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Quantum: A New Era

For the True Entrepreneur: Risky but Big

By Rogier Vergouwen • March 18, 2022

Summary:

- Quantum computing is the next technological revolution
- The scientific progress will make vast impact on humanity
- It creates tremendous opportunities for businesses and entrepreneurs
- As the technology is still in its early stage, it is risky too

Robotics, artificial intelligence and Internet-of-Things are accelerating our digital age. Substantial progress has been made in the technological field, but the biggest step has yet to come. Quantum will bring the world into a new era where breakthroughs in the development of drugs, materials and batteries will be achieved.

From Theory to Technology

With Einstein and Bohr among its founders, quantum theory is already a century old. Nowadays, its unique qualities like *superposition* and *entanglement* are rapidly being converted into commercial technologies. Scientists have been working on quantum computing since the 1980s to enhance computing power. While bits of classical computers have a value of either 0 or 1, quantum bits (qubits) can be in the contra-imaginary state of *superposition*, thus possessing both values *simultaneously*.

Consequently, whereas classical computers run calculations *after each other*, quantum computers process these all *at the same time* while its computing power grows *exponentially* with the number of qubits. A quantum computer with just 300 qubits can therefore generate 2^{300} simultaneous calculations: that is more than the number of atoms existing in our universe.

With its superior power, quantum computing will enable analyses that require to take many different factors into account. Optimization problems such as aircraft design, financial risk analysis and logistics can thus be improved, but the biggest step will take place at the intersection of chemistry, artificial intelligence and quantum.

A Big Step for Humanity

To understand atoms and their mutual interactions, artificial intelligence is being applied to perform simple chemical simulations. But as a classical computer analyzes all options one by one, it would take centuries to simulate more complicated chemical reactions. A quantum computer would solve the challenge easily, resulting in many new possibilities.

For instance, finding the most effective ingredient for a new medicine, currently explored by trial and error, can be accurately determined by a quantum computer. Another opportunity concerns the simplification in the production of fertilizers, a complicated process currently consuming three percent of the world's annual energy. When quantum simulation can unfold the enzyme responsible for its creation, the production process can be simplified and its energy consumption reduced. Further applications include the optimization to separate hydrogen from oxygen (important for hydrogen energy), new batteries and the development of improved cables losing less energy.

Where mankind till today owed scientific progress to experimental discoveries, future developments can be achieved through the understanding of subatomic physics. It will lead to a revolution as great

as the industrial revolution itself, and its economic and business opportunities will be equally big.

Entrepreneurship in an Early-Stage Industry

The quantum revolution will unlock tremendous potential, on the one hand for products and services directly in the quantum industry itself such as hardware, components, software, and cloud services; and on the other hand product improvements and efficiency gains across a wide range of other industries. It creates new opportunities for businesses and entrepreneurs.

- **Quantum Industry**

  Hardware and components are currently in its (academic) development stage. As technological breakthroughs continue and prototypes are being built, companies aim to construct a quantum computer by 2030 that will be capable to solve a problem that a classical computer cannot.

  Next, system software will be developed to operate the quantum computers and application software with which, for example, chemical reactions can be simulated to develop new medicines or better batteries. Since software has the advantage that operating costs after its development are low, and as it can distinguish itself more successfully from competitors, this market is expected to be the most profitable.

  To offer quantum computing services at a reasonable price, the first computers are likely to be cloud based, making these available to several users. Prototypes are already online available, enabling users to get acquainted with the new technology.

  When fully developed, the market size of the quantum industry is estimated at 120 billion euro per year.

- **Existing Industries**
  With quantum hardware and software available, commercial opportunities for traditional corporates will become available too. For example, pharmaceutical companies can expand their market by developing new medicines while increasing their margins: due to faster development, their R&D costs will decrease, while revenues will soar due to the extended earning period as a result of a longer validity of their patents. With an estimated annual market value of EUR 450 billion, this end-user market is expected to create the highest value, and companies already started assessing opportunities for their businesses.

As the quantum industry is in its early stage, demand for hardware is mainly limited to research institutes and companies experimenting with prototypes. As a result of the global quantum race (see frame) the market is growing rapidly: fueled by government support the number of participating research institutes increases, big tech is investing heavily, and American hardware startups have raised billions in investment money last year. They acquire the latest technology, and due to the limited number of quantum startups (around 300 worldwide), competition among these suppliers has been limited so far.

Although orders are growing and the market potential is massive, so are the risks. In addition to the regular entrepreneurial risks, this is mainly because it is not yet clear which technology will prevail as a standard for a future quantum computer (see frame). But that creates opportunities too: with all options still open, ambitious entrepreneurs capable to attract the right talent and sufficient funding can become leaders in a market that is expected to be worth hundreds of billions of euros.

Talent

The Netherlands is well equipped with quantum talent: knowledge is world-class, graduates are readily available, and enterprise experience comes both from quantum startups and big tech. Science and industry work well together within a quantum ecosystem known to be the finest in Europe.

