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Quantum Computational Physics

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Computational physics —the third pillar of physics exploration next to theory and experiment —has, for the past seven decades, evolved alongside tremendous progress in computing hardware. Today the field is on the verge of leaving behind classical computing resources, and pivoting towards quantum hardware, allowing for "quantum on quantum"simulations. In this talk will discuss the "assembler-level" of such quantum computing, asking what kind of quantum many-body phenomena one can induce in digital quantum circuits that employ not only the conventional set of unitary gates, but also mid-circuit measurements and active feedback. In essence, such quantum circuits allow for the dynamical creation, manipulation and decoding of collective entanglement structures.

As an example, I will discuss novel types of quantum criticality that can arise from shallow quantum circuits and which are generally described by (2+0)-dimensional non-unitary conformal field theories. Nishimori universality has emerged as a seemingly ubiquitous fixed point for such critical theories, which we discuss for mixed-state transitions arising from weak measurement or incoherent noise (or both). Putting Nishimori physics in competition to other critical theories, such as percolation, self-dual (Kramers-Wannier) quantum criticality or a novel tricritical theory at the intersection of phases with strong, weak or broken Z_2 symmetry, RG flows between these critical theories can be established and embedded in rich phase diagrams —some of which we have numerically explored on IBM's 127-qubit quantum processors.

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