Q1: According to the article, how do ambitions for quantum networks differ across nation-states around the world, and why? Include your own convictions about what role quantum networks should play.

C1: Compared the ambitions of at least three nation-states around the world. Commented on the difference between them. Mentioned the importance of quantum networks for the development of the quantum internet. Gave one personal opinion about the role of quantum networks.

A1: The article discusses the concept of quantum networks as one of the cornerstones of unhackable communication links. As for the international ambitions, the infrastructure necessary for supporting the quantum network technology is already established in several countries. Some countries are using the existing metropolitan areas – such as South Korea's initiative to fund a 250km link joining existing metro quantum stations. In a similar fashion, the UK is planning to deploy a network between Bristol and Cambridge, via London. Australia on the other hand, is focusing on building a closed-government network through the capital.

The author of the article puts a bigger emphasis on the network built in China, as its scale is unprecedented. It links Beijing and Shanghai and spans over 70 kilometers with 50 nodes. Moreover, it's going to be linked to another province 3000 kilometers away. China has also put significant effort in getting quantum signals into space (as distance is a significant problem in quantum networks and in theory can be conquered either by land or by air). For this purpose, alongside some tech companies, China launched a QKD-enabled satellite. Several other countries, such as Canada, Japan and Italy are also working towards this direction.

As for America, the opinions regarding quantum networks are divided. The article points out that while quantum communications are under research in the US army and navy, the air force's Scientific Advisory Board seems to disagree with the usefulness and applicability of quantum links and prefers the classical alternative. The author stresses that their main concern is the fact that encryption is not the weakest link in security.

Regarding the role of quantum networks, even though it may be too early to jump to conclusions since quantum communication is still in its early infancy, there seem to be many new frontiers worth exploring. According to The Economist article as well as Kozlowski et al. [1], quantum networks will pave the road towards a global 'quantum internet' as well as quantum distributed and cloud computing. As for personal opinion, while there are many challenges ahead, if engineered properly, this can mean having a zero-latency way of transmitting data from node X to node Y with the only latency coming from the processing at the both ends rather than the packet infrastructure that is used now. Moreover, since many countries are focusing on getting quantum communication into space, this could mean little to no physical medium needed for the travel of this data. Another role that the quantum networks would play is tied to the security aspect. This can be motivated by the fact that quantum entanglement is well-suited for applications that depend on privacy, synchronization and coordination.

Q2: Give four reasons why corporations and governments believe "the time for investment, all agree, is now" for quantum computation, according to the article. Comment on which of the reasons you believe are most convincing.

C2: Given the information presented in the article, provided four reasons on why corporations and governments believe they should invest in quantum computing now. Discussed the most convincing reason.

A2: The author of the article states that ‘the time to invest is now’ and further elaborates his claim by suggesting that even less-capable quantum-backed machines have the full potential to bring revenue. Several possible reasons/applications are then provided in the text.

Quantum Simulators are considered to be one of the early notable applications that can be exploited for profit. Engineered as a reflection of real physical systems, quantum simulators can be applied to solve several real-life problems such as architecting room-temperature semiconductors for transmitting electricity without losses or researching chemical reactions to improve the quality of fertilizers. Many predict the successful incorporation of quantum simulations in industry as well. In particular, some suggest that quantum technology may allow us to come up with more efficient batteries compared to the current lithium-powered ones. Others point out the possibility of quantum-simulating a new cheaper material for satellites and airplanes, the use of which can improve the performance by a couple of orders of magnitude. Hence, the earlier the investments are done, the more likely is the profitable outcome.

The author also cites strategic goals as a possible reasoning behind the investments. Many governments are backing up quantum research efforts in order to gain both economic and security advantage. According to the representative of the quantum-technology institute of the Netherlands, nobody wants to risk the scenario where the end money in the sphere is going to be made in the US or China. As for the security aspect, since quantum technology has possible applications in defense, buying the ready-made solutions may result in a dangerous outcome. Therefore, investments at this stage are crucial to succeed in the race and gain both technological, economic and military advantage.

The fact that hardware for quantum computing is just around the corner is yet another incentive cited in the article. D-Wave, a company specializing on producing quantum annealers, already has a serious customer base and is backed by companies like NASA. Many tech giants such as Google and IBM are doing immense steps and spending huge resources towards coming up with solutions to achieve “quantum supremacy”. These advancements will probably result in popularization and widespread of small-scale quantum-backed solutions and services, hence, the need for financing.

According to the article, there is already a huge interest for quantum technologies in the finance sector as well. This aspect is yet another motivation for making investments today. The author clearly states that the pace of development is increasing by discussing the already-existing applications. Several huge banks and financial organizations have already partnered with quantum research groups and startups. In particular, their work is oriented towards using quantum algorithms in foreign-exchange trading and arbitrage. Others are using those algorithms for optimizing trading strategies or supply chains, or monitoring network activity to spot cyber-attacks. Once the necessary hardware is there, all of those applications are most likely to become profitable.

Concerning the most convincing motivation for the investments, the strategic aspect seems to be the most realistic at the moment. Similar to the nuclear advancements or the space race, the research in the sphere of quantum technologies, especially in the post-quantum world, can drastically change the course of events. Moreover, at the moment the strength of quantum algorithms lies in the possibility of cracking the currently existing cryptosystems. Hence, in order to stay ahead and gain a head-start both in the economic and defense aspects, it is important for the governments and corporations to invest in quantum computation when it’s still in its early stages of development.

Q3: The article quotes IBM vice president Dario Gil saying, "The power of quantum computing is rediscovering all the problems that computers cannot solve, and having a path to solving them." Discuss three ways "quantum software" addresses this idea, and argue whether one should believe Dr. Gil's statement (or not).

