The Quantum Leap
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What [Would/Should/Could] We Ask a Quantum Computer?

In recent posts I have focused on the technical specifics of Quantum Computing and quantum sciences more generally (i.e., optical clocks and quantum in space), and showcased certain companies operating in the industry. However, for this post I want to focus on a more abstract theme.

If you ask just about any pundit or professional participating in the Quantum Computing industry, the biggest question of today, nearly universally posed is: "When will we achieve Quantum Advantage?" Quantum Advantage is generally defined as:

- "The achievement of demonstrated and measured success in processing a real-world problem **faster on a quantum computer than on a classical computer."**

In this writer's opinion, this focus on having Quantum Computers do things faster focuses on the wrong attributes of Quantum Computing. It is not the speed, per se, that is the key attribute that will deliver QC value, so doing things faster than classic misses the point.

The brains and core workhorse of a classical computer is its CPU or central processing unit. CPUs are made up of integrated circuits which (to grossly oversimplify) are simply billions of on/off switches. These integrated circuits are comprised of individual "bits" which are either 'one' or 'zero' (binary) and all computer processing is rooted in Boolean logic. Specifically, there are only three fundamental gates (AND, NOT, OR). That's it. There is an art to programming and a skill for parsing and processing information. Today's classical computers can apply these rules incredibly fast (gaming PCs operate at ~4GHz meaning they can manipulate 4 billion bits per second). **Clever programmers have found increasingly efficient and profound ways to implement programs despite having only two inputs (1 or 0) and only three logic gates.** We can do AMAZING things with this somewhat limited architecture.

Now let's switch our focus to QC. Instead of bit, Quantum Computers operate using qubits, which are the quantum version of on/off switches, however qubits can be in a superposition of both 'on' and 'off' at the same time. They can also be entangled, they have wave functions, and they can utilize more logic gates so can perform vastly different operations. And despite what many famous physicists have proclaimed, this is not voodoo science that nobody can understand. Quantum Computers are available today albeit with limited numbers of qubits. It is fundamental physics…it's just different from classical physics.

What does this mean and what is the thrust of this post? Since Quantum Computers operate so differently, **we can ask different questions**. Doing anything faster is not that novel (yeah, sure, you can break RSA encryption and do a few other notable things super-fast). SPEED is not the value-add, per se. With different physics you can (and should) ask different questions.

Let's look at the following example to help make this point more tangibly. Imagine that you and your partner are planning a San Francisco dream vacation. You are considering staying at one of the following two hotels:

Hotel Feature	Hotel 1	Hotel 2
Location	Fisherman's Wharf/Marina	South of Market (SoMa)
Room Rates	$400-$1,000/night	$400-$500/night
Room Style	Luxury residences	Five-Star full-service hotel
Spa	None	Full-Service w/ 5,700 sf gym
Ocean Views	Yes	None
Pool	No	50-foot saltwater lap pool
Drinks/Dining	Modest	Gourmet restaurant and separate lounge
Pet Friendly	Yes	Yes
General Rating	Extremely well reviewed	Solid reviews
Culinary Reputation	Basic 24-hour room service. Kitchenette in each room.	Award winning dining room; substantial wine list; 24-hour gourmet room service.
Amenities/Comments	• Gigantic apartments • Bay views from most rooms • Free car service w/i 2 miles • Outdoor terraces w/ firepits • Convenient to many tourist destinations • Free WiFi	• Luxury rooms • Concierge • Close to Muni/Bart stops • Nightly parking $65 • Foodie neighborhood with interesting artistic • Favored by celebrities
Personal Notes	Never stayed at this location but generally enjoy the hotel brand.	Honeymooned there and have returned one other time. Always an amazing stay.

Based on the above descriptions, which hotel should you pick?

One strategy might be to score each of the features, and then add up the scores and select the hotel with the highest score. But what about trade-offs? You may not care that much about amenities if you are conveniently located. You may also really enjoy certain features, but what if the view from the room is the most important consideration? Are any of these items deal-breakers by themselves?

Now, let's approach this problem from a quantum perspective. If one assigns a "score" to each feature, this sounds a lot like weighting or using a **superposition** to program each feature. There are also various trade-offs. You might be willing to sacrifice having a spa for proximity to a dynamic neighborhood, or perhaps room amenities are the most important feature and outweighs all others. These tradeoffs suggest that certain features are correlated or **entangled**. Most of us don't need a Quantum Computer to select which hotel we would prefer because our brain already does an informal weighting of the various features and considers the tradeoffs, and likely factors in other subtle variables not in the chart. Interestingly, different people will choose different outcomes to the same inputs…and the same person might select a different outcome over differing times.

In this context, using superposition (weighting) and entanglement (tradeoffs) does not involve mysterious quantum physics that are beyond comprehension. It is the way our brains already work. We assess

multiple variables with all sorts of subtleties on characteristics and complex "entangled" trade-offs and inter-relationships. Leveraging these features of analysis is where the "art" to QC programming will lay. This is where QC programmers will create the next generation of eBay's, DoorDash's, Oracle's, Google Search's or _____ (insert your favorite killer app).

How can superposition, entanglement, and other unique features of QCs alter the framing of the problem or the context of the answer? What are the questions nobody has ever thought to ask a computer before? Here are just a few simplistic examples:

As with the hotel choices above, QCs will be particularly valuable in problems involving weighting and tradeoffs, for example:

- Given the detailed profile of each athlete in the draft pool, and matching that with the specific needs of the team, which player should be drafted?
- With the following list of symptoms, what is the prognosis?
- What asset portfolio gives me the best risk/reward profile?

These are generally "optimization" problems, which have been well addressed by those following Quantum Computing, and early use cases using optimization are abundant.

So here are a few others, more outside the box:

- Is there a way to hear colors?
- Can we leverage QCs to enhance the capabilities of AI Chatbots like ChatGPT or Google Lambda? Should we?
- Can we leverage quantum effects to detect neutrinos and if so, can we then use them to create high-definition holograms?

Some of these feel fairly straight-forward, such as the pro team draft choice. There are many inputs that can be weighted and for which there are trade-offs. Could someone program a quantum computer to do a better job confirming draft choices versus a classical compute? I have to imagine that as the list of features grows substantially, that there could be a Quantum Advantage. And this would be a valuable tool to provide in that instance. But it's the less clear-cut problems that excite me. Imagining ways to make colors impact auditory sensors, or finding solutions sets to complex problems that were never before considered. Inquiries such as these can open all sorts of amazing new potential.

So as the QC hardware makers continue to let people test things on their increasingly powerful machines, and as the QC software companies expand the capabilities of their programs, I'm excited to see what people try. What new and novel questions they ask and what interesting and unpredicted answers are returned.

What do you think the new "killer app" will be on a Quantum Computer? What question would you like a QC to answer? I'd love to hear your ideas.

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