Title: Proposal to use humans to switch the settings in a Bell experiment

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Abstract: In this talk I will discuss how we might go about about performing a Bell experiment in which humans are used to decide the settings at each end. The radical possibility we wish to investigate is that, when humans are used to decide the settings (rather than various types of random number generators), we might then expect to see a violation of Quantum Theory in agreement with the relevant Bell inequality. Such a result, while very unlikely, would be tremendously significant for our understanding of the world (and I will discuss some interpretations).

Possible radical implications aside, performing an experiment like this would push the development of new technologies. The biggest problem would be to get sufficiently high rates wherein there has been a human induced switch at each end before a signal as to the new value of the setting could be communicated to the other end and, at the same time, a photon pair is detected.   It looks like an experiment like this, while challenging, is just about feasible with current technologies.

Plan for talk

- Beginnings
- Need for "free" settings
- Proposal for experiment
- Feasibility
- Bell inequalities with retarded settings
- Interpretation
- Conclusions

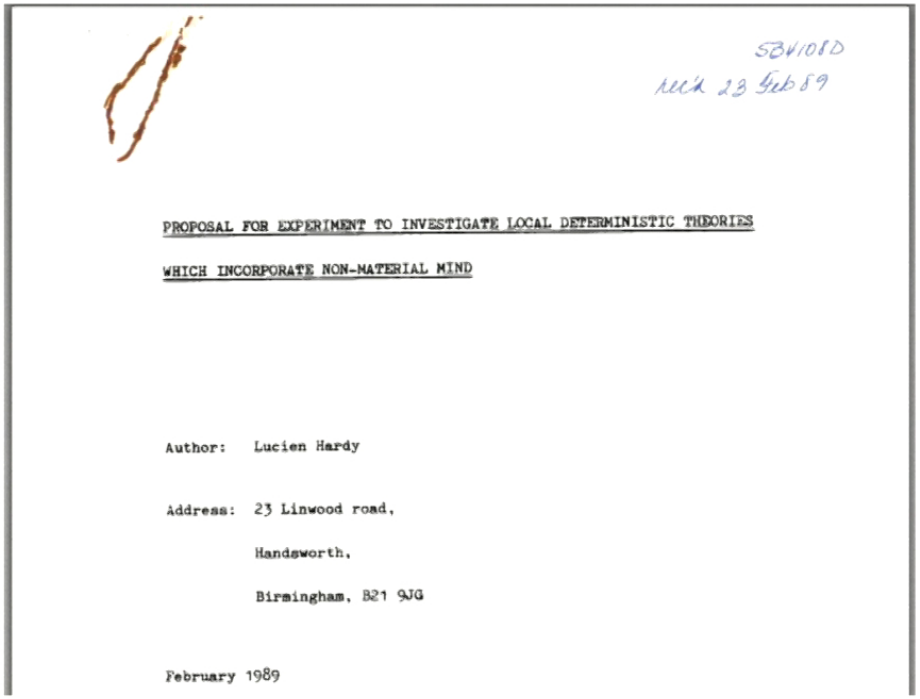
Beginnings

In 1988 I had the idea to use humans to switch the settings in a Bell experiment to test a certain idea of mind matter duality.

In 1989 I wrote two preprints on this subject - neither was accepted for publication.

1989a

Written before starting my PhD



SBW108D
Lecture 23 Feb 89

PROPOSAL FOR EXPERIMENT TO INVESTIGATE LOCAL DETERMINISTIC THEORIES

WHICH INCORPORATE NON-MATERIAL MIND

Author: Lucien Hardy

Address: 23 Linwood road,

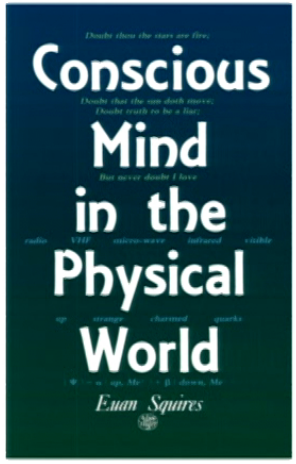
Handsworth,

Birmingham, B21 9JG

February 1989

For this I learned to type.

