Spectrum Broadcast Structure In Different Quantum Reference Frames

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Abstract. Spectrum broadcast structure is a framework that describes objective quantum states via their correlations with their environment, whereby hypothetical observers can recover information about the system by measuring the environments. However, measurement should be done with respect to a frame of reference. We take the quantum reference frame formalism of [Giacomini *et. al.*, Nat Commun 10, 494 (2019)] and find that objectivity depends on non-degenerate relative separations, sharp localisation, and sufficiently large macro-fractions, and thus is typically subjective across different reference frames.

Keywords: quantum correlations, quantum reference frames, quantum Darwinism

The quantum-to-classical transition remains a long unsolved problem. Quantum Darwinism is one approach that describes the emergence of *objectivity* [1]: a system becomes objective when many independent observers can determine the system properties independently, without perturbing the system, and arriving at the same result [2, 3]. Mathematically, objective states can be described with one of three frameworks [3, 4, 5]. Here, we consider *spectrum broadcast structure* [3], due to its clear state structure.

Quantum Darwinism assumes that hypothetical observers can make measurements on the environment. Physically, this should be done relative to some reference frame. Thus, we ask whether objectivity and spectrum broadcast structure remain consistent across different *quantum* reference frames, in the formalism of Giacomini *et al.* [6]. In this formalism, entanglement and coherence are interchangeable frame-dependent properties, as are statistical mixedness and classical correlations.

We find that various factors that effect objectivity in different frames, including localisation of quantum states, non-degeneracy of the relative positions between the states, and coherence and statistical correlations within the environment states. We find that states typically do not remain objective, and even if they do, the objective information can change in different frames, influenced by the initial internal coherences and mixedness of the environment. Objectivity can also be improved by tracing out some environments in different frames and collecting multiple environments into "macrofractions".

In the discrete setting, there is only one state structure that has consistent objectivity and consistent objective information across all frames: $\sum_i p_i |\psi_{S|i}\rangle\langle\psi_{S|i}| \otimes_{j=1}^{N} |x_{E_j|i}\rangle\langle x_{E_j|i}|$, where S is the system, E_j are the environments, and $\{p_i\}_i$ is the objective information. Note that there are further orthogonality and non-degeneracy conditions on the conditional pure states (see Theorem 1 in our paper **[7]**).

As we change reference frames, new correlations can emerge between the system and environments. Hence, objectivity is generally subjective across different quantum reference frames, and is only consistently objective for a very particular class of states.

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