QUANTUM COMPUTING

Quantum computing's six most important trends for 2025

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The financial industry is anticipated to become one of the earliest adopters of commercially useful quantum computing technologies. These technologies are expected to become available within the next few years, making it more important than ever to follow experimental developments. Therefore, as 2024 comes to a close, we pause to reflect upon what has recently transpired and look for trends we believe will continue through 2025 and beyond. This exercise has led to the identification of six trends, each of which we cover through 2024 reports and announcements:

1. More experiments with logical qubits
2. More specialized hardware/software (as opposed to universal quantum computing)
3. More networking noisy intermediate-scale quantum (NISQ) devices together

3. Improved and novel physical qubits

These trends are not ordered by significance or likelihood; we see all of these as equally likely.

More experiments with logical qubits

In “The road to useful quantum computing,” published on February 13, 2024, we reviewed the events of 2023 that started shifting our conversations from physical qubits in 2022 to logical qubits in 2024. Whereas a “physical qubit” refers to actual error-prone hardware, a “logical qubit” is an arrangement of these physical qubits that encodes information in such a way as to protect against errors [1]. We chronologically cited 19 achievements — many of which were experimental — from 23 organizations; alphabetically, they are: Alice & Bob, Amazon Web Services, Caltech, Chinese Academy of Sciences, Cornell, ETH Zurich, Fuzhou University, Google, Harvard, IBM, MIT, PsiQuantum, QC Design, Quantinuum, QuEra Computing, QuTech, Riverlane, Tsinghua University, the University of Chicago, the University of Science and Technology of China, the University of Sheffield, the University of Stuttgart, and Yale. We noted that by early 2024, QuEra and Infleqtion had already published their logical qubit roadmaps, while Alice & Bob had teased that a logical qubit roadmap would be forthcoming [2].

In 2024, we observed continued experimentation:

- On August 27, Google announced that it had demonstrated a quantum memory with below-threshold error rates and double the coherence lifetimes as compared with physical qubits [3].

- On September 10, Microsoft and Quantinuum announced that they had entangled 12 logical qubits, triple the logical qubit count from six months prior [4]. The physical error rate of 0.024 was brought down to a logical error rate of 0.0011, leading to the first ever chemistry simulation combining high-performance computing (HPC), artificial intelligence (AI), and quality control (QC) [5].

On December 3, an IBM Quantum team announced that they had demonstrated the entanglement of logical qubits using overlapping codes, applying a method thought to be impractical with limited connectivity [7].

On December 9, Google announced that its Willow chip demonstrated below-threshold error correction, lowering error rates as more physical qubits encode logical qubits [8].

We've also seen growth in the number of logical qubit roadmaps. In addition to the three companies we mentioned, Inside Quantum Technology mentioned IBM Quantum, Google, and Microsoft in "The quantum roadmap battle of logical qubits," which was published on February 27, 2024 [9]. Since that time, we have added eight more to this list (alphabetically, given that not all of them are dated):

Diraq [10]

IonQ [11]

IQM [12]

Pasqal [13]

PsiQuantum [14]

Quantinuum [15]

Quandela [16]

Xanadu [17]

While this may not be an exhaustive list, it shows a continuing trend either way.

More specialized hardware/software (as opposed to universal QC)

Building a universal quantum computer — a quantum computer that can run any quantum algorithm — is hard [18]. If it were easy, we would already have one. While this is still the end goal, multiple companies are developing specialized quantum computers for specific problems to achieve earlier commercial value:

Bleximo is building full-stack superconducting application-specific systems with co-designed processors, software, and control stacks [19].

Qilimanjaro is building quantum app-specific integrated circuits (QASICs) for superconducting analog quantum computers with full stacks co-designed for specific problems [20].

QuiX is building special-purpose photonic quantum computers for specific optimization and simulation problems [21].

On November 19, QuEra launched a full-stack quantum algorithm co-design program to optimize hardware, software, and applications for specific problems [22].