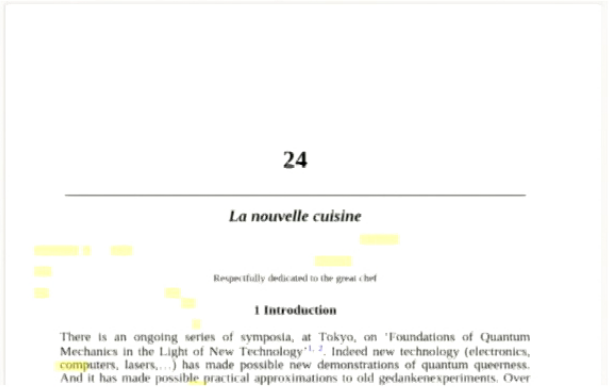
My first mention in the published record is in Euan Squires 1990 book



measuring devices. If such an experiment were possible, would it give disagreement with quantum theory? An alternative idea, being studied by a research student here in Durham, L Hardy, is that there might exist genuine free agents which are outside the physically determined world. Such free agents could be responsible for "mind-acts" affecting the settings in the EPR experiment. Assuming these are constrained by the Bell inequality, they would give rise to violations of quantum theory. (Experiments along these lines would be precise tests of a well defined type of dualism. Unfortunately, the time scales involved suggest that they would be very difficult to perform.)

John Bell on using humans

In his 1990 paper, La Nouvelle Cuisine, John Bell suggested using "experimental physicists, or some other random devices" to choose settings.



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La nouvelle cuisine

Respectfully dedicated to the great chef

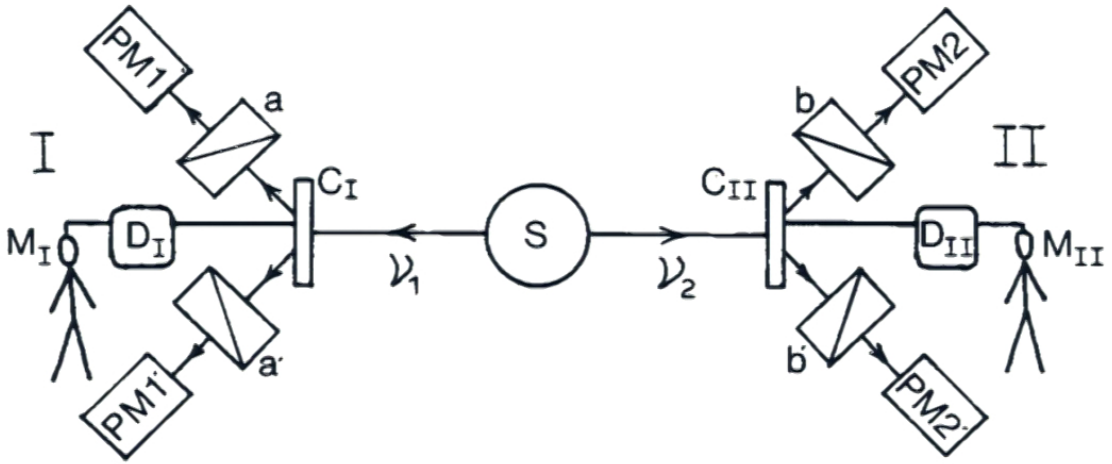
1 Introduction

There is an ongoing series of symposia, at Tokyo, on 'Foundations of Quantum Mechanics in the Light of New Technology'[1, 2]. Indeed new technology (electronics, computers, lasers,...) has made possible new demonstrations of quantum queerness. And it has made possible practical approximations to old gedankenexperiments. Over

In the application to the Einstein–Podolsky–Rosen–Bohm two-photon experiment, a and b are the polarizer settings. Then we may imagine the experiment done on such a scale, with the two sides of the experiment separated by a distance of order light minutes, that we can imagine these settings being freely chosen at the last second by two different experimental physicists, or some other random devices. If these last second choices are truly free or random, they are not influenced by the variables λ.

John Bell did not, however, discuss issue of mind (more concerned with imposing locality).

