On the Individuation of Physical Systems in Quantum Theory

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Abstract

What theoretical structures characterise our notions of what it means for a whole physical system to be the sum of its parts? We explore various aspects of this question, with emphasise on quantum theory, from the following perspective: A physical theory constitutes the definition of a set of propositions with logical relationships between them such that probabilities can be used to judge the merits of the theory, given empirical evidence. The logical relationships between the propositions characterise our semantic notions such as individuation. We distinguish between the ontological and epistemological notions of individuation.

We introduce the notion of ontological individuation within the context of ontological models. A subsystem is defined as a proposition that provides *necessary* and *sufficient* information for making useful predictions. This definition to some extent generalises the notions of separability and local causality to define systems that may not be local. It highlights the unified motivations for many assumptions in the literature, such as measurement independence, and points to hidden assumptions of causality and mutual exclusivity that occur when defining systems.

An epistemic no-signalling criterion gives rise to a tensor product structure for epistemic systems in quantum theory. We utilise a symmetry emergent from this structure to derive a bound on the observability of a large class of operations, dependent on only the purity of the quantum state. In particular, we derive an upper bound on the trace distance between an untransformed state and the state transformed by any trace preserving, unital operation.

Our notions of epistemic systems also relate to distinguishability. It is shown that for measurements of any two (finite outcome) particle quantum numbers on multi-fermion states, the total uncertainty, minimised over all states, is zero. This is because despite indistinguishability characterised as a constraint on the observable algebra, the appropriate correspondence between states of distinguishable and indistinguishable particles is one where the Hilbert space of indistinguishable particles relates to particles with an extra quantum number such that *effective* distinguishability can emerge. This Hilbert space is larger than the one for distinguishable particles and hence can (does) contain states for which the uncertainty relations for distinguishable particles are no longer valid.

We conclude by arguing that in general, epistemic systems are not necessarily distinguishable; They may be only effectively distinguishable. This would imply a theory of indistinguishable modes. Several motivations are presented and the form of the theory suggested. It is hypothesised that such a theory may provide a relativistic quantum theory, alternative to quantum field theory, that satisfies cluster decomposition.

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Limits on the observable dynamics of mixed states

Cael L. Hasse

Physical Review A, 85, 062124, 2012.

Uncertainty relations and indistinguishable particles

Cael L. Hasse

Physical Review A, 86, 062101, 2012.

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“I see on the one side the totality of sense-experiences, and, on the other, the totality of the concepts and propositions which are laid down in books. The relations between the concepts and propositions among themselves and each other are of a logical nature, and the business of logical thinking is strictly limited to the achievement of the connection between concepts and propositions among each other according to firmly laid down rules, which are the concern of logic. The concepts and propositions get ‘meaning’, viz., ‘content’, only through their connection with sense experiences. The connection of the latter with the former is purely intuitive, not itself of a logical nature.”

Albert Einstein

‘Albert Einstein: Philosopher-Scientist’, 1949.