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News & Highlights

Quantum Computing Quickly Scores Second Claim of Supremacy

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Highlighting the accelerating pace of development in the field of quantum computing, in December 2020 a Chinese team reported that its all-photonic system, called Jiuzhang, performed in 200 s what they estimated would take 2.5 billion years for a classical supercomputer to complete [1]. And while the jury remains out on when and if quantum computing will live up to its potential promise, multiple companies are pushing hard on competing technologies to deliver a verdict.

"The Chinese team has executed an amazing achievement," said Philip Walther, professor of physics and leader of the quantum computation group at the University of Vienna in Austria.

Jiuzhang's feat is just the second demonstration of "quantum supremacy," in which a quantum system overwhelmingly outperforms even the world's most powerful classical computers on certain tasks. It comes a little more than a year after Google announced the first instance of supremacy in October 2019 with its 54-bit quantum computer Sycamore, which was built on a completely different architecture based on superconducting metal loops. Sycamore in three minutes tackled what Google claims would have taken 10 000 years on a classical supercomputer built by International Business Machines Corporation (IBM) [2]. Engineers at IBM downplayed the achievement, though, arguing that its supercomputer, armed with the optimal algorithm, could produce the same result in a matter of days [2].

Jiuzhang was built by a team led by professors of physics Jian-Wei Pan and Chao-Yang Lu at the University of Science and Technology of China (USTC) in Hefei City, Anhui Province, China. It is a boson sampling machine, a device first envisioned specifically as a means for demonstrating quantum supremacy in 2010 by engineers Scott Aaronson and Aleksandr Arkhipov at the Massachusetts Institute of Technology in Cambridge, MA, USA [3]. Jiuzhang works by sending photons—which are bosons (as opposed to fermions), the category of fundamental particles with integer values of intrinsic angular momentum (or spin)—into an extremely complex maze consisting of 300 beam splitters and 75 mirrors on a roughly 3 m^2 optical table (Fig. 1).

In what is known as quantum superposition, Jiuzhang's complex network of beam splitters channel each photon down two paths simultaneously. The paths also merge, the splitting and merging causing interference between photons according to quantum rules. Detectors capture the exit of each photon from the tabletop maze through one of its 100 output channels. Over the course of many runs, this process yields a distribution of the number of photons captured at each exit location, like the bell-curved,

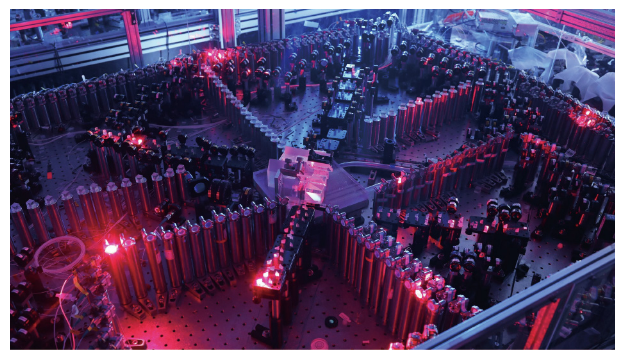

Fig. 1. A team of USTC engineers built this photonic device with 300 beam splitters and 75 mirrors on a roughly 3 m^2 optical table to perform in 200 s a measurement called boson sampling that they estimated would take 2.5 billion years for a conventional supercomputer to calculate. Credit: USTC (public domain).

normal distribution of marbles dropped into a Galton Board [4]. Jiuzhang can measure this distribution directly, but if performed with large numbers of photons and enough channels, the distribution becomes too complex for a classical computer to calculate. Rearranging the locations of the beam splitters and mirrors allows the researchers to "program" Jiuzhang to perform specific searching and sampling problems of interest.

In 2019, the USTC team demonstrated boson sampling with 14 detected photons [5], hard for a typical laptop to calculate but easy for a supercomputer. Their current device detected an average of 43 photons per run in 200 s, with one run detecting 76 photons. Per the team's estimates, China's Sunway TaihuLight supercomputer would require 2.5 billion years to calculate an equivalent distribution [1].

"They pushed the limit with that number of photons, really justifying the claim that no classic computer could do the computation and surpassing Google's Sycamore by many orders of magnitude," Walther said.

While many admire the engineering behind Jiuzhang, some researchers are less enthusiastic about the achievement. "The experiment required a lot of care and finesse, but I believe this is primarily about bragging rights," said Subhash Kak, professor of engineering at Oklahoma State University in Stillwater, OK, USA, and an expert in quantum mechanics and cryptography. "The path from here to a practical quantum computer is extremely difficult."

And, as with IBM's public rebuff of Sycamore, some researchers have expressed doubt about Jiuzhang's quantum supremacy claim.

