Reduce-and-chop: Shallow circuits for deeper problems

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The performance of state-of-the-art quantum computers is significantly restricted by number of qubits and coherence time, among others. While numerous techniques have been invented to make the most out of fewer-qubit devices [1, 2], analogous schemes for depth-limited computations are less explored.

This work investigates to what extent we can mimic the performance of a deeper quantum computation by using a shallower device repeatedly. We propose a method for this inspired by the Feynman quantum circuit simulation approach. The circuit is cut in halves. First half is executed and the most relevant outcomes are calculated. Then, the second half is run based on the outcomes. See Fig. 1 for a schematic description.

If the method is applied naively, it is inefficient due to the exponential number of possible outcomes. This is called the computational-basis (CB) rank. We propose to mitigate this using a shallow variational circuit, the reducer R , and whose purpose is to maintain the CB rank within pre-defined low limits. We identify the bottlenecks arising during the quest for R and provide a tailored optimisation method to find it.

We support the reduce-and-chop method with numerical experiments inspired in the Transverse-Field-Ising-Model (TFIM). Within this framework, we lowered the depth requirements of a quantum computer from 40 to 24 layers within controlled error levels. See Fig. 2.

Although the method as presented likely will not immediately lead to new uses of large currently available quantum computers due to practical bottlenecks, we believe it may stimulate new research towards exploiting the potential of shallow quantum computers.

References:

[1] S. C. Marshall et al. *High dimensional quantum machine learning with small quantum computers* (2022), 2203.13739.
[2] T. Peng et al, *Simulating large quantum circuits on a small quantum computer*, PRL 125, 150504 (2020)

Figures:

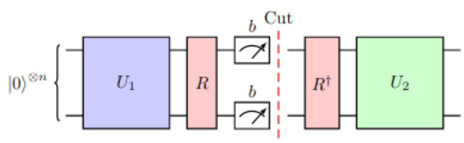

Figure 1: Schematic description of the reduce-and-chop algorithm

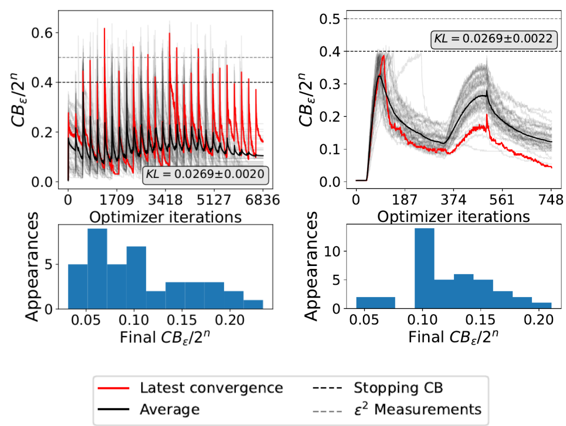

Figure 2: Two different optimization paths for the reduce-and-chop algorithm applied to a TFIM-inspired quantum circuit. This circuit has 40 layers, and is reduced to halves of 20 layers, plus a 4-layers reducer R.