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Reply to Fleming: Symmetries, observables, and the occurrence of events

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ABSTRACT

In this article I reply to Fleming's response to my 'Time and quantum theory: a history and a prospectus.' I take issue with two of his claims: (i) that quantum theory concerns the (potential) properties of eternally persisting objects; (ii) that there is an underdetermination problem for Positive Operator Valued Measures (POVMs). I advocate an event-first view which regards the probabilities supplied by quantum theory as probabilities for the occurrence of physical events rather than the possession of properties by persisting objects.

First I want to thank Prof. Fleming for his detailed, thoughtful, and thought-provoking remarks, and particularly for his generous advice on how to improve successive versions of the conference paper presented here in its final form. While our continuing correspondence has led to something of a convergence of views, there are several differences of opinion that resist this reconciliation. In this reply I will present my side of two of these remaining disputes, which are particularly relevant for understanding how accepting my account of event time observables (sketched in the final section of the paper) leads to a distinctive view of quantum theory. The core of what is distinctive about my view is that it restores a certain symmetry between time and space with respect to what is observable according to the theory. The empirical motivation for this view is that often the outcomes of an experiment may be located in *time* as well as in space. The theoretical consequence of this view is that time covariant POVMs must be provided which have this specific empirical interpretation.

1. On what is located where, and whence

I think that both Prof. Fleming and I agree that 'standard QM' (i.e., the Dirac–von Neumann formalism) is ill-equipped to supply observables that apply not to an instant of time but an interval of time. However, whereas I view that as a problem to be overcome through (conservative) modification of the formalism, Prof. Fleming appears to view this feature as somehow constitutive of quantum theory, writing

> QM is a theory of *temporally persistent dynamical systems*, indeed of *eternal* systems which live in a fixed classical space-time. …The basic observables of standard QM …are designed to answer questions about …possible properties of persistent physical systems *at specified times* (or, relativistically, on specified space-like hypersurfaces). (His emphasis.)

On the other hand, I take the view that the time-dependent observables of QM (and in particular position observables) should be thought to concern the properties of events in whose production the system is involved, not the properties of the system itself.

In order to draw out this contrast, let us consider the instantaneous measurement of position of a system in state ψ at a particular time t, corresponding to the Heisenberg picture projection $P_\Delta(t) = U_t P_\Delta U_t$. For Prof. Fleming, the (pure) state ψ describes the (possible) properties of an eternally persisting object, whose values are realized on measurement (according to the conventional interpretation) or (according to the dynamical collapse interpretation he favors) given (nearly) determinate values by a

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distinct stochastic localization process.[1] Regardless, what is being localized (and what is correspondingly measured by $P_\Delta(t)$) is a property of the system as a whole, namely its location. According to his view, if we have a situation in which $\langle\psi|P_\Delta(t)\psi\rangle = 1$, then this reveals the quantum system described by ψ to be *entirely located* within the spatial region Δ at time t.[2] This view leads to certain difficulties regarding relativistic localization, to which much of Prof. Fleming's work has been addressed.

In contrast, my view is that ultimately $P_\Delta(t)$ is to be understood in terms of the location of a detection event within a suitable experimental apparatus. (Think here of a diffraction experiment with a luminescent screen or a Wilson cloud chamber.) Thus $\langle\psi|P_\Delta(t)\psi\rangle = 1$ is to be interpreted as saying, with certainty, that such an event did occur located within Δ at time t. On this view, $P_\Delta(t)$ does not concern the location of the system entire, conceived as a persisting material object, but rather the experimentally determinable, spatio-temporally located events that occur in interaction of the system in question with other physical systems, namely (in this case) the experimental apparatus.[3] We can call this view the *event-first* view of quantum theory, in which the quantum state concerns the probabilities for the occurrence of events, in contrast to the *system-first* view that Prof. Fleming adopts, in which the quantum state concerns the (potential) properties of a persisting object.

In this connection, let me quote Dirac's remarks to the 1927 Solvay conference regarding the interpretation of quantum theory, in which he famously claimed that 'Nature makes a choice.' (It is important to note that Dirac is here speaking before the establishment of "standard QM," i.e., in advance of Hilbert space methods having become commonplace.)

