Re-thinking local causality

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31.07.2013
München

Overview

1. Local causality—different concepts
2. Local causality and the Principal Principle
3. An objection
4. Summary

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Quantum non-locality and relativity

Predictions based on entangled quantum states are often regarded as indicating a tension between quantum theory and special relativity:

- John S. Bell (1984): “an apparent incompatibility, at the deepest level, between the two fundamental pillars of contemporary theory”
- Albert and Galchen (2009): “quantum threat to special relativity”
- Michael Seevinck (2010): “a good and fair case can be made that a basic inconsistency exists between quantum theory and relativity.”

For a book-length treatment see “Quantum nonlocality and relativity” (1994) by Tim Maudlin.

But why?

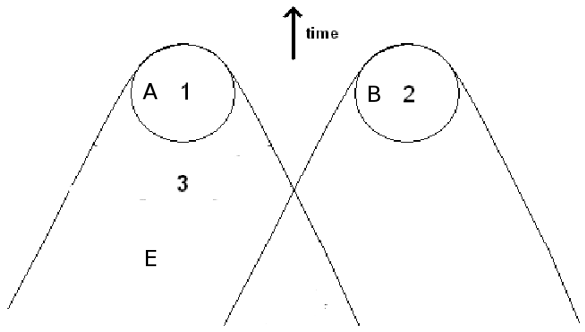
- Sometimes heard: wave function collapse must violate Lorentz covariance...,
- ...but this is only problematic on an “ontic” view of the wave function.
- Main argument: Quantum theory violates *local causality*.

Bell’s intuitive characterisation: In a locally causal theory...

> *“[t]he direct causes (and effects) of events are near by, and even the indirect causes (and effects) are no further away than permitted by the velocity of light.” (1990)*

Probabilistic local causality

For probabilistic theories:



A theory will be said to be locally causal if the probabilities attached to the values of local beables in a space-time region 1 are unaltered by specification of values of local beables in a space-like separated region 2, when what happens in the backward light cone of 1 is already sufficiently specified, for example by a full specification of local beables in a space-time region 3. (Bell 1990)

Quantum theory and local causality

An intuitive formulation:

- (IPLC) “Intuitive Probabilistic Local Causality”:
  T is locally causal iff the probability of A in region 1 depends only on what happens in the backward light cone of region 1 according to T.

Motivation: The probability of A depends only on events which causally influence whether or not A takes place.

...and Bell's criterion:

- (BPLC) "Bellian Probabilistic Local Causality":
  T is locally causal iff

$$P(A|E) = P(A|E, B)$$

  for space-like separated beables A and B and E a complete specification of A's backward light cone.

(BPLC) seems very natural as a way of making (IPLC) precise.

Quantum theory and local causality

- Quantum theory: Probabilities derived from entangled states (seem to) violate (BPLC):

$$P(S_x^A = +1/2|\psi_{EPRB}) = 1/2$$

and

$$P(S_x^A = +1/2|\psi_{EPRB}, S_x^B = +1/2) = 0$$

- So quantum theory itself is not locally causal by the standards of (BPLC)...
- ... just as, according to Bell's theorem, any theory in which quantum theory may be embedded.

My claim

I contend:

- (BPLC) does not adequately spell out (IPLC).
- Whether (BPLC) holds is irrelevant for whether or not local causality—properly construed—holds.
- No-signalling-type conditions have better prospects to secure (IPLC).

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Chance and rational credence

First remember David Lewis:

> *Don't call any alleged feature of reality 'chance' unless you've already shown that you have something, knowledge of which could constrain rational credence. (Lewis 1994)*

Let's check whether we are looking at the right "probabilities"!

David Lewis' **Principal Principle**:

- Objective probabilities constrain rational degrees of belief according to:
- $P_y(A) = cr(A|E_y T)$,
- Here E_y is "admissible evidence" and T "chance theory", e.g. quantum theory.
- Intuitively: Evidence is inadmissible if one could have it only "magically".

My claim: In a locally causal theory, evidence about B is **inadmissible** for an agent in region 1.

Ought implies can!

- Evidence about chances is always admissible. (“ought implies can”)
- If an agent in 1 **cannot** have any evidence about B at space-like distance in 2, it cannot be **rational** for her to take B into account when forming $cr(A|E_1T)$!
- Therefore, $P(A|E) = P(A|EB)$ matters only if B is *admissible* with respect to region 1. Otherwise, $P(A|EB)$ has nothing to do with the *chance* of A in 1.
- To sum up: Local causality is violated if agents can be held responsible for (not) taking into account evidence about space-like separated events for their rational credences.

The relevance of no-signalling

But, given quantum theory, *can* an agent in 1 have evidence that B (prior to detecting A)?

- The impossibility of superluminal signalling seems sufficient to exclude that.
- Implemented by "relativistic causality" (operators associated with observables at space-like distance commute)
- $\Rightarrow$ Vindication of standard approach to QFTs.

(IPLC) is fulfilled in quantum theory: $P_1(A)$ depends only on what occurs in the backward light cone of region 1.

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But how do EPR-correlations come about?

An objection:

- Considerations about agents and their rational credences are anthropocentric and don't tell us anything about why which events come about.
- The probabilities $P_1(A)$, $P_2(B)$ should be those which *govern* whether or not A and B come about, not the rational credences of co-located agents.
- One of $P_1(A)$, $P_2(B)$ must depend on whether or not the other event occurs.
- Otherwise, correlations would not come about as predicted by quantum theory.

My answer: This objection is based on propensity-mysticism about probabilities.

The block universe

To answer, consider the least anthropocentric perspective:

- The block universe: “*flow of time*”, and “*coming about*” are anthropocentric concepts.
- The complete spatio-temporal distribution of events assumed as primitively given.
- From this perspective: cannot ask how events “come about” such that quantum correlations arise.
- They’re just there!

Becoming

- When we ask how nature manages to evolve things such that EPR-correlations arise, our perspective is already (partly) anthropocentric.
- Then let's be consistent!
- ... and adopt an anthropocentric approach to quantum probabilities as well...
- ... which is what the Principal Principle helps us do...
- ... without denying that quantum probabilities are objective!
- Result: The best possible rational credences for spatiotemporally situated agents in quantum theory depend only—at most!—on what occurs in their backward light cone (or possibly future light cone).

More generally: The "quantum threat" to special relativity is a consequence of a partial and inconsistent anthropocentricism!

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Summary

- There is widespread belief a tension between quantum theory and special relativity due to the violation of local causality in the first.
- That Bell's criterion $P(A|E) = P(A|E, B)$ is apparently violated in quantum theory...
- ... does not not mean that local causality, properly construed, is violated.
- The Principal Principle delivers good reasons for thinking that it isn't.
- *No-signalling* principles seem more closely related to local causality.
- There is neither a problem if we adopt the least anthropocentric perspective (block universe) nor if we take into account the anthropocentric aspects consistently.