Modularity drives quantum scalability

UQ Insight Report

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Executive summary

Quantum computers must execute long, intricate sequences of operations to tackle the most valuable problems. To do that, we need more qubits without compromising performance. Yet as systems grow, so do manufacturing defects, which threaten to undo every advance. The answer lies in modular design, where multiple smaller processors are linked to form a powerful whole.

By adopting standard fabrication methods for each module, yields improve , we reduce costs and simplify testing and control integration. Consistency in design then carries across generations. These benefits depend on interconnects that are fast, numerous and maintain very high fidelity. Without robust links, modularity itself becomes a bottleneck, slowing algorithms and halting further scale up.

This shift to modular architectures also presents opportunities across the quantum supply chain. Vendors can adapt existing manufacturing processes to become quantum ready and end users can help mature algorithms today so that proofs of concept evolve seamlessly into practical solutions tomorrow.

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We need scale

A truly useful quantum computer will one day boast millions of qubits. Our previous report, “Scalability Is the Lifeline of Quantum Computing,” explores how noise, error correction and key performance metrics all shape this challenge. Simply adding a few more qubits will not suffice. We must increase qubit counts by orders of magnitude while preserving fidelity and operational speed, and do so in a way that remains economically viable.

That requires mass-manufacture techniques and supply chains capable of producing chips at high yield and low unit cost, even as devices become more complex.

A quantum computer Is more than just its qubits

Every element of a quantum system, from the qubit layer to analogue control electronics, is vulnerable to manufacturing tolerances and defects. If these errors accumulate unchecked, adding more qubits can degrade overall performance. To avoid this, we must scale each subsystem in harmony.

A truly scalable process requires:

- Consistent yields and quality for all components
- Pre-integration testing of individual parts
- Cost-effective, proven fabrication methods
- Clearly defined tolerances and mitigation strategies
- Control systems that can grow with qubit count

Larger monolithic chips risk lower yields and higher unit costs. Increasing qubit density can overload control systems or introduce noise. Any viable architecture must allow for error compensation and avoid recurring integration challenges with each new generation.

Modularity is an unspoken need for scaling

A truly modular design sidesteps the pitfalls of ever-larger single chips. By producing many identical modules via conventional fabrication, we keep defects to a minimum and maintain cost effectiveness. Multiple modules slot together, each with its own control electronics, avoiding an intractable wiring problem.

Once the core engineering problems are solved, the same modular blueprint carries through future generations. Monolithic systems often demand complete re-engineering as chip sizes and densities increase, leading to brittle designs and longer development cycles.

However, modularity shifts some complexity into the interconnects. For these modules to behave as a single device, we must create multiple quantum-grade links that are both rapid and of very high quality.

The need for excellent connections

For modular quantum computing to outperform monolithic approaches, inter-module connections must match the speed and fidelity of operations within each module. Furthermore, a single link would choke algorithmic throughput. Instead, we need many connections between modules, that enables parallel operations.

Key requirements for these interconnects include:

1. Operation rates on par with native gate speeds so that cross-module operations do not lag behind

2. Fidelity of the link equivalent to intra-module interactions to preserve quantum information

3. The number of links is proportional to each module's qubit count to sustain full network connectivity

4. Scalable manufacture with the same yield, testing and cost standards as the modules themselves

Thoughts for buyers and investors

Traditionally, qubit count and fidelity milestones have been the go-to metrics for evaluating quantum roadmaps. Yet these figures do not reveal whether an architecture can grow sustainably. Different qubit technologies face unique hurdles: superconducting systems require extreme cooling while some atoms and ion modalities require precise laser delivery. Some challenges emerge only at scale, such as linking multiple cryostats or integrating new interconnect technologies.

When comparing vendors, ask:

- Which challenges are solved for today's devices and which scale-up challenges lie ahead?

- Are there hard performance limits on key components, and how will they be addressed?

- Has the interconnect technology hit the metrics required for scale? If not, what is required?

- Will future hardware generations demand incremental updates or a major overhaul of enabling technologies?

Answering these questions will help you avoid unwelcome surprises as systems grow.

Thoughts for government and supply chain

In some cases, Governments are also buyers of quantum computers, and the guidance in the section above is also relevant to them. But Government also has a significant role in developing ecosystems for quantum computing.

Building a fault-tolerant quantum computer demands a mature, reliable supply chain. We must help existing vendors become quantum ready or invest in new ones. If this effort is delayed, manufacturing will bottleneck deployment and value realisation, even after the technology itself is proven.

Architectures being built today using standard production methods will have the edge. This applies not only to chips but also to cooling, vacuum and control systems. Bespoke components require significant development to achieve the necessary quality and reliability. Government-sponsored manufacturing challenges and incentives are required for the much-needed acceleration of progress and can help governments position themselves at the forefront of the global quantum ecosystem.

Thoughts for end users

Headline applications such as drug discovery, battery design and new materials will need millions of qubits. Yet immediate progress depends on end users testing real-world problems on today's modest-scale devices. By working on down-scaled versions of practical challenges, users help refine algorithms and validate architectures.

Quantum vendors should provide high-level, consistent interfaces for these proof-of-concept tests. End users must be confident that their work will adapt smoothly to larger, modular platforms without a complete rewrite. This approach ensures algorithmic maturity keeps pace with hardware advances, turning early investments into future impact.

About Universal Quantum
Universal Quantum is pioneering scalable trapped ion quantum computers, poised to revolutionise multiple industries.

With breakthrough technologies like UQConnect, enabling world-record quantum connections between chips, and UQLogic, offering robust and scalable qubit control, we are paving the way to utility-scale quantum systems. Crucially, our innovative quantum computers are being built using readily available manufacturing technologies and operate at a practical temperature of 70K.

Contact us at **info@universalquantum.com** to find out more about Universal Quantum.

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