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Blind Spots of Randomized Benchmarking in the Presence of Temporal Correlations

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Randomized benchmarking (RB) is the most widely used characterisation technique for assessing gate quality via a single decay parameter, but standard protocols implicitly assume temporally uncorrelated (Markovian) noise. In realistic devices, environmental fluctuations induce correlations in time (non-Markovianity), motivating extensions of RB beyond the Markovian regime. Recently, some efforts have been made to formalise RB in non-Markovian scenarios. However, RB's behaviour across non-Markovian noise classes with differing environmental memory structures remains largely unexplored.

In this work, we study the randomised benchmarking protocol in the presence of a classical memory environment, where the memory can have its origin from interactions with nearby quantum systems. We show that the average sequence fidelity (ASF) curve is monotonically decreasing with sequence length for classical memory processes. Therefore, a deviation from monotonic behavior is a witness of a quantum memory environment. Moreover, we show that there are classes of processes for which, regardless of the amount of non-Markovianity, RB yields an identical average sequence fidelity, whereas the worst-case error—a relevant metric for fault-tolerant computation—correlates significantly with the amount of memory, resulting in RB characterisation missing important aspects of memory. In addition, we provide a class of interactions that results in an ASF identical to the Markovian case, making this class of non-Markovian processes inaccessible through randomised benchmarking.

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