Title: Quantum Non-Booleanity, Simultaneity and the Despatialization of Time

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Abstract: Lee Smolin has argued that one of the barriers to understanding time in a quantum world is our tendency to spatialize time. The question is whether there is anything in physics that could lead us to mathematically characterize time so that it is not just another funny spatial dimension. I will explore the possibility(already considered by Smolin and others) that time may be distinguished from space by what I will call a measure of Booleanity. The Bell-Kochen-Specker Theorem shows that the statistics of quantum systems (unlike that of classical systems) do not in general permit of a Boolean substructure. I will outline reasons for thinking that time is the dimension in which the Booleanity of spacetime (considered as a quantum system) varies, while space is characterized by constant Booleanity. I will not be able to give a mathematically complete characterization of the Booleanity of a region of spacetime, since that would require nothing less than knowing how to quantize spacetime; however, I will argue that something like this is needed if one is to make any sense of an ontological distinction between past, present, and future in terms of modern physics. I will also briefly consider possible objections to this view arising from the relativity of simultaneity, which (on its usual interpretation) apparently places all events on an equal ontological footing. In order to get around this we need a generalized conception of simultaneity that treats Einstein's notion of simultaneity as a special case, and which allows for equivalence classes of spacelike separate events distinguished by covariant quantities such as action, phase, and (as I will argue) any reasonable measure of Booleanity.

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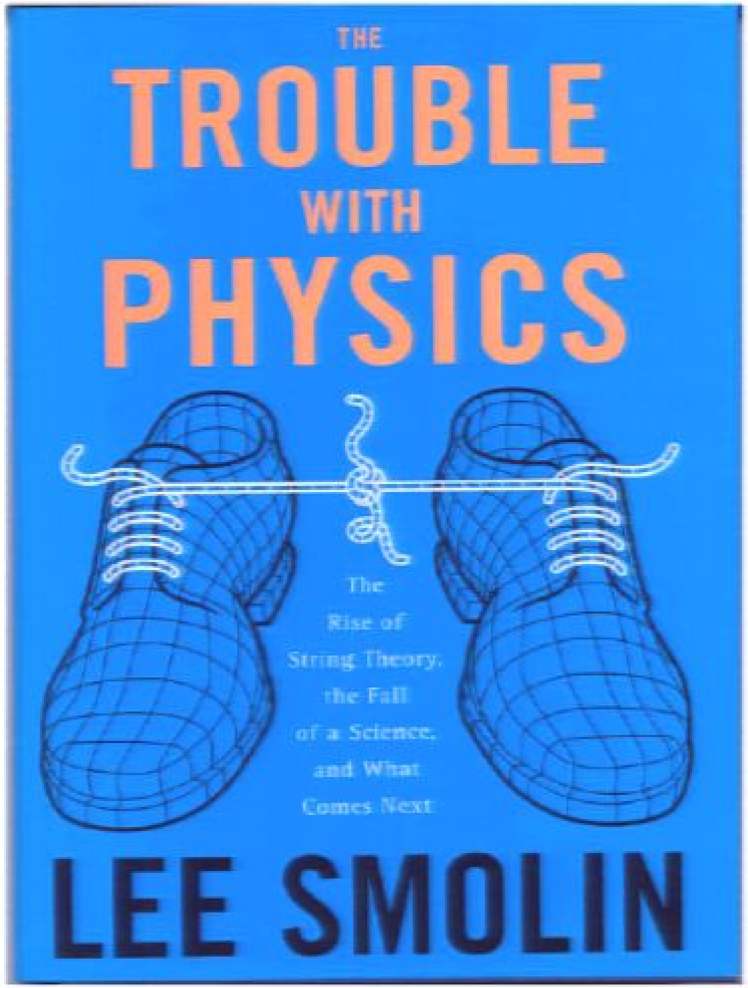
Is There Trouble With Physics?