> It is essential that the result of an experiment shall be a permanent record. The numbers that describe such a result must help to not only describe the state of the world at the instant the experiment is ended, but also help to describe the state of the world at any subsequent time. These numbers describe what is common to all the events in a certain chain of causally connected events, extending indefinitely into the future. Take as an example a Wilson cloud expansion experiment. The causal chain here consists of the formation of drops of water round ions, the scattering of light by these drops of water, and the action of this light on a photographic plate, where it leaves a permanent record. The numbers that form the result of the experiment describe all of the events in this chain equally well and help to describe the state of the world at any time after the chain began. (Bacciagaluppi & Valentini, 2009, p. 447)

What do these 'numbers' (i.e., c-numbers) concern? I contend that they concern (at least) the spatio-temporal location of the ionization event (brought about by the quantum system in question) that sets in motion the chain of events leading to a permanent record of this outcome.[4] On the events-first view, the quantum state is to provide predictions of where these events are located in space *and in time*.

Now, if the outcomes of this experiment are to be predicted by observables of the theory, then these observables had better assign probabilities to the spatio-temporal location of these events. As I discussed in the paper, it is hard to see how standard QM could do this if $P_\Delta(t)$ is interpreted as supplying probabilities for the results of a measurement at time t. But Prof. Fleming suggests an alternative view of quantum theory, which differs from the usual Schrödinger dynamics by the addition of an additional dynamical process of stochastic state reduction. On this view, presumably, the appearance of particle (or quanton) tracks in a cloud chamber (which, note, are not continuous trajectories but a discontinuous series of sites of condensation) is due to the repeated localization of the *system* (e.g., an alpha particle) and its subsequent interaction with the water molecules; or, perhaps, the spontaneous localization of *both* water molecules and alpha particle brought about by the stochastic localization process. Prof. Fleming notes that these spontaneous localizations are, like measurement in standard QM, to be thought of as occurring instantaneously and at definite times. This leads to the view that

> …there would be no question of measuring *when* the primordial reductions occur and trying to measure *just when* a measurement exploited reduction occurs (within the exploiting measurement) would be an instance of measuring a case specific time observable.

However, on the event-first view, the theory *already* provides probabilities for events to occur at particular times in particular locations (at least, when supplied with appropriate observables), and so there is no need to introduce an additional mechanism to bring about their occurrence. On the event-first view, the spatio-temporal properties measured in an experiment are not the properties *of* the system since it is the events that come to be spatio-temporally located not 'the system.'

Admittedly, the interpretation of event time POVMs in terms of conditional probabilities for an event to occur at a particular time (given that the event occur at *some* time) is not inconsistent with the idea that the event in question is a "primordial reduction." However, the probabilities supplied by a dynamical collapse model would not (in general) meet the required condition.[5] And since these probabilities may be determined from the Schrödinger equation (or the extended Schrödinger equation) without introducing an additional stochastic process, there is simply no technical, nor interpretative, need for such a process. That is, we need not imagine that in, e.g., a cloud chamber ionization two separate events occur: first the state reduction and *then* the ionization. The event-first view maintains that in reality there is a single thing that occurs at some time in a particular spatial location: the ionization event (which is followed by certain other events which together comprise the collection of molecules observed by the human eye).

I conclude this section by addressing Prof. Fleming's skepticism regarding the experimental realization of the time of arrival operator that we both consider. He complains that the statistics of such an operator concern arrival at a point (or plane) and require an experiment to run for all (eternal) time. An exactly analogous objection could equally be mounted to the instantaneous measurement of the position observable: the statistics it supplies concern an experiment that takes place over all of (infinite) space, and which runs for a mere instant. Regarded as a description of an experiment that takes place in a (spatially bounded) lab over some extended period of time, we

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[1] For some potential difficulties of thinking about quantum systems as persisting objects, see my 'Do Quantum Objects Have Temporal Parts?,' Pashby (2013).

[2] Note that this is precisely the interpretation adopted by Wightman (1962).

[3] To head off potential confusion, I do not mean to say that quantum theory concerns *only* such events, or that the events in question need to be *observable* (in the sense of van Fraassen, i.e., by human senses alone).

[4] While I do think that Dirac's words here present an effective characterization of the view I am advocating, his language of 'causal connections' should not be read as an invocation of any philosophically loaded notion of causation. Given Dirac's self-described contempt for philosophy, and generally instrumentalist bent, it is anyway unlikely that he had such ideas in mind.

[5] It may be objected that it is only under special circumstances that such probabilities apply, but note that experimental arrangements are often chosen so as to expressly provide these circumstances.