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Indefinite Causal Structures on an Integrated Silicon Platform for Applications in Quantum Computing

Results in Brief

Superposition of operation orders for more efficient quantum computing

Experimental demonstrations of quantum computation still have a long way to go. The InCaSQuC team is convinced that a promising avenue resides in the superposition of operations enabled by quantum mechanics. They have been devising a quantum switch to showcase the scalability of this approach.

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Ever heard of quantum switches? If not, suppose that you need to perform a computation involving two operators (A and B). Instead of choosing between order AB and BA, a quantum switch can go for both orders simultaneously by superposing them – making for a more efficient computation.

This is perhaps one of the most promising pathways for quantum computing. While quantum computation usually increases speed by placing quantum bits (qubits) by superimposing different states, quantum mechanics allows for going a step further by enabling the superimposition of both states and operations. In other words, tasks can be completed with fewer operations than with any other known quantum algorithm.

More complex than just A, B, C

But what if the computation involves three operators instead of two? Suddenly, things become more complex. “In the A, B, C situation, the options are much wider. Do we mix orders ABC and ACB, or maybe just CBA and ABC? There are 57 options in total,” says Nadia Belabas, coordinator of the InCaSQuC project on behalf of C2N – a joint laboratory of CNRS and the University of Paris Saclay.

Together with Marie Skłodowska-Curie fellow Lorenzo Procopio, Belabas has set out to achieve such scalability. They specifically investigated how integrated and fibred optics could enable the creation of a quantum switch for more than two operations.

“We are talking about a complex quantum circuit combining a source of quantum light with operators A, B and C. It should be able to implement and switch between the different possible routes by following the principles of quantum mechanics. Experimentally, this poses similar difficulties to implementing any circuit for quantum light: detrimental losses,” explains Procopio.

InCaSQuC’s first merit lies in the theoretical demonstration of these complex conditions, in which a quantum switch needs to handle more than two operations. In the context of quantum communication, for instance, the team could elaborate on a pioneering study from researcher Giulio Chiribella which had showed how putting two noisy channels in an indefinite order counterintuitively allowed for the transmission of information. “We have shown that this effect gets stronger when all six possible orders of three channels are superimposed, but also when a lower number of orders is used,” Procopio notes.

Inspired by, but not limited to, silicon photonics

To implement these ideas, the project team drew inspiration from recent progress in silicon photonics. “Silicon photonics is a mature technology for active and passive devices,” Belabas explains. “We are collaborating closely with teams at C2N and InPhyNi who have developed beyond-state-of-the-art filters and sources in the telecom regime. We are especially interested in the high dimension of the frequency space accessible with these sources.”

Although ultimately all functionalities can be achieved on chip and high quality samples are made available through foundries, the InCaSQuC approach stands out because it can also be achieved with off-the-shelf telecom components. As Procopio explains, “Silicon is indeed a very promising horizon, but we want to focus on the implementation of indefinite causal order regardless of the platform.”

With three months to go before its completion, InCaSQuC enters its most crucial phase. Whether an experimental demonstration will be achieved remains to be seen. As Belabas explains, a fully scalable implementation of the quantum switch in a multi-operation scenario is particularly challenging even in the absence of a pandemic crisis. “We need to control many experimental parameters and the cumulative losses of each element. If we can demonstrate the necessary key elements – such as frequency-encoded quantum operations on appropriately bright sources – it would be a decisive step towards a scalable, integrated and fibred version of the quantum switch,” she says.

Should such demonstrations take place, the superposition of operators will undoubtedly become a serious option in the future implementation of quantum computing.

Keywords

InCaSQuC | superposition | quantum computing | quantum mechanics | quantum switch | multi-operation

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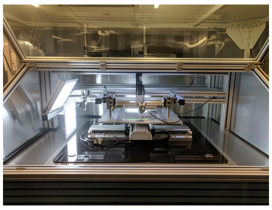

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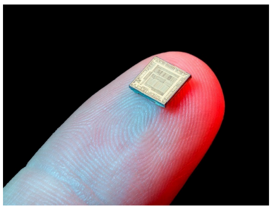

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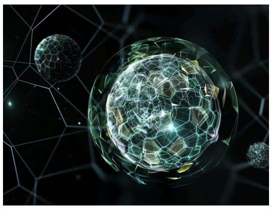

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