- "Why, despite so much effort by thousands of the most talented and well-trained scientists, has fundamental physics made so little definitive progress in the last twenty-five years?"
- One would have to go back to the time of Lavoisier to find a twenty-five year period in which there have been fewer advances in *fundamental* understanding.

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  - Carlo Rovelli, Bill Unruh, and others have made similar remarks.
- Perhaps we need to "despatialize" time.
  - I'll explore what this could mean.

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- My hope today is to make some interesting mistakes!

Staticist Views About Time

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- Gödel (in Rucker): Our persistent belief in the reality of change is due to a failure to *understand* spacetime structure.
- Barbour: "stillness reigns".

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    - Accepting reality of motion could force us to accept limitations on rational describability, similar to those following from work of Heisenberg & Gödel.
    - Maybe the best we can do in order to defend the reality of change is to show that the notion that it's " all there" is in conflict with (quantum) physics.

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  - This is mostly what I will argue for today.
- Quantum indeterminacy is in part a reflection of an inherent dynamism in the physical world; and thus—
- In contrast to Barbour, I believe that "movement reigns."

But Does Quantum Indeterminacy Imply Openness?

- Many authors take it as obvious that in a quantum universe particle trajectories are not exact. E.g., Paul Teller:

> *. . . on a prequantum conception, a particle always has an exact spacetime trajectory. As I am sure all readers know, conventional quantum mechanics already gives up on exact trajectories. The uncertainty relations for position and momentum require these never to receive simultaneous exact values in quantum descriptions of particles. . . (Teller 1995, p. 10)*

Wheeler: "No meaning for spacetime. . ."

- Misner, Wheeler, and Thorne reject not only the concept of spacetime trajectory, but classical spacetime itself:

> *The uncertainty principle. . . deprives one of any way whatsoever to predict. . . "the deterministic classical history of space evolving in time."* **No prediction of spacetime, therefore no meaning for spacetime**, *is the verdict of the quantum principle. That object which is central to all of classical general relativity, the four-dimensional spacetime geometry, simply does not exist, except in a classical approximation. (Misner, Thorne, & Wheeler, 1973, pp. 1182–1183).*

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- This was reinforced by great successes of quantum electrodynamics & field theory in the 1940s and 1950s.
- Standard Model uses classical Minkowskian background, and many physicists are reluctant to move away from it.
- Hence despite intuitions of Born, Wheeler, et al., the closed future/block universe picture still lives.

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- Only invariant structures (those that link the same sets of events regardless of their description in different frames of reference) can mark an objective or ontological distinction, such as that between past and future.
- Therefore, there is no way, in a relativistic universe, to mark an ontological distinction between past, present, and future; the past, present, and future are all equally real or equally unreal.

Requisites. . .

- A three-part argument is needed:
  1. We need a precise mathematical characterization of the notion of a closed future.
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- General idea is to see if one can construct a quantum “no-go” theorem against the closed future.

From EPR to Bell

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- Von Neumann (1930s) argues that "hidden variable" underpinnings of quantum statistics are mathematically impossible.
- Bohm (1952) proves him wrong, but Bohm's theory depends on nonlocal dynamics *via* the quantum potential.

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- Meanwhile, mathematical work by Gleason (1957), Kochen and Specker (1967), showed that predictions of QM are in general inconsistent with Boolean underpinning of quantum statistics.
- Bell's Theorem is special case of generalized Bell-KS Theorem for spacelike separate entangled particles (Bub, Mermin).

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  - Every possible experimental question we could ask about the thing already has an answer *before we ask it*.
  - The properties of the thing can be described by "urn" model (Pitowsky 1994).
    - Pitowsky showed that the Bell Inequalities were first discovered by George Boole in the 1850s, and were called by Boole "conditions of possible experience."
    - The Boole-Bell Inequalities are simply consistency conditions *given that* one examines a system *without altering its properties*.

