Why the Quantum?

This is an Editorial on "Classification of all alternatives to the Born rule in terms of informational properties" by Thomas D. Galley and Lluis Masanes, published in Quantum 1, 15 (2017).

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One of the burning questions within quantum foundations is "Why the Quantum?" — what makes quantum theory special, singling it out from the space of possible theories?

The celebrated Gleason's theorem is one of the earliest in a class of results that select some parts of the quantum formalism and aim to derive the rest from it. Gleason shows that if we assume the quantum representation of measurement outcomes as projectors on a Hilbert space, then any noncontextual assignment of probabilities has the same form as the quantum Born rule. Others, such as Deutsch and Zurek, have proposed derivations of the Born rule from the structure of the quantum state space and dynamics (plus some extra assumptions). One of the aims of this latter approach is to resolve the measurement problem within an Everettian "no-collapse" interpretation. Whether they achieve that aim, however, remains a matter of controversy.

The present paper likewise starts from the assumption that states and transformations have the same structure as in quantum theory, and asks what are all possible alternatives to represent measurements and probability rules compatible with those. Given this classification, what principles could single out the quantum Born rule?

The work is set within the framework of *generalised probabilistic theories* (GPTs). Based on work from Lucien Hardy, it provides a bare-bones description of physical theories through their operational implications, as tools to calculate probabilities for outcomes of measurements, given the state preparations and transformations allowed by the theory. Finding a resolution to "Why the Quantum" then reduces to finding "reasonable" physical principles that allow one to single out quantum theory from the space of GPTs.

Galley and Masanes draw heavily upon group representation to show that all the alternatives compatible with the structure of the quantum state space and dynamics are in correspondence to a certain class of representations of the unitary group. This provides a full classification of all theories with alternative measurement postulates to the standard quantum ones. Quantum theory is then picked out as the unique theory that satisfies two hypotheses: no-restriction on measurements and pure-state bit symmetry.

Informally, 'no-restriction' postulates that all possible measurements on a state space are allowed by the theory. Bit symmetry is the requirement that any pair of distinguishable states can be mapped into any other pair of distinguishable states via an allowed transformation. While no restriction has a less direct operational meaning, bit-symmetry has an information-theoretic interpretation, and is related to the possibility of reversible computation.

The present work represents a significant technical contribution to the field of generalised probabilistic theories, and opens several questions, including the effect of including measurement update rules, composition of systems, and the information-processing capabilities of the classes of alternative theories introduced here.

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