It's reasonable to assume that this list will continue to grow. Likewise, it's presumably easier to sell a special-purpose quantum computer that provides a commercial advantage for one or a few problems than it is to sell a general-purpose quantum computer that does not yet provide commercial advantages for any problems.

More networking NISQ devices together

Two ways to scale up a quantum computer are to add more qubits to a single quantum computer or to interconnect multiple quantum computers, creating a entanglement, linking qubits within separate quantum computers [23].

On October 30, QuTech announced that it had connected two small quantum computers in two different cities [24].

IBM is building L-couplers to scale its systems [25]. On November 21, it announced that it had classically linked two 127-qubit quantum processors to create a virtual 142-qubit system [26].

There is far more research going into quantum networks than the examples here, but not all of it links to quantum computers just yet. Researchers are still developing the infrastructure. However, experimental demonstrations of interconnected and internetworked quantum computers are bound to lead to experimentation with distributed applications using more of these nascent quantum networks.

More layers of software abstraction

A major challenge in adopting quantum computers is learning how to use them. Quantum algorithms and quantum hardware are significantly different from their classical counterparts. Fortunately, multiple companies are designing interfaces so users might not need to know anything about quantum computers:

Multiverse Computing's Singularity uses a spreadsheet to abstract away whether it is using quantum or quantum-inspired computing to solve optimization problems [27].

The Strangeworks model allows you to define your problem. Once you've done that, you simply select a solver — quantum or otherwise — and run it [28].

Quantastica's Quantum Algorithm Generator doesn't completely abstract hardware layers so it's easier to develop cross-platform applications. However, this still requires a considerable amount of quantum computing knowledge. These solutions are halfway there, though, and simply need the software component to join this list.

More workforce development tools

There is no shortage of introductory quantum computing materials, but the vast majority are self-paced or structured for individuals. At least two companies offer programs with enterprises in mind, recognizing the need for workforce development rather than just career development:

Q-CTRL's Black Opal is an interactive online learning platform that individuals can use, but it can also be embedded into a formal curriculum with a capstone project, exams, and automatic grading [30].

QURECA offers customized training programs tailored to organizational needs, various roles, and different business sectors [31]. There is also a team-building program that bridges quantum computing hard skills and enterprise soft skills [32].

MIT offers a two-course program from MIT xPRO that is designed for working professionals and awards a certificate. Professor Peter Shor, the developer behind Shor's algorithm, and Professor Isaac Chuang, co-author of "The Bible of quantum computing," are two of the instructors [33]. It is easy to imagine similar programs being adapted to individual enterprises, where an entire course consists of employees from the same organization.

Improved and novel physical qubits

Two ways to lower error rates on quantum computers are to improve the physical qubits and to implement high-overhead error correction codes. It is widely believed that quantum error correction (QEC) will be necessary; however, require fewer components than electron spin qubits [35].

On September 19, University College Dublin announced that "split-electrons," so-called “Majorana fermions,” can theoretically be used as topological qubits [36].

On September 21, Brookhaven National Laboratory announced it had used constriction junctions, which simplify chip fabrication to enable mass production [37].

On November 26, The Quantum Insider reported that Quantinuum, Harvard, and Caltech experimentally demonstrated the first “true topological qubit,” robustly encoding information in systems’ relationship patterns instead of within the systems [38].

On November 26, as part of the Q-LEAP project, RIKEN and Toshiba announced a double-transmon coupler (DTC), which has been proposed to improve gate fidelity [39].

On November 26, The Wall Street Journal reported that Ephos uses glass chips instead of silicon to reduce energy consumption and information loss [40].

On December 4, the American Physical Society reported in its Physics publication that ETH Zurich demonstrated a mechanical qubit consisting of two sapphire chips, with a superconducting qubit on top with a mechanical resonator below [41].

It’s impossible to know everything that is being researched at any given time. We can assume, however, that research continues in universities and labs around the world, as well as at many quantum computing companies.

Conclusion

we continue along the path toward fault-tolerant quantum computing.

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