C3: Discussed three ways in which the article addresses the phrase: “The power of quantum computing is rediscovering all the problems that computers cannot solve, and having a path to solving them.” Discussed the accuracy of the phrase.

A3: Throughout the article the author makes points which directly or indirectly address the statement made by Dr. Gil. Perhaps the most obvious problem which was re-discovered with the introduction of quantum technology is the idea of cracking global encryption. While the RSA system at the moment is more or less secure and no feasible classical algorithms exist that can efficiently break it, once the necessary hardware arrives, global encryption standards will crumble in the face of quantum computing.

Another way in which quantum software tackles the idea proposed by Dr. Gil has to do with the rising attention to the fields of Machine Learning and AI. Since those deal with huge amounts of data, some of the algorithms and approaches are limited by the available computational power. According to the article, quantum software can be used to lift those constraints. For example, it can help with simply sifting through impractically large data sets or with matrix-heavy operations such as constructing recommendation engines. Therefore, the incorporation of quantum software can help the researchers focus on computationally heavy algorithms.

The part of the phrase “and having a path to solving them” does not necessarily imply that this path will be paved with quantum technologies. On the contrary, the search for the quantum solution can serve as a stimulus for optimizing the classical algorithms. When discussing the already-existing approaches, the author of the article indirectly addresses the statement made by Dr. Gil by quoting the co-founder of 1Qbit, L. Downs. According to him, by looking through the lens on how one could formulate an algorithm on a quantum computer, one can often find improvements on classical algorithms and that’s where lots of their successes come from.

While all of the above-mentioned points support Dr. Gil’s claim, it still should be taken with a grain of salt. Even though at the moment quantum software serves as a catalyst for re-discovering previously unsolved problems, it does not necessarily solve them. Today no beefy general-purpose quantum computer exists yet. Once it arrives, no one knows whether it can beat its classical counterpart. Another reason why Dr. Gil’s statement is not entirely correct is the fact that while quantum software and quantum technologies may assist and even solve some of the existing and re-discovered problems, those approaches are going to create new (perhaps unsolvable) problems as well. One particular example is the above-mentioned Shor’s algorithm and the breaking of current cryptosystems. Once those are cracked, tons of new problems may arise: researchers will need to come up with a new secure (both classically and quantum-wise) cryptographic algorithm, governments and organization will need to transition to the new systems and protect the valuable information, the newly developed post-quantum solutions may not be integrated that easily and etc. Hence, the main takeaway is that even though Dr. Gil's statement is somewhat correct and the advancements in quantum research do, in fact, find the gaps in classical computing, those gaps are not necessarily filled with solutions provided by quantum technologies. Moreover, those solutions may create more gaps on their own as well.

Q4: The article states "subjects that used to be mere footnotes to physics will rule, and engineers (and perhaps even consumers) will have to learn to speak quantum." How is this point presented in the article (cite corporate and government examples), and can you give examples from your own experience?

C4: Summarized at least three corporate and government examples given in the article. Explained why engineers will need to learn about quantum computing. Using personal experiences provided one or more examples on the need to learn quantum computing.

A4: In the concluding part of the article, the author emphasizes how the engineers will need to learn about quantum computing and how the quantum-related terms will no longer be mere footnotes in scientific articles.

Perhaps the most convincing argument that supports this claim is tied to the problem of cracking RSA. As this idea represents a danger for the future, and retrospectively even today, engineers will need to come up with ways to develop post-quantum cyphers and successfully transition to using them. Huge efforts are already underway: both research centers and huge corporations, such as Google and IBM, as well as companies and startups are focusing their research efforts towards the problem of making the encryption quantum-computer-poof. Transitioning from the current global encryption system will also require not only significant efforts but also a certain degree of knowledge of quantum computing. Moreover, this transitioning process will affect and will need to be tackled not only on corporate and organizational, but also on government levels.

The development of quantum networks will also increase the need for more engineers to “speak” quantum. As quantum networks are beginning to look like a strategic must have, more and more countries will need to dedicate resources towards quantum research. There are already huge changes in the field. For example, The European Telecommunications Standards Institute, which sets benchmarks for the industry, is already working to define quantum cryptography standards. As for the corporate examples, the author also points out miniaturization efforts are well under way as well. That means that soon enough the necessary equipment may fit in a phone, therefore, it is important for companies that produce hardware and middleware for general consumers to have engineers that can incorporate quantum technologies in their products, if necessary.

The rise of quantum technology will also result in a greater need of specific materials, as well as of precisely engineered versions of existing ones. For example, Intel aims to build qubits into silicon but that will require the material to be produced to a much higher purity. For that purpose they have already partnered with several other companies. Therefore, in order to solve this and similar problems, there will be a high demand for ‘quantum-educated’ engineers.

Regarding personal experience, for someone who is interested in Machine Learning and its applications, recently there has been a lot of discussion on quantum machine learning. Even though it seems like a very niche area, the number of papers that fall on the intersection of two areas is rising very fast from year to year. Despite the fact that at the moment there are no real applicable algorithms which surpass their classical counterparts, according to predictions quantum machine learning is likely to dominate the sphere in the upcoming years. Therefore, for someone who'd like to work in this field and stay up to date with the state-of-the-art research, it's important to have a certain knowledge of quantum computing.

References

[1] Wojciech Kozlowski and Stephanie Wehner. 2019. *Towards Large-Scale Quantum Networks*. In Proceedings of the Sixth Annual ACM International Conference on Nanoscale Computing and Communication (NANOCOM '19). Association for Computing Machinery, New York, NY, USA, Article 3, 1–7. Retrieved from: https://dl.acm.org/doi/10.1145/3345312.3345497