Ready-to-Run
Quantum Systems

Future Thinking
Quantum Computing
Hybrid Architectures

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When we speak of hybrid quantum systems today, we assume we're discussing the blend of a classical and a quantum computer. These two systems can be configured, thanks to orchestration, to work together to perform a computation, for example solving an optimization or training a machine learning model. The assumption is that by working together and sharing the processing loads, the hybrid quantum system will deliver better results in many cases than either will on its own.

We all know that quantum computing hybrids will be the dominant configuration for extracting quantum value in many applications and use cases. It's not a question of classical vs. quantum. It's a question of how to best harness the upside power of each of these processing architectures to achieve the optimum value.

Most quantum experts believe that a hybrid approach is the solution of choice for optimization, as well as other nearer-term computational applications and use cases. We all agree that the first uses of quantum will be in a hybrid architecture, which accelerates quantum availability and potentially quantum advantage, ahead of pure quantum-only architectures.

Why Every Quantum Computer is a Hybrid

The reality is that every single quantum computer has to function as a hybrid system. Even if the classical system and quantum system are not working together to solve the problem, they will be working together. Here's why.

Quantum computers:

- Do not have databases to store data, or memory to use for processing.
- They do not have drives to store programs and applications.
- Cannot in any way be used to develop, compile or optimize programs or applications to be run on the quantum computing unit (QPU), aka the hardware.
- Don't process a workflow that would coordinate all of the many subcomponents of any processing or program, what we call orchestration in the quantum world.
- Do not collect, interpret or analyze results from said processing of a computation or problem.

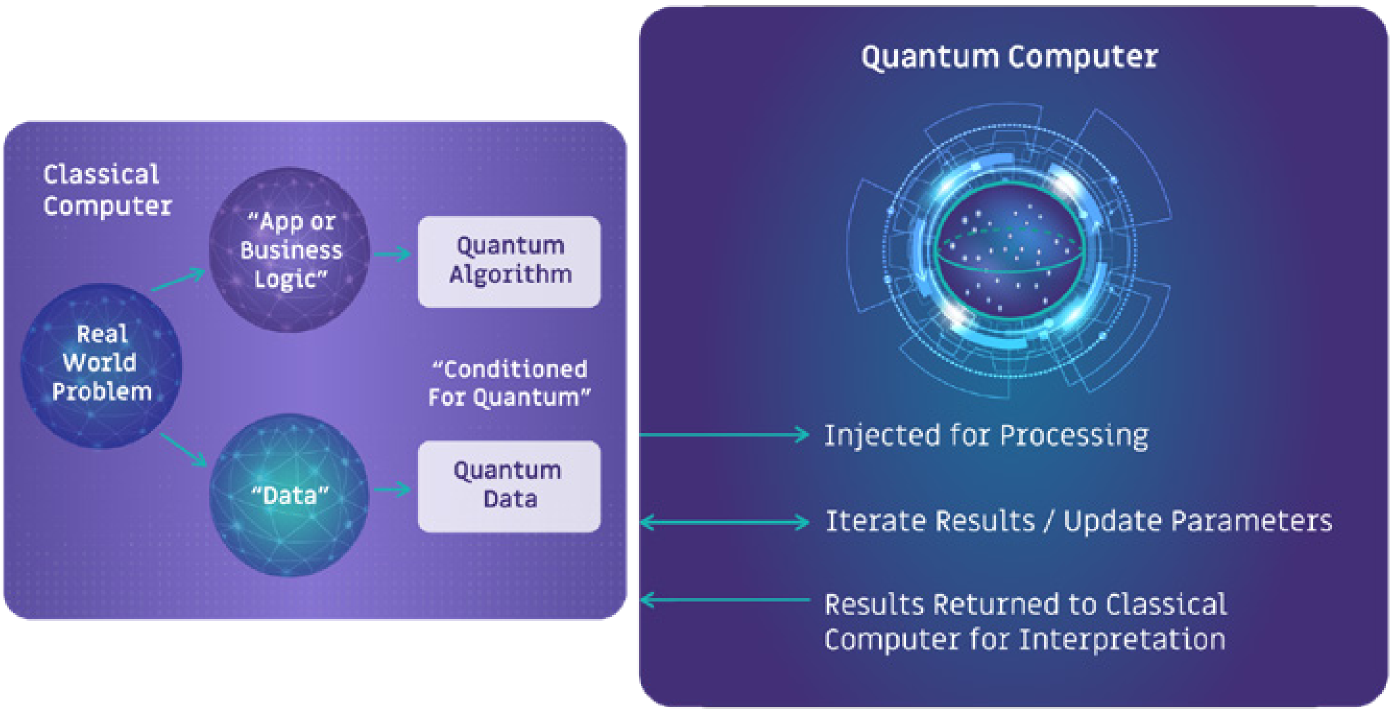
They do compute and provide solutions to extremely complex problems in ways no classical computer can ever accomplish. We've had so much focus on quantum hardware, aka the QPUs. The reality is that any quantum computer requires an integrated classical computer to control, program and measure the actual QPU and its qubits.

