A reinterpretation of Quantum Causality.

Johan Noldus*

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Abstract

In a recent series of papers [1, 2, 3] of this author, we generalized quantum field theory to any curved spacetime. More in particular, in [1] we derived the spin statistics theorem without appealing to anything isomorphic to the vanishing of the field (anti-)commutatation relations at spacelike distances. The correct propagators were derived by means of other principles and no reference towards an operational approach has ever been made; this casts into doubt the operational principle of quantum causality since up till now it is widely believed to constitute a necessity rather than just an axiom added to the theory.

1 Introduction.

The most prominent role for the principle of quantum causality became appearant in the celebrated spin statistics theorem by Pauli; surely the spin statistics relation is necessary to build ordinary matter so therefore, the very assumption behind it gets a large weight also. This assumption is that at spacelike separated distances all physical field operators should commute or anti-commute and moreover, one adds that all physical observables should be constructed out of local field operators. This very formulation already depends upon the a priori knowledge of two types of statistics only, Bose and Fermi, something which is usually derived by other means. In a first paper on the topic [1] by this author, we did not need other arguments about statistics to begin with; we simply derived from first principles the two point functions of the theory for spin-0, $\frac{1}{2}, 1$ particles and observed that they all had the correct symmetry properties, in either that those for spin $0, 1$ corresponded to a bosonic statistics and for spin $\frac{1}{2}$ to fermionic statistics. The reader is invited to carefully go through this paper to convince himself that this is true indeed; since our approach was non-operational, we did not need to worry about (anti-)commutation properties of observables which are spatially separated. This is a *necessary* thing since we had the compelling interpretation of the two point function, and in particular the Feynman propagator, as something which could eventually be directly measured. Denote for the sequel by $|x\rangle = \phi(x)|0\rangle$ where $\phi(x)$ is the distributional field operator and $|0\rangle$ the vacuum state, then we have that

$$\langle y|x\rangle = W(x, y)$$

*email: johan.noldus@gmail.com, Relativity group, departement of mathematical analysis, University of Gent, Belgium.

where $W(x, y)$ is the two point function of the theory. This suggests one to define generalized "projection" operators

$$P_x = |x\rangle\langle x|$$

which can get a more precise meaning by working with smeared states

$$|\Psi_x\rangle = \int d^4y \sqrt{-g(y)}\Psi_x(y)|x\rangle$$

instead. Then, one notices that

$$P_x P_y = |x\rangle\langle y|W(x, y)$$

and therefore $P_x P_y \neq P_y P_x$ even if $W(x, y) = W(y, x)$ for spacelike separated points x, y. Hence, the observables P_x in the standard dogma are unphysical and the modulus squared of the propagator $|W(x, y)|^2$ cannot be thought of as a probability arising from performing two measurements on an identical particle. This is a bad situation as the very issue of general covariance requires that one must be able to perform position measurements and that the latter are of primary importance for the interpretation of the theory. Nevertheless, from the point of view of spatial commutativity, they are forbidden and therefore one proclaims it is impossible to observe the propagation of a single particle in the theory! This position is, as the reader may understand, not a comfortable one as in the Newtonian limit, the propagation of a single particle is the most important quantity to be measured and one can doubt if any other quantitity is ever observed in nature. On the other hand, one has several problems with the promotion of the field operator as the standard observable quantitity as this author has stressed in the past. We will come back to both these issues and other viewpoints in the next section.

2 What Causality principle should really hold in general spacetime theories?

In this section, we shall motivate from different angles that there is no good motivation for the quantum causality constraint, not even in the operational formalism of quantum mechanics. By the quantum causality condition, we mean the strong one that *all* spatially separated observables should commute and not just the field operators. Let us start by summing up some general remarks which should give a good indication what is true or not true about it. First of all, relativity does not require at all that processes travel in the forward lightcone; while this may automatically be the case for fields satisfying second order hyperbolic differential equations there is no general rule in nature that this must be so as a matter of principle. For example, spacelike geodesics are curves which travel outside the lightcone and may be thought of as channels for transmitting information about particles; also, I do not know about a general rule that in an arbitrary force field, a classical particle with momentum in the lightcone should remain so. In other words, it appears to me that a suitable dynamics can exist such that particles acquire superluminal momenta. Now, suppose you have a theory with superluminal information propagation about particles at the very core, how perverse is it then to say that our measurement apparati should not make use out of it? That all observables allowed by nature should be oblivious to this glaring fact? For example, that it would not be possible to send Mozart's magic flute faster than light given that information about particles can travel faster than light too? Perverse indeed, but mandatory as most quantum field theorists would claim since it is needed for the spin statistics theorem. But is it really so, even from an operational point of view? Here, I remember the wisdom of Weinberg [4] who does not really enter into the discussion and prefers to say that *fields* need to satisfy these (anti-)commutation relations due to Lorentz invariance of the scattering matrix given the way the Hamiltonian is build out of them. This by itself is sufficient to arrive at the spin statistics relation, he does not mention in any way that all acceptable *observables* should be polynomially build from those fundamental fields and therefore satisfy the commutation relations too if every monomial comes with an even number of Fermi fields. Indeed, it should be possible to build "'local" operators like P_x too and endow them with a suitable meaning which allows for a pieceful coexistence of the spin statistics relation with spacetime event operators measuring the probability to be measured at a point and to propagate from one to another. Given that this author has rederived the spin statistics relation in an entirely different language, than the operational framework of standard quantum theory, in which the propagator is a very real entity, this only confirms my view on Weinberg's prudence when it comes down to this issue. I would encourage his collegues to take on the same attitude as the existence of this small note is the result of some Blog discussions and writings at various websites on precisely this issue. The best argument is a rather flegmatic one which shows one should never reject a very possibility based upon an extrapolation of some prejudice a theorem *appears* to call for.

This is as far as the positive arguments for our position go, there are also negative ones, meaning shortcomings in the standard strong negation of superluminal information transfer. The most critical one is that the smeared field operators are not diagonal in the particle basis as they are linear superpositions of particle creation and annihilation operators. This means that there is no local observable in the theory with an approximate definite particle number which is a pretty bad thing given that only integer numbers of particle clicks are ever measured. Also, more philosophically, making such observables well defined requires the use of a non-physical smearing function, something which should not happen in a background independent approach towards physics.

3 Further discussion and conclusions.

Does all of this mean that we will have superluminal earphones and spaceships arriving on earth as some must most likely think? Not at all, as is well known, the amplitudes $W(x,y)$ become very small rapidly as the spacelike geodesic distance between them increases so that "tunneling" through the lightcone remains an activity of very limited probability which is as good as zero for macroscopic objects. Likewise, one has at this level that $P_xP_y \sim P_yP_x \sim 0$ if x and y are sufficiently spacelike separated so that position measurements do not deviate much from conventional wisdom. So, the reader must be ultimately left with the question “what is quantum causality?”. For me, it means that information processes do not directly travel into the relativistic past and there might exist nontrivial correlations between outcomes of spacelike separated measurements. It is a slight weakening of the standard approach which assumes information to be travelling inside the future lightcone but alas, there is no good reason for this. For others, who still want to insist upon the symmetry properties of the Wightman function, it must mean the *same* as the spin-statistics relation: that is, the amplitude for a particle to propagate from x to y equals plusminus the amplitude for its anti-particle to travel from y to x if x, y are spacelike separated. But it for sure doesn't mean anything operational something Feynman himself would have detested.

References

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