Figure from 1989a



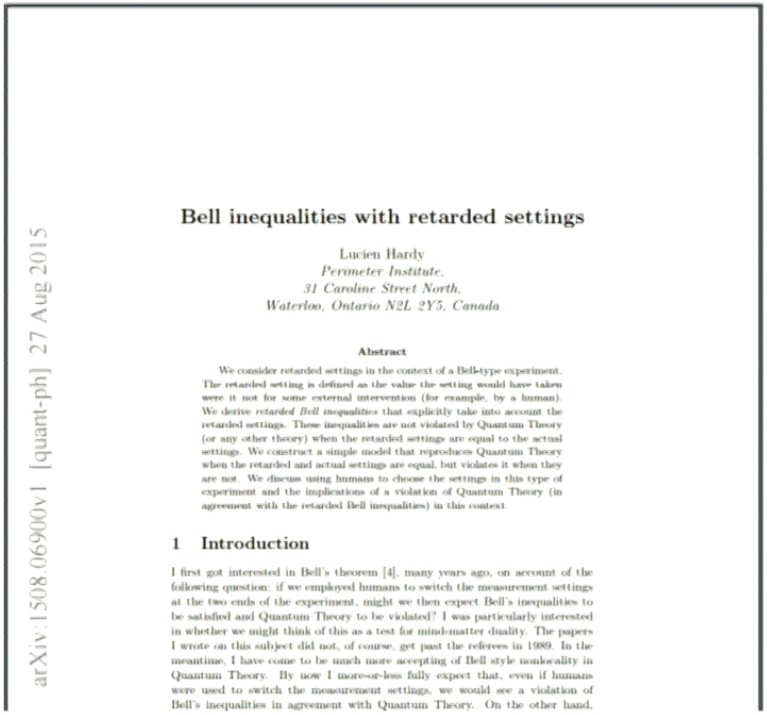
EEG signals from brain are used directly to switch settings.

In 1989 I believed such an experiment was very likely to lead to a violation of QT.

However, I gave up at the time on convincing people that this was an experiment worth doing.

Instead, I built a more conventional career in Quantum Foundations.

Bell inequalities with retarded settings



Bell inequalities with retarded settings

Lucien Hardy
Perimeter Institute,
31 Caroline Street North,
Waterloo, Ontario N2L 2Y5, Canada

Abstract

We consider retarded settings in the context of a Bell-type experiment. The retarded setting is defined as the value the setting would have taken were it not for some external intervention (for example, by a human). We derive *retarded Bell inequalities* that explicitly take into account the retarded settings. These inequalities are not violated by Quantum Theory (or any other theory) when the retarded settings are equal to the actual settings. We construct a simple model that reproduces Quantum Theory when the retarded and actual settings are equal, but violates it when they are not. We discuss using humans to choose the settings in this type of experiment and the implications of a violation of Quantum Theory (in agreement with the retarded Bell inequalities) in this context.

1 Introduction

I first got interested in Bell's theorem [4], many years ago, on account of the following question: if we employed humans to switch the measurement settings at the two ends of the experiment, might we then expect Bell's inequalities to be satisfied and Quantum Theory to be violated? I was particularly interested in whether we might think of this as a test for mind-matter duality. The papers I wrote on this subject did not, of course, get past the referees in 1989. In the meantime, I have come to be much more accepting of Bell style nonlocality in Quantum Theory. By now I more-or-less fully expect that, even if humans were used to switch the measurement settings, we would see a violation of Bell's inequalities in agreement with Quantum Theory. On the other hand,

In 2015 I put a paper on the arXiv re-activating some of these ideas.

This got Mike Lazaridis's attention "we should do this experiment" ...
"send me a proposal"

Three things have changed since 1989:

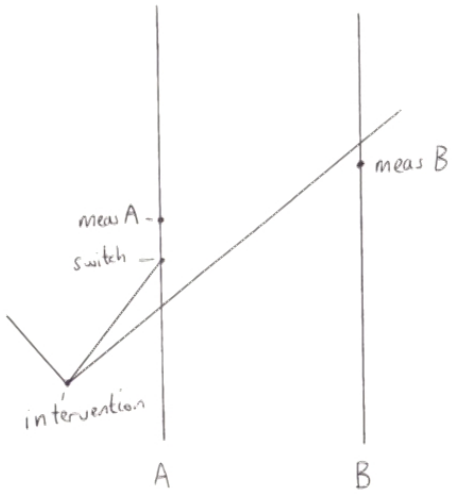
1. Attitudes have changed (several mentions of idea in serious papers published in Nature, and Big Bell test).
2. Experiment is just about feasible.
3. I have tenure.

Such an experiment would act as a stretch goal pushing the development of new technologies.

By now, I think it far less likely that QT would be violated.

But probability $\times$ payoff is, I think, very big.