This is why all quantum computers will be hybrids.

The Role of Classical in Hybrid Quantum Systems

Classical systems are required to literally control and manage the processing of the quantum computer itself, aka orchestrating the quantum computer and its processing.

For example, let's look at a very simple set of basic steps involved in submitting and solving a computation on a quantum computer.



- First, you need data, and a problem to solve using that data. A classical computer is used to select, prepare or format and deliver data to the QPU as part of the computation. Remember, quantum systems do not have databases or storage.

- Next, you need to condition or transform the data and the business logic for the problem/computation into forms that a quantum computer can understand and process, aka energy as quantum data in the form of quantum circuits or Hamiltonians.

- Then, you need to submit the energetic version (e.g. a Hamiltonian) of the data and the program that tells the quantum computer what computation you want to perform. Again, the classical system orchestrates the submission of the data and the algorithm, as well as the progression of a computational algorithm on a QPU. The logic, or software, resides on the classical system.

  By the way, in case you're wondering, in many architectures the classical system uses a selection of laser beam pulses to control the QPUs processing. Remember, we are in quantum space where energy is the fundamental asset. We are also in a processing paradigm where iteration, or running the same problem again and again, is part and parcel of finding the diverse results that provide value. The orchestration of the iteration is managed by the classical system as well.

During iteration, you need a way to collect and capture the results. Once all of the potential results are collected, you then need to analyze, format and deliver those results back to the submitter. That work is also done by a classical system as part of the overall orchestration.

As we all now know, will quantum replace classical truly is the wrong question. We usually refer to that when it comes to the question of whether quantum processing will supersede and replace classical systems. The answer to that is a resounding no. A quantum computer can't process a transaction, create a document or send an email.

The reality beyond the applications and computational differences points to an even greater dependence on classical systems. Without them working in concert with quantum computers, we won't have quantum computing at all.

What Does Hybrid Mean in the Market?

As we've discussed, in the industry, a hybrid refers to shared processing of a computation, simulation, or other solution. In this case, the two system types iterate processing, can share results, and are working together to find the solution you need.

There are a variety of ways you can think about a hybrid.

Here are two primary examples.

Example 1. Classical pre- and post-processing, quantum computations

In this hybrid, a classical computer performs some form of pre-processing ahead of the problem being submitted to a quantum system.

For example, a classical system stores the problem set (data) for a computation. Analyzing the problem set of data defines the partitions or subsets of the data that best reflect the overall problem. Mathematically pre-processing these subsets of data, potentially by performing some initial probing using suboptimal classical heuristics, creates a series of smaller problems a quantum computer can process.

The smaller problems are modeled and then submitted to the quantum computer for iterative processing. The classical system analyzes the solutions returned from the quantum system, analyzes them, determines the best results, and returns those results to the submission.

This hybrid helps solve the limitation of quantum systems due to their small size and inability to ingest or process the number of variables (data) that real-world problems require.

Example 2. Shared Classical and Quantum Processing

This hybrid uses both types of computers to solve the problem. We see this as a target architecture for optimization computations. Classical computers do a good job of solving optimizations when the problem set is sparsely coupled, meaning the data matrix is not fully populated across every single field. Classical systems are excellent at this type of operation.

This said, when the data matrix is densely coupled, meaning the potential fields are heavily populated so the matrix is more complex, classical systems bog down. This is where quantum systems shine as they process such complex data matrices in a multi-dimensional manner.