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"Experimentally, it is a technological feat, but I am not convinced that it shows true quantum advantage," said Itay Hen, associate professor of physics and quantum computing researcher at the University of Southern California in Los Angeles, CA, USA. "I can almost guarantee that in the near future somebody will say, 'Look, with the amount of error you introduced and with your underlying assumptions, we can do the calculation classically in much less time.'"

As for the usefulness of Jiuzhang's boson-sampling computation, Walther admits it is fairly specialized and not easily translated to general use. "For photons, computing concepts based on interference are easy," he said. "If we go to textbook computations with many so-called two-qubit gate operations, that is harder for photons."

One firm working to develop a more practical, "universal" photonic quantum computer is Xanadu (Toronto, Canada). Xanadu's quantum computer is based on integrated silicon photonics that fit on a computer chip rather than a tabletop like Jiuzhang. Xanadu's latest chip, the 4 mm by 10 mm X8, is effectively an eight-qubit quantum computer [6]. Infrared laser pulses fired into the X8 chip are coupled to microscopic resonators to generate so-called "squeezed states" consisting of superpositions of multiple photons. The photons then flow out of the chip to superconducting detectors that count them to derive answers to quantum computations.

The company's engineers say its chip is fabricated with conventional semiconductor industry techniques and easily integrated into an existing fiberoptic-based telecommunications infrastructure. The technology could potentially link up quantum computers into an "unhackable" quantum internet, the possibility of which has already been demonstrated by Pan's USTC group [7]. Xanadu claims it will be able to scale up to one million qubits by 2026, though the vast majority of these qubits will be used for correcting the numerous errors that occur in quantum systems, rather than data processing [6].

In another photonic-based effort, the startup PsiQuantum in Palo Alto, CA, USA, has raised at least 215 million USD to build its own programmable photonic quantum computer [8]. The company believes it can build a million-qubit machine by 2025, thanks in large part to a manufacturing partnership with GlobalFoundries (Santa Clara, CA, USA), one of the world's leading semiconductor makers.

While quantum computations performed with superconducting loops and photonics have made headlines with supremacy claims, researchers using quantum computing architectures based on trapped ions and so-called neutral atoms are also making progress. Because the qubits in both of these system types are inherently identical, they maintain their coherence longer than superconducting or semiconductor qubits typically do, thereby improving the odds of successfully completing computations before the qubits decohere.

Startup firm IonQ (College Park, MD, USA), which went public in March 2021 in a special purpose acquisition company (SPAC) deal worth an estimated 2 billion USD [9], uses lasers to read out the quantum state of ytterbium ions trapped in magnetic fields. IonQ engineers recently reported achieving a 0.3% error rate for a logical qubit encoded with 13 physical qubits [10]. In August 2020, IonQ made an 11-qubit quantum computer open to the public on Amazon's Braket cloud platform; just three months later, the company released a 32-qubit version [11].

Also raising the level of competition is Honeywell, a US-based, global technology and manufacturing conglomerate headquartered in Charlotte, NC, USA. In June 2021, the company announced the merger of its quantum computing division with Cambridge Quantum Computing, a Cambridge, UK-developer of software for quantum chemistry, quantum machine learning, and quantum-augmented cybersecurity applications [12]. Several months earlier, in March 2021, Honeywell announced that its trapped ion-based quantum computer achieved a quantum volume of 512 [13], the highest value measured on a company-developed quantum computer to date. Quantum volume—a metric accounting for both the number of qubits in a system as well as their decoherence times—provides a fuller picture of not only the size of a calculation a system can handle, but also how reliably the system can carry out its computations.

Though neutral-atom startups have raised considerably less money and the technology is less developed, these systems are also showing potential. They work by using laser pulses to trap arrays of atoms in vacuum chambers. Other lasers then excite the atoms' outermost electrons and move them away from their nuclei, inflating the atoms to billions of times their normal size. Once in this state, the atoms behave more like ions, interacting electromagnetically with neighboring atoms, enabling the formation of entangled quantum bits that can be used to perform computations.

French company Pasqal (Massy, France) has built a 200-qubit neutral-atom processor that it plans to roll out in a cloud-based service in late 2021 [14]. The company is hoping to develop a 1000-qubit processor by 2023 [15]. Another neutral-atom startup, ColdQuanta (Boulder, CO, USA) plans to release a 100-qubit device in late 2021 [16], with a 1000-qubit version slated for 2023.

"Ion computing is very strong, particularly in Europe and the United States, and neutral-atom computing is catching up," Walther said. "I am pretty sure they will also have a supremacy claim in the not-too-distant future. It is an open race to decide which is the best system, and I'm excited to see who the winner will be."

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