The need for "free" settings in Bell experiments

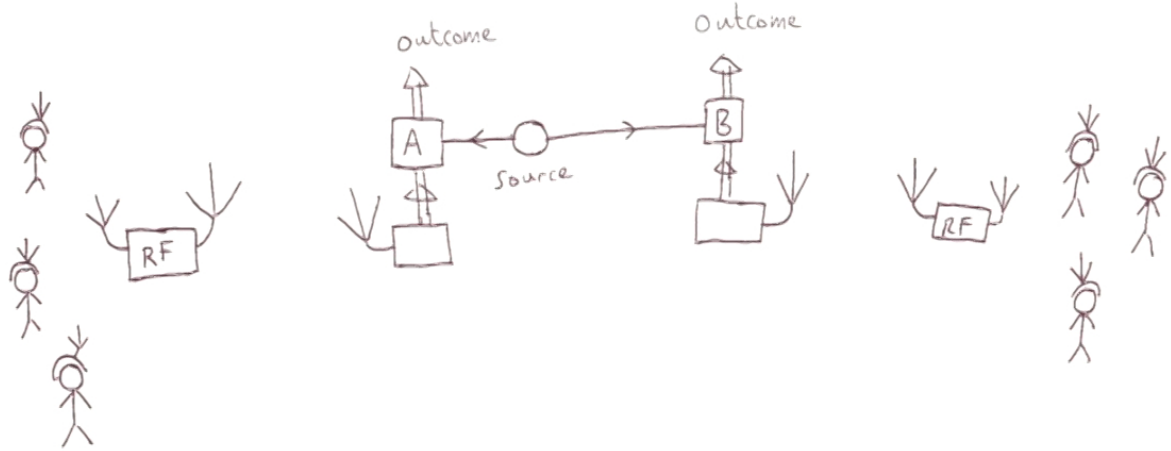


- If settings static then a light speed (or slower) signal can communicate setting to other end.
- If settings are decided by deterministic process then a light speed (or slower) signal can communicate earlier state to other side (from which setting can be calculated).
- If, however, settings can be decided freely by interventions then no way for light speed signal to communicate signal to other end.

Could use

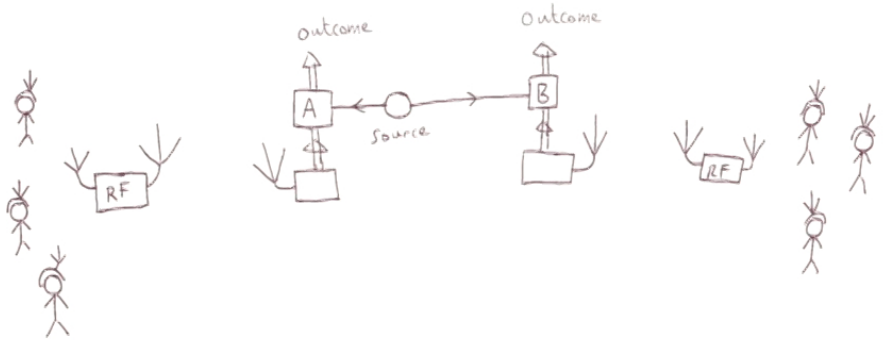
- Random number generators.
- Signals from distant galaxies.
- Humans . . .

Proposed Experiment



For example, could have

- Free space transmission of entangled photons over about 100km at altitude between remote locations.
- About 100 people at each end in towns one either side of Bell experiment for two hours.



This experiment has various components

Bell experiment. A long Bell experiment with electric input controlling settings at each end.

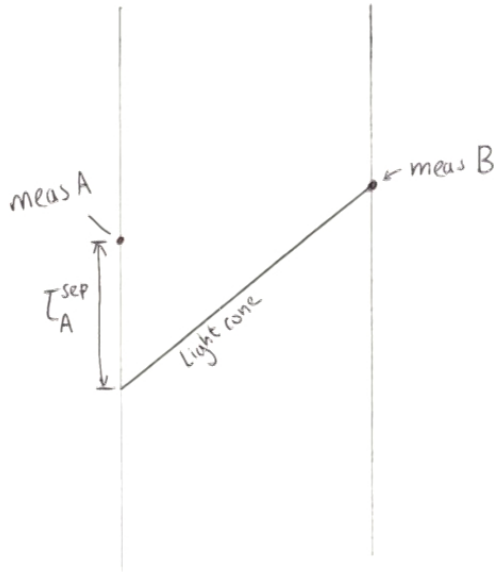
Human inputs. A large number of humans providing input at each end via EEG headsets.

