though A and B are spatially distant (Fig. 6):

$\Delta s^2 = c^2(\tau_B - \tau_A)^2 - (x_B - x_A)^2 = \Delta\tau^2 - \Delta x^2 > 0.$

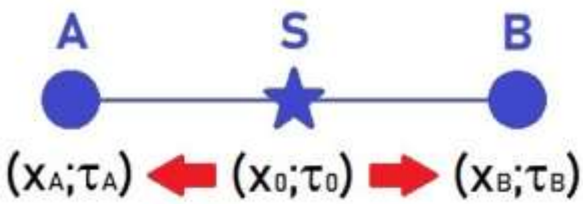

Figure 6. Polarization-entangled photons with MDT.

Since $\Delta s^2 > 0$ means $\Delta x/\Delta\tau < c$ (a subluminal velocity), the *local causality* would be restored (Fig. 7).

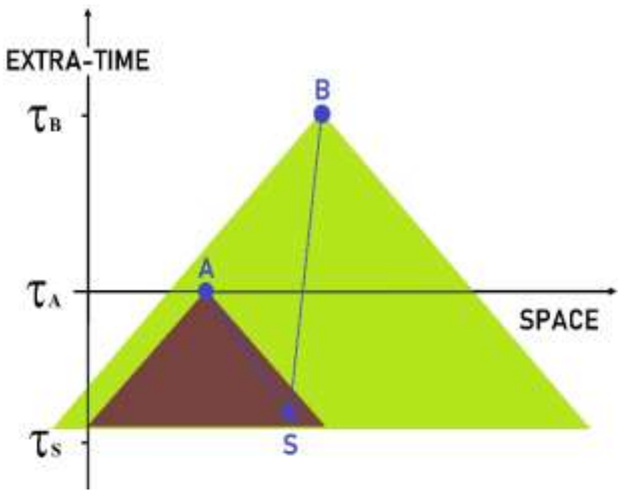

Figure 7. Backward light cones overlapping with MDT.

3.3 An inseparable pair?

The time extra-dimension τ (Eq. 1) could lead to the further conclusion of a "null" interval, i.e., A and B do not separate albeit they are far apart from each other:

$\Delta s^2 = c^2(\tau_B - \tau_A)^2 - (x_B - x_A)^2 = \Delta\tau^2 - \Delta x^2 = 0$

Anyway, since $\Delta s^2 = 0$ implies $\Delta x/\Delta\tau = c$, there likely exists another temporal hidden variable θ (Eq. 2) increasing the total time T up to a subluminal speed $\Delta x/\Delta T < c$. This is an additional reason to credit the *three-dimensional* time $T(t, \tau, \theta)$ as MDT (Eq. 3).

3.4 Two proposals similar, but not identical

As clarified in Paragraph 2.4, our deterministic approach (E=MDT) and the one from Price & Wharton (E=CCC) are siblings but not twins.

Firstly, A and B may influence each other:

- directly in *E=MDT*, overlapping backward light cones;
- indirectly in *E=CCC*, via a biased past collider.

Secondly, the temporal causal symmetry of *E=CCC* does not necessarily need the MDT, being compatible with the ordinary time (Costa de Beauregard, 1976).

4. Conclusions

Einstein's dream of an objective Quantum Mechanics could benefit from a hypothetical Multidimensional Time (MDT) restoring the *local causality* to an entangled pair of particles subject to Bell-type constraints.

The MDT would allow spatially distant events to be in the same timelike region ($ds^2 > 0$) avoiding the 4D *superluminal* communication.

Consistent with the 6D spacetime on SO(3,3)-group supported by several scholars, the MDT would provide a deterministic correlation for the particles (E=MDT).

Two hidden temporal extra-dimensions would put us in an ultrahyperbolic manifold where the events are described by three spacelike $S(x, y, z)$ and three timelike $T(t, \tau, \theta)$ for a total of six dimensions $E(x, y, z, t, \tau, \theta)$.

The MDT includes also timelike curves where an effect can precede its cause (retrocausality), which is the key to a recent explanation of quantum entanglement violating the independence of measurements through a past-collider bias. Proposed by Price & Wharton (2023), it would be a connection across constrained colliders (E=CCC).

Thus the MDT, an entity whose falsification relies on spotting the exact dimensionality of time (whether greater than one), would shake both the pillars of Bell's theorem: the local causality and the statistical independence.

Remarks

The light cone used in the Figures 1 and 2 is available under the Creative Commons CC0 Universal Public Domain Dedication.

Acknowledgments

We wish to thank the anonymous Referees and the Editor for their valuable comments and suggestions, which significantly improved our manuscript.

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