Analyzing the problem set identifies the data partitions that are sparsely vs. the densely coupled areas, directing them to different processors for computation, based on whether a classical or quantum system can best process the data.

Each system is directed to compute the optimization on a specific part of the data, and the results are iterated between them, as well as within their own processing. Then the results are analyzed, and the best solutions returned as insights for the organization.

This approach empowers both the quantum computer and the classical computer to do what each is good at doing - so you get the best out of each architecture and better results overall.

Future Thinking Quantum Hybrid Systems

As we've noted, when we speak of hybrid quantum systems today, we assume we're discussing the blend of a classical and a quantum computer. But what if we adopted a mindshift beyond today's thinking, which tends to still be founded in classical supercomputing?

Let's begin by asking a few questions.

If quantum computers are so powerful, why would we need hybrid quantum systems?

The answer today is pretty straightforward.

Quantum computers do not scale to process the large data sets required by complex computations, today or in the near future. Additionally, today's qubits are not the high quality we need to solve production problems.

Certainly, more scalable quantum computers with less noisy qubits are on the horizon. In fact, many would say the hardware vendors are accelerating their scale much faster than was expected. This may be one reason we tend to visualize them as massive supercomputer-like processors. But that's not true today or in the near term.

Why are we viewing today's quantum computers as if they were the next generation versions of large-scale supercomputers?

Most likely it's because many of the early quantum computers were seen as extensions of current classical computing and supercomputing. The promise of scale and performance, along with the demand for super-cooling, special environments, and tender loving care mirrors the needs of supercomputers and early classical mainframes. So it's a natural, learned analogy.

The reality is that they are not supercomputers or mainframes today, which results in the market pointing to them and saying they aren't meeting their promise. That's a pretty rigid comparison for an early technology that's still in a pure innovation and exploration state. Kind of like comparing a 2000's electric car prototype to a Maserati and calling EVs a failure.

That said, the situation suggests to me that the time has come to see these next-generation computers as they are today, and to find ways to apply and use them to deliver value. Not as massive supercomputer wannabes, but as the systems with the capabilities they have today and over the next few years, applied to exploring their potential value, learning what we can expect and what we need to shift in our knowledge, processes, and organizations to be able to leverage them effectively when they do mature.

What if we looked at hybrids not just as a single classical and quantum computer together?

What if, instead, we looked at a hybrid quantum system that includes multiple quantum computers, as well as classical, working together to solve problems in a way that delivers more value than a single QPU can provide today?

For example, using different quantum computing paradigms and architectures such as superconducting, photonics, trapped ions, and more, together. Think nodal or mesh processing where multiple systems work together, sharing individual QPU's progressively to get better results to enhance processing across all nodes, to deliver an end result, vs. one gigantic machine working alone.

I know, you may be thinking that each quantum computer type requires specific low-level coding for software and algorithms to work. That would mean you couldn't share software or computations across different vendors' systems.

That's not a technical barrier. It's a typical early hardware platform requirement put in place by vendors as they introduce new hardware architectures.

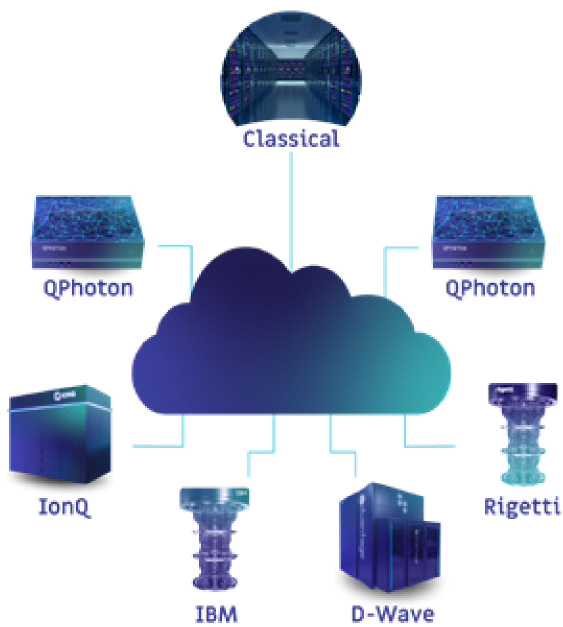
Qatalyst, and any well-architected quantum software can and should eliminate that barrier. Qatalyst is purpose-designed to eliminate the need for low-level coding and lock-in to specific QPU vendor architectures. Additionally, its microservices run and compute across diverse QPU and CPU hardware. The same exact problem submission(s) are processed across diverse QPUs and CPUs, seamlessly. The processing services can be allocated to the best possible processor, or node.