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- Anticipated (though not proven formally) by Schrödinger (1935):

> *. . . if I wish to ascribe to the model [of a quantum mechanical oscillator] at each moment a definite (merely not known exactly to me) state, or (which is the same) to* **all** *determining parts definite (merely not known exactly to me) numerical values, then there is no supposition as to these numerical values* **to be imagined** *that would not conflict with some portion of quantum theoretical assertions.*

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  - There will be a lump!
  - You can move it around and even hide it under furniture, but you can't make it go away.
- It is not entirely accurate to call the "no-go" theorems "no hidden variable" theorems; more accurately, they are *no Boolean variable* theories.
  - Even more precisely, *not enough Boolean variable theorems*, since non-Boolean quantum systems can have Boolean subspaces defined by CSCO.

Bell-KS Theorem in Summary:

- QM in general disagrees with presumption that all experimentally answerable questions have yes/no answers before we ask them.
  - "Before" does not mean with respect to a time coordinate, but with respect to the invariant sequence of preparation and measurement operations taken on the system.

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- "For Whom Bell's Theorem Tolls" is therefore a double pun.
- No-go theorems are negative results; they show what cannot be the case, but they do not directly show us what must be the case.

Why Non-Booleanity?

- Non-Booleanity is formally a consequence of the fact that quantum mechanical observables come in non-commuting conjugate pairs (Bub):
  - $[\hat{A}. \hat{B}] = i\hbar\hat{C}$.

Phase Quantization and Quantum Gravity

- The notion that all rotations are finite is consistent with DSR and quantum gravitational theories in which spacetime is discrete.
- But which comes first?
  - Are rotations finite because spacetime is discrete?

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- Well-verified set-ups like this show that the *past* is to some degree non-Boolean!

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- No; we could not deflect a bullet and save a certain president because we know we did not.
- The only events we can change in the past are among those we do not know about now!
- Analogous to double-slit experiment in which knowing which slit the particle goes through wipes out interference (and thereby wipes out non-Boolean effect).

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  - One would almost certainly find that the correlations would violate the assumption that the emitters of the advanced potentials in the future had a Boolean property structure.
  - This ought to be doable!
    - In fact, J. D. Franson (early 1990s) may have already done this, but I am not sure if his work has been interpreted this way.

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- To compute degree of uncertainty of region of spacetime (its ontological "gappiness") would require a theory of quantum gravity that tells us how to count the *states of space*.
- Reasonable guess is that the future has a much greater measure of uncertainty (non-Booleanity) than the past.
- Proposal: *time is the direction in which the measure of non-Booleanity varies.*

What About the Standard Argument?

- The notion of ontological distinctions between regions of spacetime seems to violate the relativity of simultaneity.

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- Proper quantities such as action, phase, can form natural basis for invariant simultaneity relations which give us tools to discuss ontological distinctions between regions of spacetime.

Does This Despatialize Time?

- I'm not sure, but it certainly makes time a lot *less* like a spatial coordinate, in the following sense:
- *Space* is characterized by joint or co-existence, or perhaps "concurrence."
  - Concurrence is definable not in terms of time coordinate, but in terms of dynamical properties of matter.

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- Space is constructed out of states that are compossible.
- Time is defined as an ordering of states that *cannot* coexist or be compossible.
- In some cases it may be possible to define a time or time-like parameter that labels the succession of possible spaces, but this is *not* absolute time!

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- The classical picture is one of maximal compossibility: roughly, what is not compulsory is forbidden.
- On the quantum view there is less restriction on what is possible in general but not everything that is possible is compossible.
- That makes for a more interesting universe, in my view!

What About the Standard Argument?

- The notion of ontological distinctions between regions of spacetime seems to violate the relativity of simultaneity.
- We need a more general conception of simultaneity, conceived of as equivalence relation on events.
- *Simul* (Latin) has two meanings:
  - At the same time.
  - In joint process.
- Only in a universe with absolute time does it makes sense to equate these two conceptions.
- The fact that we still insist that physical changes (such as state reduction) have to be linked to the *time coordinate* just shows how hard it is to get away from the Newtonian picture.