# WHEN BUSINESS MANAGEMENT MEETS QUANTUM COMPUTATION

SRIDHAR TAYUR*

*A short conversation on May 13, 2019, of the author with his students and fellow colleagues on the topic.*

**Q: Congratulations on being elected University Professor. In your quote that was part of the University Professor announcement, you mentioned quantum computing (QC). Now that sounds very different from your research in supply chains and healthcare operations. How does QC fit in with your research interests?**

**A:** Actually, it is very much in line with my core research interests of exploring new mathematics and technologies in search of very different types of algorithms to solve industrial scale problems faster.

**Q: Can you give a quick overview of quantum computing landscape?**

**A:** The hardware for quantum computing (QC) is still not mature. There are two dominant paradigms for QC: Gate (or Circuit) model and Adiabatic Quantum Computing (AQC).

Google, IBM and (a startup called) Rigetti are building physical devices in the Gate model paradigm. This is very, very early and these machines have a lot of noise, low number of qubits and limited connectivity between qubits. A fancy name Noisy Intermediate Scale Quantum (NISQ) computers – has been given to these devices in the hope that they gain some intellectual respectability! But if you strip out the smoke and mirrors, they are not useful at this time for practical purposes, but are good toys for us academic researchers. Having said that, both IBM and Google have announced that devices with more qubits and better connectivity will be available by the end of the year.

The hardware on AQC paradigm from D-Wave (Chimera architecture) is a bit more mature, and their next version (Pegasus) slated to be available soon appears even more so. Our experience with Chimera (and outlook based on Pegasus) is presented in our paper: Graver Bases via Quantum Annealing with Application to Non-Linear Integer Programs. (Link: https://arxiv.org/abs/1902.04215). Some instances of industrial problems that have resisted good solutions by commercially available classical solvers are solvable on Chimera using our hybrid quantum-classical approach, and this is very encouraging as we know Pegasus can do so much more.

**Q: So how do you see your research plans in this context?**

**A:** I come to quantum computing from an application software perspective. That is, I would like to develop algorithms (and commercialize them, as I did classical ones with my software company SmartOps, acquired by SAP, in 2013) to solve industrial problems in supply chains, manufacturing and distribution, and so on.

The most prototypical application of quantum computing, however, is (and has been) in quantum chemistry. There is (of course) interest in quantum cryptography (thanks to the work of Peter Shor). There are many theory papers on quantum machine learning these days. Another area that others have been focusing on has to do with trying to show quantum supremacy by trying to find better worst-case performance of academic

* Quantum Computing Group, Tepper School of Business, Carnegie Mellon University, Pittsburgh, PA 15213
Email : stayur@cmu.edu

combinatorial models (like max-cut of a graph). All of these very different from my application interests and so our research at CMU is clearly distinct from those of other groups at MIT, Berkeley, Google or IBM.

We have developed a hybrid quantum-classical approach for solving models that are directly applicable in industry, in finance and in chemical industry, as two instances. This approach is very versatile, even amenable to semi-classical solvers (say through optical annealers) as our decomposition involves solving an Ising model. Interestingly, we are developing effective quantum inspired algorithms that are entirely classical, a serendipitous by-product of working in QC!

**Q: How do you have access to quantum hardware?**

**A:** We have access to D-Wave through a consortium of NASA, USRA and Google. At this time, I am working to obtain access to Google and IBM devices. IBM has a 5-qubit device that is available in the open, but that is too limited to be of much use to us. They have devices (50 qubits, I think) that are available to limited number of collaborators, and that would be good to have access to. I think Google has a 72 qubit device in the works.

**Q: Once you have access to the hardware, is it easy to test out application algorithms?**

**A:** Yes and no! Yes, in the sense that they have APIs that we can use to represent our algorithms in the devices. That is, they have some basic compilers. But, QC is still in its infancy, not only in terms of hardware, but also in terms of infrastructure for application software. We have had to also conduct research in, and develop algorithms for, compiling. We found that existing compilers are fragile and based on ad-hoc methods that can be made more robust. So, we developed frameworks for compiling, both for AQC and Circuit models! (Links: https://arxiv.org/abs/1810.01440 and https://arxiv.org/abs/1905.00129). Indeed, NASA Quantum AI Lab (QuAIL) and USRA are having a CMU PhD student as summer intern to program our compiler frameworks and test them out.

This is not something I had to do in my earlier commercialization efforts at SmartOps because then the (classical) server hardware, accessing via internet (middleware, browser etc) and all that stuff were already in pretty mature state. All I had to do (and it was plenty!) was to build the application software layer where my optimization algorithms (for global inventory optimization) was imbedded.

**Q: Three to Five years from now, what do you see as best-case outcome of your QC research?**

**A:** At this time, not only are the hardware and infrastructure software domains lacking in sophistication, QC is early enough as a computational paradigm that analysis of speedup possible due to QC itself is a hotly debated area and a subject of basic research! So, we started to also understand quantum speedup. We are bringing new and powerful techniques – Morse Homology, Cerf Theory, Differential Geometry that provide far deeper understanding of speedup than methods currently in use. (Links: https://arxiv.org/abs/1903.01486 and https://arxiv.org/abs/1811.00675). This is closer to fundamental research than it is to application software!

I hope that through accumulated experience with these devices (and their next generation versions) and sophisticated analysis of the fundamental mechanisms that underlie quantum speedups, we will be able to publish a book called Practical Algorithms for Quantum Computers and commercialize some of these algorithms that users can access easily, making quantum computing as a service a reality. ❐