# Implementation of a controlled-swap gate using structured light

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**Abstract:** We implement a controlled-swap gate using structured light that carry orbital angular momentum (OAM). The control parameter is the polarization, while the information exchanged is encoded into spatial modes with a given OAM.

The controlled-swap gate is an essential element of the quantum fingerprinting protocol [1], that can determine the degree of overlap between two quantum states and thus evaluate whether they are equal or not. This gate is remarkably difficult to implement experimentally as originally devised, and only with the help of post-selection of appropriate outcomes has been recently implemented a probabilistic version of the protocol [2].

In this work we implement a quantum-inspired version of the controlled-swap circuit using light beams carrying orbital angular momentum (OAM). Our method makes use of the polarization of light as the control bit, which determines the swap operation between OAM beams with opposite m indexes. In our experiment, the information is encoded in the complex amplitudes $A_m$ and $B_m$ of Laguerre-Gauss beams $LG^m$ (index p is assumed to be zero) as

$$\sum_{m=1}^{N} \left( A_m LG^m + B_m LG^{-m} \right)$$

With a measure of polarization of the output beam the method measure the degree of similarity between sequences $A_m$ and $B_m$, demonstrating in this way that is able to compare streams of data without evaluating the data itself.

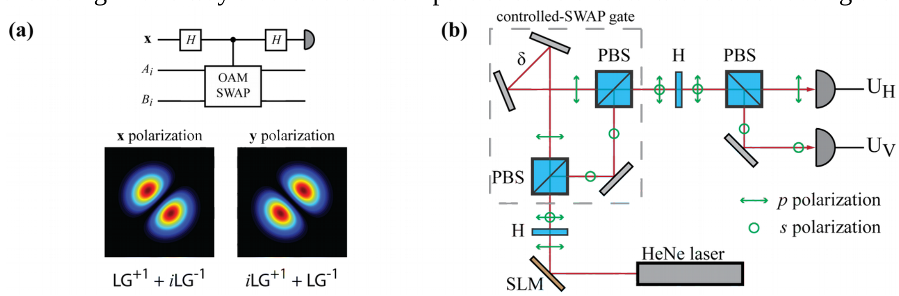


Figure 1. (a) Top: Controlled-swap gate with three inputs and three outputs. *x* and *y* designate orthogonal polarizations, and H is a Hadamard gate (half-wave plate). Bottom: output beam when the input beam is a superposition of two LG beams with OAM of m=1 and m=-1. Their OAM are swapped depending on the polarization. (b) Experimental setup: the structured beam is generated by a spatial light modulator SLM and it enters the controlled-swap gate. The Hadamard gates are implemented with half-wave plates oriented at 45° with respect to the horizontal polarization. The controlled-swap is built up with a polarizing beam splitter cube that splits the beam into their *x* and *y* components. The x polarized beam swaps its OAM at the output of a second *PBS* due to an uneven number of reflections. We measure the polarization of the outgoing beam after a second *H* and a third *PBS*.

The experiment implements the controlled-swap test with an unbalanced polarization-dependent Mach-Zehnder (MZ) interferometer. A superposition of Laguerre-Gauss beams enters the MZ interferometer, where information is encoded in the complex amplitude carried by each LG mode of the superposition. Beams traversing each arm of the interferometer, with orthogonal polarizations, experience a dissimilar number of reflections. The OAM of beams is reversed for an uneven number of reflections and remains the same for an even number of reflections. In order to realize a quantum-inspired quantum fingerprinting protocol, two Hadamard gates have to be implemented in the control bit. In our method, the control bit is the polarization of the light beam, and therefore, the Hadamard gates are easily translated to half-wave plates. Finally, the comparison between both messages (encoded in the complex amplitudes) may be done by projecting the output beam in two orthogonal polarization states. The measured power of each projection is proportional to the overlap between both messages.

[1] H. Buhrman et al, "Quantum Fingerprinting", *Phys. Rev. Lett.* **87**, 167902 (2001).
[2] R. B. Patel, *et al.*, "A quantum Fredkin gate" *Sci. Adv.* **2,** e1501531 (2016).