The Magic in Quantum Machine Learning

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The boundary between classically simulable and computationally superior quantum systems is fundamental to identifying true quantum advantage. In this talk, we will first discuss our recent work based on interacting non-Hermitian spin system defined on random graphs [1]. We show that the onset of the first exceptional point - marking the real-to-complex spectral transition - also corresponds to an abrupt change in the system's learning capacity. We further demonstrate that this transition is controllable via local disorder and spin interactions strength, thereby defining a tunable learnability threshold. Within the learning phase, the system exhibits the key features required for memory-dependent reservoir computing. We further examine a class of tunable N-qubit random circuit models with a combination of Clifford and nonstabilizing gates [2]. We establish a direct correspondence between the reservoir's performance on temporal processing tasks and its entanglement spectrum statistics and long-range nonstabilizer resource content. Our offer a general strategy for designing powerful and trainable quantum machine learning systems and clarify the physical resources underpinning quantum computational advantage.

This work was supported by the European Union and the European Innovation Council through the Horizon Europe project QRC-4-ESP (Grant Agreement No. 101129663), and EU Horizon Europe Quest project (No. 10116088), and the Academy of Finland through its QTF Center of Excellence program (Project No. 312298).

[1] Moein N. Ivaki, Austin J. Szuminsky, Achilleas Lazarides, Alexandre Zagoskin, Gerard McCaul, Tapio Ala-Nissila, arXiv:2506.07676.

[2] Moein N. Ivaki, Matias Karjula, Tapio Ala-Nissila, arXiv:2510.18623.