Fast electronics. We need to keep delays getting human input to Bell experiment to a minimum.

Neurological analysis. We may want to study what EEG signals correspond to human interventions.

People management. Would need to manage large numbers of people.

A Bell experiment



We define τ_A^{sep} as time interval at end A between last chance to send a signal to measurement at end B and the measurement at end A.

If symmetric then

$$\tau_A^{\text{sep}} = \tau_B^{\text{sep}} = \tau^{\text{sep}}$$

We define T_{exp} as the time taken to obtain a violation of the Bell inequalities to some given standard significance (when there is no human switching).

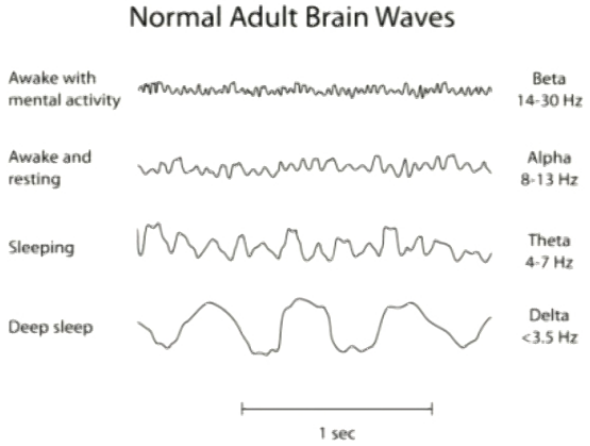
Human inputs

Could imagine humans pushing buttons to choose setting. However, can predict from EEG signals $\frac{1}{10}$s earlier what choice will be. In this time a light speed signal could carry information about the setting could be several times the radius of the earth away.

Propose, instead, to use EEG signals directly. Electrical signals travel through brain at near light speed so little delay incurred.

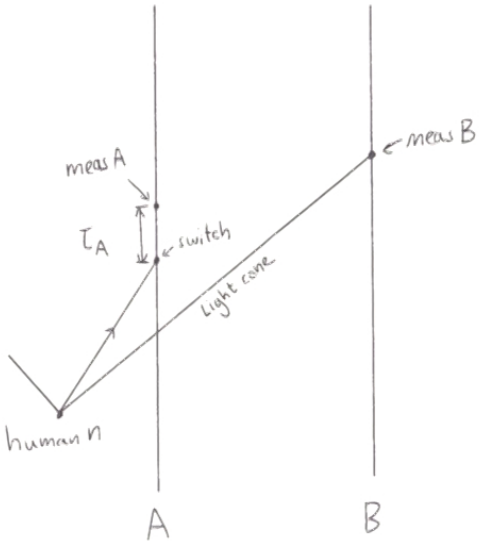
Neurological analysis

Can filter for EEG signal features proposed to be associated with "free choices". Let rate at which a human produces these be r_{human}.
For sake of having a number, we will assume $r_{\text{human}} = 10\text{Hz}$



Let $r_A \approx N_A r_{\text{human}}$ be the rate of human induced switching due to the N_A humans at end A.

Define τ_A^n as time interval measured at end A during which a human intervention has caused the setting at end A to be changed and the latest subsequent time at end A that a measurement could occur before a light speed signal could arrive at the corresponding measurement event at end B carrying information from the location of human n about this intervention.



Define average

$$\tau_A = \sum_{n=1}^{N_A} \tau_A^n$$

Fast electronics

We can define

$$\tau_A^{\text{delay}} = \tau_A^{\text{sep}} - \tau_A \qquad \tau_B^{\text{delay}} = \tau_B^{\text{sep}} - \tau_B$$

Various sources of delay

- Delay in getting signal from brain interior to EEG headset.
- Electrical delays in equipment.
- Delays due to RF waves refractive index being bigger than 1.
- Geometric effects.

People management

A new feature of this experiment is that we would have to manage a large number of people.

- Could arrange two simultaneous public outreach events.
- Would need to fit headsets.
- Would need to engage them in appropriate activity

The α fraction

We define α to be the proportion of time, during the running of the experiment, that there is human induced switch at each end and yet no signal (carrying information as to the new value of the setting) can have reached the other end.