Since I can submit the same problem to many QPUs and CPUs, I can use these diverse processors in a way that better matches their current capabilities. And you can use the information you gather about their processing to create a strategy to deliver even more valuable processing in the future.

A near term example that customers are requesting is a variation on the above - the ability to simultaneously run problems on diverse QPUs types and then compare their capabilities across performance, precision, scale and more. This initial form of hybrid quantum processing focuses on distributing a full problem to multiple QPUs. Next stages could include distributing components of processing (aka pre-processing vs compute) across diverse systems based on their specific capabilities.

Let's explore this initial example of heterogeneous quantum hybrids, distributing a problem across multiple QPUs to explore, measure and analyze their performance, precision and more.

1. Identify Models
- Classical data is analyzed
- Appropriate data sets are identified



2. Condition data for QPUs
- Quantum Transformation for each QPU
- Pre-Processing algorithms and functions

3. Problems iterate across heterogenous QPUs
- Quantum optimization on one or more QPUs
- Same problem submitted for individual QPU demands

4. Results Returned
- Optimum results are analyzed, best diversity of results returned
- Comparison of QPUs

Let's work through this example step by step.

Step 1. Identify Data/Models

The first step selects the data and evaluate it for quantum use. For extremely large data sets, smaller models can be created based on approaches used today with extremely large problems to be run on classical machines, for instance using the MapReduce paradigm with Hadoop, Spark etc. You can analyze and decompose the computation via mapping, machine learning, distillation or other mathematical methods, to create "model" problems that are sized so that today's QPUs can process. These models are created from areas in the data set that are known to contain the answers, thanks to machine learning.

Step 2. Condition the Problems for Specific QPUs and/or CPUs

Different QPU types require a different canonical format for the data and problem submission. For example, one QPU may have 150 connected qubits in an annealing architecture, while another may have 22 “algorithmic” qubits in a gate model architecture. This means that the submission must be conditioned to match their specific requirements, then transformed into an energetic pattern for injection into the QPU. Similarly, a CPU requires a different structure of the data, in bits, than a QPU.

Step 3. Iterate Problems on Diverse Processors

The next step is to submit each of these problems, or the model problems to a variety of QPUs. Each system processes the computation iterating and sharing their individual best results for further analysis.

Step 4. Collate and Interpret Results

Next, collate and analyze the results across ALL of the systems, then identify the best possible diversity of results and return them. The insights to compare the processing accuracy/precision and performance of the various QPUs are also included, as are extrapolations concerning the increases in performance and precision as systems scale over time.

This approach results in a superior result, both for the computation and for your business as you explore quantum computing value.

- You leverage diverse processing approaches, since different QPUs process different problems in different ways. The result is experience with a range of systems and quantum computing approaches.
- You optimize each QPU’s computations as part of the conditioning process to assure each system has the structure and form it needs to complete processing.
- You send more models or full problems to more machines, so you get a more precise and accurate set of results thanks to that diversity.
- Simultaneously, you review the diverse QPUs to learn which architecture best maps to the specific problem/computation you’re running. You get insights into how you’ll get your best possible results for those types of problems in the future. Insights that can be used to guide your strategy and planning for quantum computing.

As we all see, by applying classical and quantum technology in a different, yet market-proven manner, we can achieve much more powerful exploration and valuable business insights. Especially compared to approaches that only focus on one quantum computer as a processing target, leveraging small problems designed for the qubit limits of the specific QPU architecture.

The Bottom Line

As with any emerging technology market, quantum computing is in a state of constant change and innovation. That goes for the technology, the architectures, the processes, as well as the descriptors of all of the above.

Which is why the quantum computing market is naturally aligned with a bit of confusion. After all, it's a completely new paradigm for computing. We are all learning about these amazingly powerful, yet dramatically innovative, systems.

In quantum computing, as in any advanced technology market, it always pays to think differently.

Hybrid quantum systems are one place to apply even more innovative thinking as we explore ways to accelerate our exploration of quantum value.

So here's to the hybrids, in all their forms and functions.