Superconducting Quantum Computing Beyond 100 Qubits

A new high-performance quantum processor boasts 105 superconducting qubits and rivals Google's acclaimed Willow processor.

By **Barry C. Sanders**

In the quest for useful quantum computers, processors based on superconducting qubits are especially promising. These devices are both programmable and capable of error correction. In December 2024, researchers at Google Quantum AI in California reported a 105-qubit superconducting processor known as Willow (see **Research News: Cracking the Challenge of Quantum Error Correction**) [1]. Now Jian-Wei Pan at the University of Science and Technology of China and colleagues have demonstrated their own 105-qubit processor, Zuchongzhi 3.0 (Fig. 1) [2]. The two processors have similar performances, indicating a neck-and-neck race between the two groups.

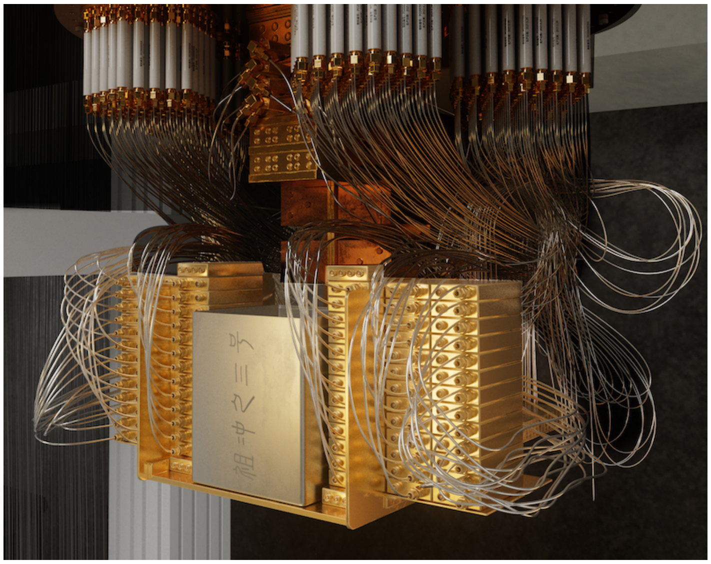

Figure 1: Photo of the cryostat holding the Zuchongzhi 3.0 processor.
Credit: USTC

Quantum advantage is the claim that a quantum computer can perform a specific task faster than the most powerful nonquantum, or classical, computer. A standard task for this purpose is called random circuit sampling, and it works as follows. The quantum computer applies a sequence of randomly ordered operations, known as a random circuit, to a set of qubits. This circuit transforms the qubits in a unique and complex way. The computer then measures the final states of the qubits. By repeating this process many times with different random circuits, the quantum computer records a probability distribution of final qubit states.

For the classical computer, the equivalent problem would be to simulate that distribution by computing the transformation of the qubits into their final states. However, this task is not actually performed because it is too difficult for such a computer. Instead, researchers infer the complexity of the classical simulation based on reasonable assumptions about the best-known simulation approach and its required resources, especially run-time—although such assumptions can be contentious [3].

In 2021, Pan and colleagues used random circuit sampling to claim quantum advantage in their original Zuchongzhi processor (see **Viewpoint: Quantum Leap for Quantum Primacy**) [4]. This device was named after the Chinese polymath who calculated pi with record-breaking precision in the fifth century. The original processor had 66 qubits and 110 qubit couplers, and the team performed random circuit sampling on a subset of 56 qubits with up to 20 logical cycles—a measure of the complexity of the qubit operations. The researchers concluded that their 56-qubit subset outperformed Google's 53-qubit superconducting processor, Sycamore,

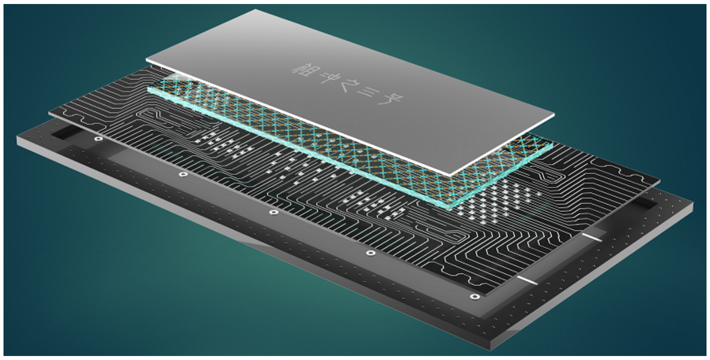

Figure 2: Illustration of the Zuchongzhi 3.0 quantum processor demonstrated by Jian-Wei Pan and colleagues [**2**].
Credit: D. Gao ***et al.*** [**2**]

reported in 2019 [**5**]. Subsequently, there has been a dramatic race between Pan's team and Google to build larger high-quality superconducting processors.

Google's 105-qubit Willow processor announced last December has garnered widespread admiration, not only for its quality and scale but also for its ability to host below-threshold surface-code memory—a type of memory that could be useful for fault-tolerant quantum computing [**1**]. And now Pan and colleagues present Zuchongzhi 3.0, which has 105 qubits, arranged in a 15 × 7 array, and 182 qubit couplers (Fig. **2**) [**2**]. The researchers tested their new device by running random circuit sampling on a subset of 83 qubits with 32 logical cycles. They determined that the most powerful classical computer would need several billion years of run-time to simulate the probability distribution generated by their quantum processor in only 100 seconds. This performance was several orders of magnitude better than that of Google's 67- and 70-qubit Sycamore processors [**6**], two precursors to Willow.

Both Zuchongzhi 3.0 and Willow have executed random circuit sampling, but comparing their performances is not straightforward because the tasks differed in complexity. According to a Google blog, benchmarking of Willow shows that today's fastest classical computers would need 10^{25} years to simulate the results produced by Willow in 5 minutes [**7**]. Nevertheless, the key properties of the two quantum processors can be compared, as exemplified by a table in the Quantum Computing Report released by GQI, a quantum intelligence firm [**8**]. This table lists averages of the following parameters: qubit connectivity, rates of spontaneous emission and dephasing (two qubit effects that can cause errors), fidelities for one- and two-qubit logic gates and for qubit readout, and time delays in those gates.

According to the table, Willow and Zuchongzhi 3.0 are tied for average qubit connectivity, and Willow has a slight edge on the other measures. But the race is not over. These results are simply a glimpse at where the two runners are at this time in the race, and their separation is small.

Pan and colleagues describe the challenges they overcame to achieve their high-performing quantum processor. The key advance was an increase in the coherence time—the duration over which the qubits' fragile quantum states persisted. The team made this improvement by reducing charge and flux noise through an optimization of parameters describing the device's capacitance and superconducting inductance. Additionally, the researchers reshaped qubit capacitor pads to limit energy loss, upgraded wiring to minimize noise produced by room-temperature electronics, and bonded together two substrates to increase qubit relaxation and dephasing times.

This race for large-scale superconducting computing is all the more intriguing because of complex geopolitics. Quantum computing is regarded as an emerging dual-use technology, meaning that its development and applications—which are still unrealized and largely unpredictable—could have both civilian and military uses. Given this context, international discussions have led to export restrictions on quantum computers and components that can process, with low errors, 34-qubits worth of information [**9**]. The experiments by Pan's team and Google show that, despite such measures, competitors separated by geopolitics are in a close race.

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