Fujitsu on Quantum Computing

January 2024

Overview

- As silicon-based classical computing approaches its technological limits, quantum computing offers the potential to find new solutions to the most complex business and societal challenges.
- The key limitation in quantum computing is errors occurring in qubits during operation. Without solutions here, quantum computing will remain lab-based.
- Fujitsu is working on solutions to the quantum error mitigation/correction challenge that may involve AI and hybrid CMOS/quantum technology. Advances in both areas are accelerating progress towards reliable systems, and commercial applications are not far away.

Industry Trends in Brief

- Further improvement in computing performance faces significant challenges. The most notable is that the end of Moore's Law is approaching: If transistor size cannot be reduced further, computing power will hit a ceiling.
- To overcome these limitations, quantum computers are a hot research topic. Operating on different principles, they can solve problems significantly faster than conventional computers in specific applications and solve complex challenges, such as quantum dynamics calculations, at much higher speed. For other applications — those where only simple addition and multiplication are more important, for example — conventional computers will likely remain more relevant for some time.
- The development of various quantum computing architectures has been progressing at high speed in recent years. However, despite being potentially many times faster than conventional computing, quantum computing is still error prone.
- Quantum computers are exciting because they exploit the superposition and entanglement properties of quantum physics. While classical computers process each bit state sequentially, a quantum computer can process many states in parallel due to these properties. This “quantum acceleration“ potentially makes quantum computers much faster than conventional computers and able to process different classes of calculation. They can be expected to lead to new discoveries in core physical principles, as well as new materials and drugs, and even accurate future price predictions in financial markets.
- The use of qubits also brings challenges. Since a qubit's superposition is extremely delicate and can be easily disturbed by external noise, a phenomenon known as 'decoherence', it is inherently prone to errors. Any computing architecture has to deal with some level of error, but quantum computing tends to be vulnerable to errors due to this delicate nature.

Furthermore, because of entanglement, those errors are instantaneously transmitted to each qubit.

- The latest quantum devices are working with up to 1,000 "physical qubits". These are so-called NISQ computers (Noisy Intermediate-Scale Quantum), and are capable of manipulating shallow quantum circuits only. However, to be usable for practical purposes, extra physical qubits are needed to compensate for error correction, resulting in much smaller numbers of usable "logical qubits". Researchers estimate that to achieve a Fault-Tolerant Quantum Computer (FTQC) we will need devices with at least 1 million physical qubits.
- In addition, some of the current qubit technologies require powerful refrigeration to operate at temperatures close to absolute zero: in the case of superconducting qubit technology, the operation temperature is as low as 10 mK (-273.14°C).

Fujitsu and Quantum Computing

- Within its computing portfolio, Fujitsu offers HPC/supercomputing, a quantum simulator, the quantum-inspired Digital Annealer, and quantum computing. Fujitsu is a world leader in several of these technologies.
- Fujitsu's quantum strategy is to address multiple hardware technologies, by working with the world's leading research institutions, and to focus on quantum software technologies with the objective to develop end-user applications.
- In error correction, Fujitsu has established the Fujitsu Quantum Computing Joint Research Division at Osaka University. In March 2023, Fujitsu and Osaka University announced a new quantum computing architecture with error correction that significantly reduces the number of physical qubits required for usable logical qubits compared to conventional architectures, enabling practical application of quantum computers from about 10,000 physical qubits, rather than the 1 million currently predicted.
- Fujitsu and Japanese research institute RIKEN are developing hardware and software technologies, as well as technologies to achieve more precise quantum gate operations, to realize a quantum computer with as many as 1,000 physical qubits. The partners have already successfully developed a 64 qubit superconducting quantum computer at the RIKEN RQC-Fujitsu Collaboration Center.
- Fujitsu is also working with TU Delft in The Netherlands on a new "diamond spin" quantum architecture. The architecture enables gate operations between distant qubits via light and holds the promise of greater scalability through integration of multiple quantum modules. It also operates at relatively higher temperatures (1-10K) to address refrigeration issues.
- As a hybrid hardware/software approach to quantum computing, Fujitsu is leveraging its HPC-based quantum computer simulator. Quantum computer simulators, which can digitally imitate quantum computation, provide a vital bridge toward the development of practical, fault-tolerant quantum computing. Unlike current quantum computers, quantum simulators can perform error-free and long-step computations as they do not rely on error-prone qubits. However, as quantum simulators only digitally reproduce quantum computation on classical computers, they cannot realize actual quantum acceleration.

- To bring this approach to market, Fujitsu has developed a platform for hybrid quantum computing, which combines the computing power of the 64 qubit superconducting quantum computer at the RIKEN RQC-Fujitsu Collaboration Center with one of the world's largest 40 qubit quantum computer simulators developed by Fujitsu.
- By linking a quantum computer with a quantum simulator that runs on HPC, Fujitsu has succeeded in developing a hybrid quantum algorithm that enables quantum chemistry calculations with greater accuracy than conventional classical algorithms (CCSD(T)). The intended market is research companies working in the fields of medicines, materials, and finance. Fujitsu expects quantum computing to have a major positive impact in a range of fields including chemicals, pharmaceuticals, mobility and finance.
- Fujitsu is also working to allow users without specialized knowledge to use quantum simulators and HPC technology to provide effective solutions to real-world problems. It plans to develop a quantum/HPC hybrid computing technology that automatically optimizes workload selection for customers. The new AI-based software, which serves as a precursor to a future computer workload broker technology, automatically selects from different next-generation computing platforms to offer the optimal solution to customers' problems based on parameters including calculation time, calculation accuracy, and costs.

Fujitsu quotes – Dr. Shintaro Sato, Fellow, SVP & Head of Quantum Laboratory at Fujitsu Research, Fujitsu Limited

- "We're on the brink of a symbiotic relationship between quantum and AI with enormous potential to drive advances in both fields, pushing the boundaries of what's possible."
- "Looking into the future, we envision the seamless integration of quantum computers, quantum simulators and HPC in a hybrid platform, which ensures smooth transitioning between quantum and classical computations as needed."