We have

$$\alpha \approx r_A r_B \tau_A \tau_B \approx N_A N_B \tau_A \tau_B r_{\text{human}}^2$$

assuming that $r_A \tau_A << 1$ and $r_B \tau_B << 1$ (so that the time intervals during which a human intervention is internal do not overlap too much)

This is the proportion of cases where we might expect a violation of Quantum Theory (and Bell's inequalities to be satisfied).

Two modes of operation

We can imagine two modes of operation for such an experiment

1. We look at all data collected and look for shift in violation of the Bell inequalities proportional to $-\alpha$.
2. We filter for those cases where we believe there is a human induced switch.

Feasibility

Previous long Bell experiments:

Experiment	d_{sep}	T_{exp}(significance)	α	T_{exp}(significance)
1998 Innsbruck	400m	10s(30)	10^{-6}	4months(30)
1997 Geneva	10.9km	1hour(10)	10^{-3}	1000hours(10)
Canary 2010	50km	10min (16)	10^{-2}	16hours(16)

We are assuming $r_{\text{human}} = 10Hz$ and $\tau_{A,B}^{\text{delay}} << \tau_{A,B}^{\text{sep}}$

Canary Islands Experiment

PNAS PNAS

Violation of local realism with freedom of choice

Thomas Scheidl[a], Rupert Ursin[a], Johannes Kofler[a,b,1], Sven Ramelow[a,b], Xiao-Song Ma[a,b], Thomas Herbst[b], Lothar Ratschbacher[a,2], Alessandro Fedrizzi[a,3], Nathan K. Langford[a,4], Thomas Jennewein[a,5], and Anton Zeilinger[a,b,1]

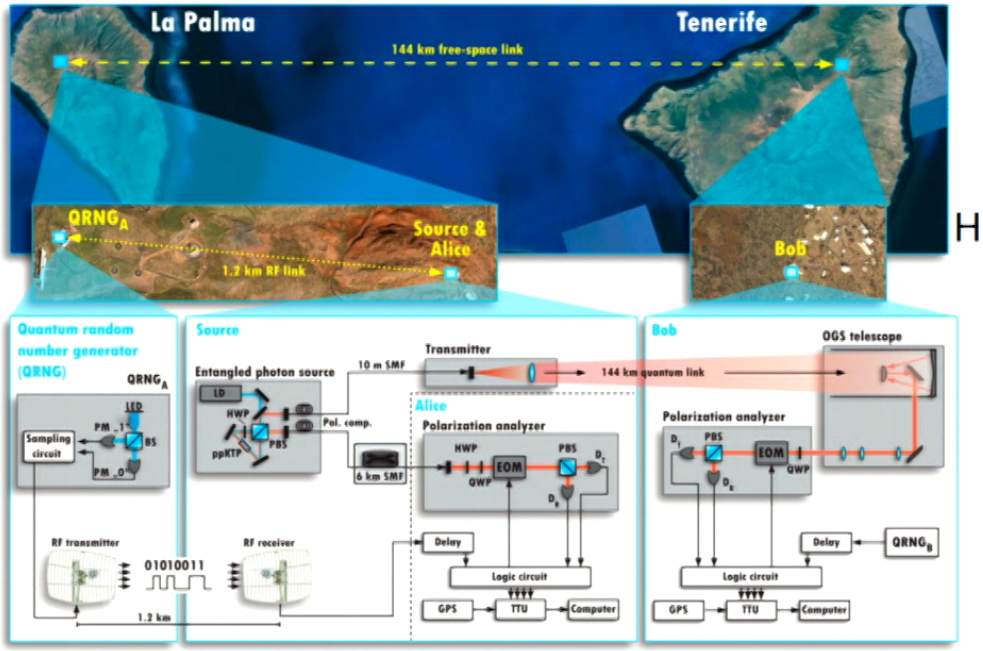
[a]Institute for Quantum Optics and Quantum Information, Austrian Academy of Sciences, Boltzmanngasse 3, 1090 Vienna, Austria; and [b]Faculty of Physics, University of Vienna, Boltzmanngasse 5, 1090 Vienna, Austria

Edited by William D. Phillips, National Institute of Standards and Technology, Gaithersburg, MD, and approved September 15, 2010 (received for review March 4, 2010)

Bell's theorem shows that local realistic theories place strong restrictions on observable correlations between different systems, giving rise to Bell's inequality which can be violated in experiments using entangled quantum states. Bell's theorem is based on the assumptions of realism, locality, and the freedom to choose between measurement settings. In experimental tests, "loopholes" arise which allow observed violations to still be explained by local realistic theories. Violating Bell's inequality while simultaneously closing all such loopholes is one of the most significant still open challenges in fundamental physics today. In this paper, we present an experiment that violates Bell's inequality while simultaneously closing the locality loophole and addressing the freedom-of-choice loophole, also closing the latter within a reasonable set of assumptions. We also explain that the locality and freedom-of-choice loopholes can be closed only within nondeterminism, i.e., in the context of stochastic local realism.

probability zero or one. Mathematically, stochastic hidden variable theories (23, 24) can be seen as mixtures of deterministic theories (25).

