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WHAT KINDS OF PROBLEMS REQUIRE QUANTUM SOLUTIONS?

A PLAIN LANGUAGE SUMMARY OF BOOZ ALLEN'S RECENT QUANTUM RESEARCH

For organizations interested in integrating quantum computing capabilities into their operations, identifying where and how quantum will offer an advantage represents a major challenge. While at Booz Allen, researcher Dr. Michael Jarret focused on the respective boundaries of quantum and classical computing to identify where quantum provides worthwhile advantage and where equivalent non-quantum solutions may exist. Targeted research along these lines enables stakeholders to **focus their efforts on quantum solutions that truly offer a major advantage over their classical computing counterparts.**

In 2019, a quantum computer performed a calculation that would have taken classical computers 10,000 years to complete. The achievement was a big step toward realizing a claim that physicists have been working toward for decades: Quantum computers will one day demolish limits that researchers and technologists have long considered absolute by offering radically more efficient solutions to otherwise intractable problems.

This radical leap in efficiency has been a holy grail and is commonly referred to as "quantum advantage." Two key components will go into realizing it. We will need physical devices that operate in fundamentally different ways than today's computers, and we will need novel algorithms designed specifically to run on these new devices. An important challenge will be determining the problem areas in which quantum advantage is truly feasible—versus those that would be better addressed through advancements in normal computing.

This division will be determined by restrictions on how quantum devices can be built—for example, on how many internal variables are allowed to interact at each step of a calculation—as well as restrictions on allowed operations—basically the depth of the collection of essential algorithmic building blocks available to the computer for use in calculations. Knowing this, are there ways to identify problem areas that may initially appear to be ripe for quantum advancement, but that in reality could be better tackled through innovation in classical computing?

Resources:

Paper: Effective Gaps Are Not Effective: Quasipolynomial Classical Simulation of Obstructed Stoquastic Hamiltonians

1: M. Jarret and J. Bringewatt. Phys. Rev. Lett. 125, 170504, 2020. (See also arXiv: 2004.08681)

2: M. B. Hastings. arXiv: 2005.03791, 2020.

WHAT DOES IT MEAN TO SAY ONE PROBLEM IS HARDER THAN ANOTHER?

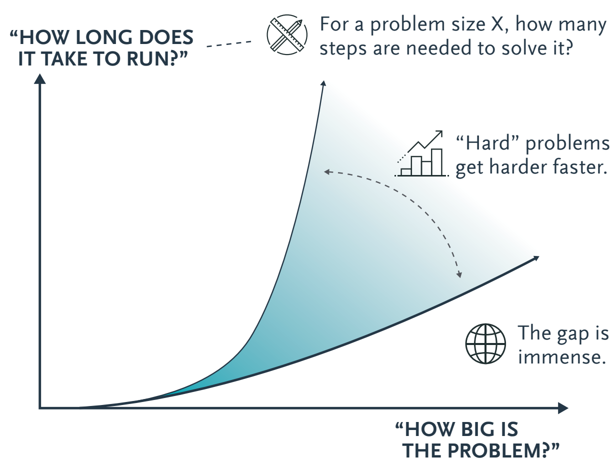

Figure 1: We group problems together based on how fast they get harder as the problem grows in scale.

In a paper[1] published in the American Physical Society's Physical Review Letters in October 2020, Dr. Jarret shows that **with some assumptions about how a quantum computer is built, problems that involve a lot of redundancy** (i.e., in which many parts are repeated, like a deck of cards where each suite is structured identically) **can be solved just as well by traditional computers. Further, Dr. Jarret shows that this is the case even when the problem's redundancy is not known in advance.**

For these types of problems, quantum computers should seemingly be able to outperform classical computers by enormous, "exponential" margins (Figure 1). Were this the case, achieving solutions of the same quality with traditional computers would take too long and cost too much to be practical if it were even possible at all. This result demonstrates that the performance gap is, in fact, much smaller than previously thought—meaning that many of these kinds of problems may be approachable without the need for new kinds of computers.

To demonstrate that such problems can be efficiently solved using traditional computers, Dr. Jarret developed a new algorithm that locates parts of the problem that occur multiple times and exploits them all at once. His result provides a surprising example of how restrictions on a computer's architecture and the peculiarities of a particular problem can combine to create circumstances where non-quantum solutions are as viable as quantum approaches. The fact that Dr. Jarret's algorithm shows how to achieve this efficiency for problems with this redundancy even when said redundancy is not known at the outset suggests that **the principles currently driving some candidate quantum computing architectures may not be the most efficient route to achieving general quantum advantage.**

This example shows that for one specific class of problem, traditional computers will remain viable alternatives to their quantum competitors.

Complementary work by leading researchers[2] shows that other **closely related problems do not share this property:** Without the restrictions on the quantum device's architecture, modern computer-based solutions may not remain viable. A major goal of modern quantum computing research is locating the boundary between problems that will demonstrate quantum advantage and problems that are just as accessible by traditional computers. With this new work, we have given the quantum research community a more precise picture of where that boundary lies (Figure 2).

WHAT KINDS OF PROBLEMS WILL BENEFIT FROM QUANTUM COMPUTERS?

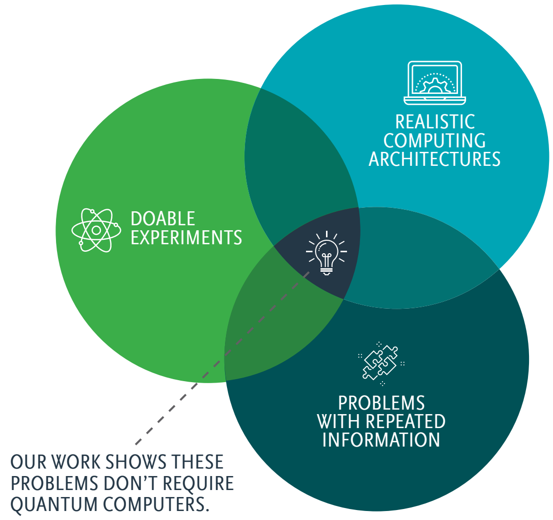

Figure 2: This work shows these problem are approachable, but other recent results show that closely related problems may not be. What makes a problem require a quantum solution?

About Booz Allen's Quantum Research:

Booz Allen's quantum research team is focused on basic, theoretical research addressing client needs not prioritized by academic researchers. Through this targeted, original research, the team focuses on bringing deep quantum expertise and mission-minded experience directly to clients to identify and fill capability gaps across the defense, civil, and commercial spaces.

Learn more at **boozallen.com/quantum.**

About the Expert:

Dr. Michael Jarret is a former member of Booz Allen's quantum research team, and is now a professor at George Mason University with the Department of Mathematical Sciences and the Department of Computer Science. He was the first student to receive a Ph.D. from the Joint Center for Quantum Information and Computer Science at the University of Maryland. Afterward he was a postdoctoral scholar at the Perimeter Institute. At Booz Allen, Dr. Jarret studied quantum and classical algorithms to distinguish the power of different models of computation. Dr. Jarret continues to work with Booz Allen's quantum team through a collaboration with George Mason University.