Storage and retrieval of quantum operations – an experimental test

Robert Stárek[1]
N. Horová[1], M. Mičuda[1], J. Fiurášek[1], A. Bisio[2], M. Sedlák[3]

[1] *Department of Optics, Faculty of Science, Palacký University, 17. Listopadu 1192/12, 77900 Olomouc, Czechia*
[2] *Dipartimento di Fisica, Universit`a di Pavia, via Bassi 6, 27100 Pavia, Italy*
[3] *RCQI, Institute of Physics, Slovak Academy of Sciences, Dúbravská cesta 9, 84511 Bratislava, Slovakia*
starek@optics.upol.cz

The fundamental requirement for quantum information science is the ability to encode, transfer, process, decode, and store quantum information. An interesting application of quantum state storage is the storage of unknown unitary operations [1]. Here, we analyze and experimentally test a protocol in which we leverage partial prior knowledge about the to-be-stored unitary.

Fig. 1(a) depicts the situation. The stored unitary operation is unknown, but we know it can be either U_0 or U_1, both a priori known and equally probable. We imprint the operation into an auxiliary quantum state $|a\rangle$ and obtain state $|s\rangle$, which can be stored. To retrieve the operation, we let $|s\rangle$ couple with the target state $|\psi\rangle$ and perform quantum state discrimination on the auxiliary system. When the discrimination succeeds, the stored operation is perfectly retrieved and applied to the target state.

We analyze the probability of correct retrieval as a function of the closeness of two operations to be stored. Then, we show that the success probability can be increased by repeatedly applying the stored operation to the auxiliary system. We show that the quantum operation performing the protocol is a solution to the positive-semidefinite program. If we additionally allow imperfect retrieval, we go beyond this protocol and can trade the effective fidelity for success probability.

Finally, we present an experimental retrieval of an unknown phase-shifting operation, either $+\alpha$ or $-\alpha$ phase shift, using linear quantum optics [2]. The storage quality is assessed using quantum tomography of states and processes [3], and the results are compared to the reference case of the measure-and-prepare strategy.

References

[1] M. Sedlák, A. Bisio, M. Ziman, Phys. Rev. Lett. 122, 170502 (2019).
[2] E. Knill, R. Laflamme, G. Milburn, Nature 409, 46–52 (2001).
[3] Z. Hradil, J. Řeháček, J. Fiurášek, M. Ježek, 3 - Maximum-Likelihood Methods in Quantum Mechanics. In: *Quantum State Estimation*. Lecture Notes in Physics, vol 649.

Figures

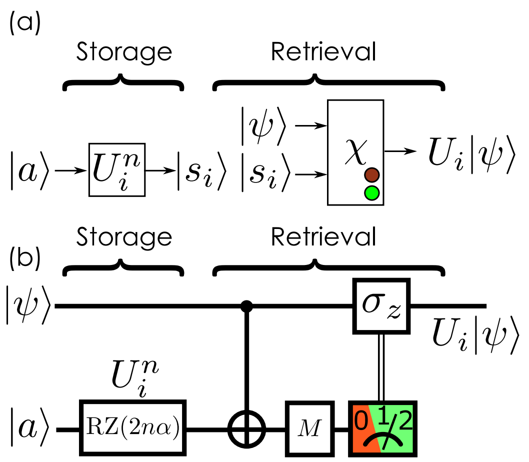

Figure 1: (a) One of two possible operations (U_0 or U_1) is imprinted into an auxiliary state. Then the operation is probabilistically retrieved and applied on a target state.
(b) Experimental implementation – stored operation is phase shift, retrieval is achieved with CNOT gate, POVM measurement performing quantum state discrimination, and feed-forward.