In an experiment, the *locality loophole* arises when Alice's measurement result can in principle be causally influenced by a physical (subluminal or luminal) signal from Bob's measurement event or Bob's choice event, and vice versa. The best available way to close this loophole is to space-like separate every measurement event on one side from both the measurement [outcome independence (26)] and setting choice [setting independence (26)] on the other side. Then, special relativity ensures that no physical signals between the events, which can never propagate faster than the speed of light, can influence the observed correlations. Experimentally, the locality loophole was addressed by the pioneering work of Aspect et al. (7) (using periodic changes of the analyzer settings while the photons were in flight) and further tightened by Weihs et al. (13) (using random changes).



Have

$$c\tau_A^{\text{sep}} = 6km$$

$$c\tau_B^{\text{sep}} = 144km$$

Get

$$\alpha = 0.01$$

Could have

$$T_{\text{exp}}(\text{significance}) = 2\text{hours}(6)$$

More improvements?

Could make other improvements

- More people, better EEG headsets, faster electronics.
- Greater distance.
- More efficient detectors.

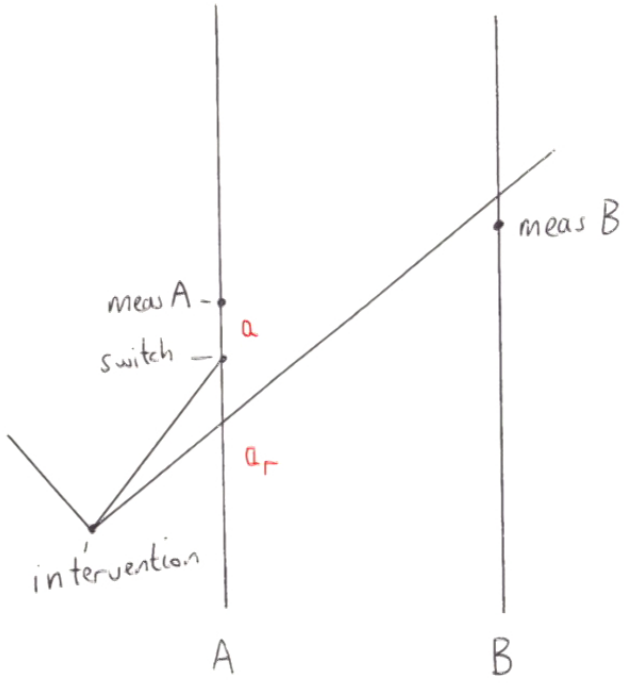
Bell inequalities with retarded settings

Assume outcome at end B can depend on b, a_r, and some local hidden variables.

$$B(b, a_r, \lambda)$$

Similarly we have

$$A(a, b_r, \lambda)$$



We use the mathematical result

$$X'Y' + X'Y + XY' - XY = \pm 2$$

where $X, X', Y, Y' = \pm 1$. We put

$$\begin{aligned} X &= A(a, b_r, \lambda) \\ X' &= A(a', b'_r, \lambda) \\ Y &= B(b, a_r, \lambda) \\ Y' &= B(b', a'_r, \lambda) \end{aligned}$$

Substitute integrate over λ

$$-2 \leq E(a', b'|a'_r, b'_r) + E(a', b|a_r, b'_r) + E(a, b'|a'_r, b_r) - E(a, b|a_r, b_r) \leq +2$$

These are the retarded Bell inequalities.

