Dynamical phase transitions in quantum reservoir computing

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Unconventional computing is an interdisciplinary branch of science that aims to uncover new computing and information processing mechanisms in physical, chemical, and biological systems [1]. When it comes to solving temporal tasks, reservoir computing is a machine learning example of such an approach where rich dynamical properties are exploited [2]. For big-data processing, an exceptional playground where rich dynamics can be exploited is certainly provided by quantum systems, whose exponentially large number of degrees of freedom pushes them toward computational limits that are not achievable by classical systems. This is the potential envisaged in quantum reservoir computing (QRC) [3]. Although all the previous works in the field provide examples of functioning quantum reservoir computers, a fundamental issue remains open: what conditions must a physical system fulfil to be a good quantum reservoir computer? The aim of our work is to establish the relation between the operation regime of complex computing systems and the performance of QRC [4]. For closed quantum systems, these operation regimes can be very diverse, like many-body localization or thermalization, which determine the mechanisms of spread and processing of information, as represented by the phase diagram of Fig. 1. We address the impact of these dynamical phases in QRC for networks of quantum spins, establishing that the thermal phase (regions II and IV in Fig. 1) is naturally adapted to the requirements of QRC and report an increased performance at the thermalization transition for the studied benchmark tasks. However localization (regions I and III in Fig. 1), and the presence of local conserved quantities, is detrimental for an optimal information processing performance due to a slow convergence. Uncovering the underlying physical mechanisms behind optimal information processing capabilities of spin networks is essential for future experimental implementations and provides a new perspective on dynamical phases.

References

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Figures

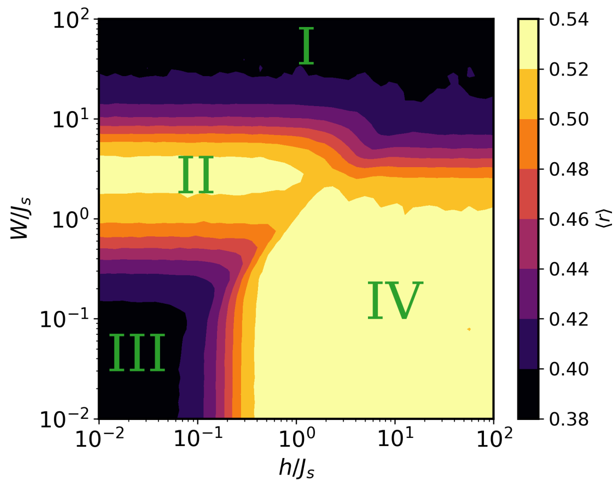

Figure 1: Phase diagram of dynamical regimes for the Transverse-field Ising model. Parameters h and W are the homogeneous magnetic field and the strength of the random heterogeneous magnetic field, respectively (in units of the interaction strength Js).