Making quantum simulations of quantum field theories more affordable

This is a Perspective on "Quantum Algorithms for Simulating the Lattice Schwinger Model" by Alexander F. Shaw, Pavel Lougovski, Jesse R. Stryker, and Nathan Wiebe, published in Quantum 4, 306 (2020).

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The standard model of particle physics is among the most successful scientific achievements in human history. However, further progress is being hampered by the enormous computing power that is needed to explore beyond what is already known. The reason for this is the exponential explosion in the number of resources needed to simulate large quantum systems.

As Richard Feynman envisioned [1], quantum simulators could be a possible avenue to overcome this limitation. These devices are genuine quantum systems that can simulate other quantum systems in an efficient way. Typically, there are two kinds of quantum simulators being explored, namely, analog quantum simulations, and digital quantum simulations [2]. The former employ a quantum device with similar dynamics to the system being simulated, while the latter makes use of a digital decomposition onto elementary gates [3]. It is worth mentioning that a third avenue is currently under analysis, namely, digital-analog quantum simulations [4], which combine the scalability of the analog and the versatility and universality of the digital quantum simulators.

Quantum field theories and high energy physics have been explored in the past few years in the context of quantum simulations [5] , with several works in theory [6], proposals for implementations [7,8,9,10,11,12], and experimental implementations [13,14]. However, the resources needed for fully scalable quantum simulations of quantum field theories are still too large to be useful.

In this article [15], Alexander Shaw et al. carry out a thorough and rigorous analysis of digital quantum simulations of the Schwinger model, a (1+1)-dimension QED model that exhibits properties, such as confinement, which are typical from a non-Abelian gauge theory such as Quantum Chromodynamics (QCD). They obtain novel and tight bounds of low-order digital expansions such as Trotter decomposition. They discover that the digital quantum simulation of the Schwinger model can be carried out with more efficient resources than what was previously known, with respect to other methods such as, e.g., qubitization. They also analyze useful ways of extracting the measurement information from the quantum simulator, completing an interesting analysis of the full quantum simulation proposal.

This kind of works helps to establish the ultimate limits to digital quantum simulations with controllable quantum platforms, and serves as a benchmark with which to elucidate how far we are from achieving a useful quantum simulation of quantum field theories that provides new knowledge beyond the standard model of particle physics.

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