A model

Let

$$0 \leq \lambda < 2\pi \qquad \Gamma = \frac{1}{2\pi}$$

Define

$$A(a, b_r, \lambda) = \left\{ \begin{array}{ll} +1 & \text{for } \theta_L \leq \lambda < \theta_L + \pi \\ -1 & \text{for } \theta_L + \pi \leq \lambda < \theta_L + 2\pi \end{array} \right\}$$

and

$$B(b, a_r, \lambda) = \left\{ \begin{array}{ll} +1 & \text{for } \theta_R \leq \lambda < \theta_R + \pi \\ -1 & \text{for } \theta_R + \pi \leq \lambda < \theta_R + 2\pi \end{array} \right\}$$

It is easy to prove that

$$E(a, b|a_r, b_r) = 1 - \frac{2|\theta_R - \theta_L|}{\pi}$$

What if QT were violated . . .

Consequences for Quantum Foundations would be significant

- Locality
- Super-determinism

But, the real importance would be for the study of mind . . .

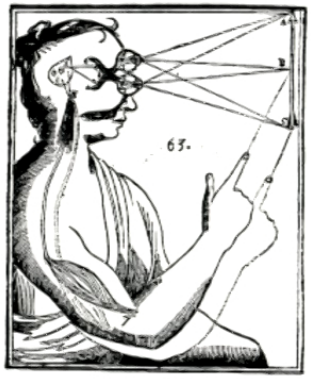
How would we account for such a result?

Two possibilities

- Local (super)-deterministic dualistic theories (LDD).
- Local (super)-deterministic free brain theories (LDFB).

Local (super)-deterministic dualistic theories

Descartes proposed mind-matter duality wherein mind is "non-physical" and acts on the brain.



These "mind-acts" could provide the interventions that make the settings free.

Not about randomness as such.

History of thinking about duality in Quantum Foundations (Wigner, Many Minds Interpretation, Copenhagen(?), . . .).

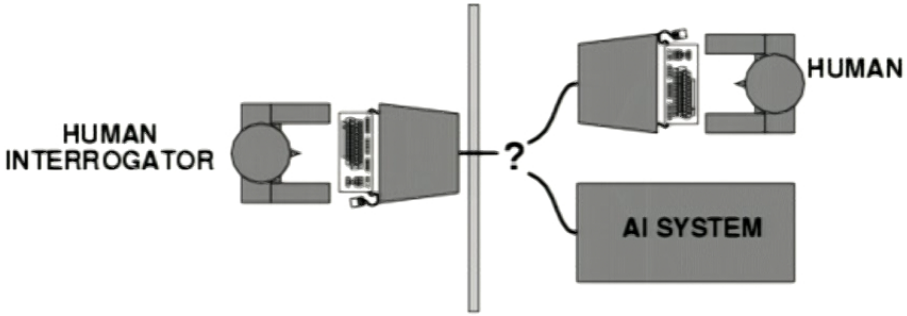
Here have a different flavour (not about solving the measurement problem).

Local (super)-deterministic free brain theories

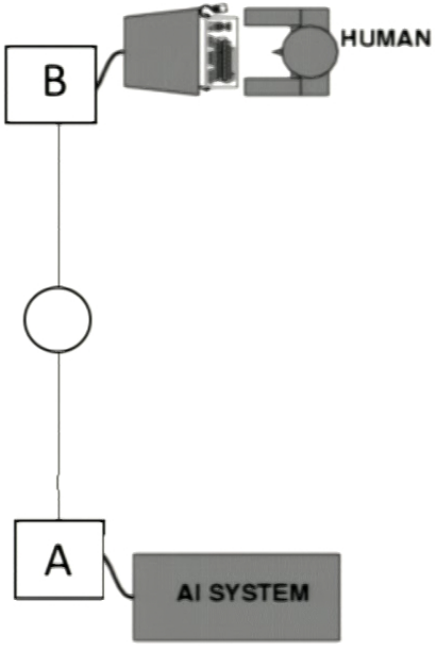
It could be that physical systems are super-deterministic except for systems that are complex in the kind of way that is found inside brains.

Problem is that locality dictates that we have micro-physical laws and it is difficult to see how to build this kind of theory.

Turing-style test



The Turing test



New kind of Turing test - but objective.

To pass, have to cause Bell inequalities to be satisfied.

Discussion

- Experiment is difficult, but just feasible. Would act as a stretch goal.
- Open up field of BQI (Brain Quantum Interface) experiments.
- Unlikely QT would be violated. For me it is the super-determinism that is hardest to believe.
- If QT were violated, this would be a tremendously significant result (especially because of relationship with issue of mind).
- Would then need to perform future experiments using more and more complex inanimate systems, as well as other types of animate system.
- What are the odds?


Thank you!