Delft has vast expertise in developing quantum hardware. In number of quantum publications, *Delft University of Technology* ranked third (only after the *University of Science and Technology of China* and *Massachusetts Institute of Technology*) between 2015 and 2020. The first European cloud-based quantum computer was built here (2017), both Intel and Microsoft opened their labs for qubit development and the startup climate is flourishing too: of the 57 global hardware startups as published by *Quantum Computing Report*, 6 are from Delft. In the east and the south, the *Technical Universities of Twente* and *Eindhoven* have leading expertise in photonics, a possible technology for both qubits and quantum communication (see frame), and a startup from Enschede recently introduced the world's most advanced quantum photonics processor.

Amsterdam is a leading hub for software: both the Center for Mathematics and Computer Science (CWI), in 1990 the place where computer language *Python* had been developed, and the *University of Amsterdam* have topnotch expertise in quantum algorithms. For the development of application software, these institutes work together under the name *QuSoft*, and a commercial startup has been successful in the same field for several years too. The city is also one of the leading European hubs in artificial intelligence, resulting in plenty of talent in application software. Last year, Microsoft opened here an artificial intelligence laboratory for the development of new materials, and together with the new location of the *European Medicines Agency*, it could boost new drug development in Amsterdam. To support startups and unite scientists with entrepreneurs, a *Quantum Application Lab* and *Innovation Center for Artificial Intelligence* will be opened in Amsterdam soon. In enterprise experience the city is successful too: 12 unicorns, mainly in tech, are operating from Amsterdam, and in terms of company value it is currently the largest tech city in the European Union. A source for talent in software, artificial intelligence, quantum and startups is therefore readily available.

Financing

Due to the industry's early stage where revenues are still limited, capital from outside is required to fund a company's research and development. As a result of the global quantum race, the European Union, national governments and public investment funds provide grants and loans generously to fuel the industry's growth. Private investors as venture capital or stock listings are another source.

Towards Market Leadership

Ambitious entrepreneurs not just aiming for growth but for future market leadership require even larger investments. Increased equity enables them to engage extra talent to speed up their product development and gain a technological advantage. It creates a vicious circle too as its technological strength attracts even more bright minds, thus enhancing the probability to develop a winning technology leading to market leadership.

Quantum startups in America have been able to raise large sums through the stock exchange, SPACs and venture capital, turning them into unicorns overnight. Raising such amounts, without significant revenues from a commercially available product, increases the risk in this early market too. So, as with entrepreneurs, the adage applies for investors too: investments in the early industry may be risky but the opportunities are big.

Technological Developments

Since the construction of a quantum computer began, scientists have been searching for the perfect qubit. Research institutes and tech companies currently develop qubits based on various technologies, such as superconducting, semiconducting, trapped ions, cold atoms, photons and NV centers. In addition, Microsoft's Quantum Lab at Delft University of Technology is conducting research on majoranas.

Except for majoranas, the different technologies are existing, but none of them are perfect. For example, while photons can function at room temperature, most qubits need to be cooled to around zero degrees Kelvin (-273 Celsius). Superconducting qubits can only be cooled in so-called cryostats (refrigerators), but that leads to the next challenge: as soon as more qubits are scaled up, more cables must be led into the cryostats to control and read out the qubits. Due to the extra cables, more heat is entering the cryostat, making it at a certain point impossible to cool the qubits to the low temperatures required. Stability of the qubits is another challenge: the longer they remain in superposition, the more accurate calculations can be made. One more challenge is the size of the facility: is it compact enough for a commercial quantum computer?

As each technology has its advantages and disadvantages, scientists research how to improve each technology to make the qubits stable and scalable. For example, silicon-based qubits (semi-conducting) are more easily scalable and stable but have the problem of being less reliable. Until recently, as three global research groups (including one from Delft) have developed a more reliable silicon qubit. The quantum computer is getting closer and closer.

Quantum Sensors and Communications

Next to quantum computing, quantum sensors and quantum communications are being developed. Quantum sensors use quantum properties to detect small changes in physical states, leading to the development of more accurate medical devices, gravimeters and navigation systems. The first quantum sensors such as gravimeters and accelerometers have already been developed, and have been commercially available for several years.

In addition, quantum technology can provide more secure communications. On the one hand, the (future) powerful quantum computer creates a risk: current encryption of our data, based on pairs of large prime numbers that would take a classical computer years to crack, can be quickly solved by a quantum computer. But fortunately, another unique property of quantum, *entanglement*, makes it possible to build secure communications. These connections are based on photons, a technology in which the Netherlands is strong worldwide, and is rapidly being developed. Together with the knowledge about algorithms and Europe's largest internet node in Amsterdam (AMS-IX), it offers additional opportunities for entrepreneurs. Although quantum-internet is still under development, it is expected to become available in the near future.

The Global Quantum Race

The revolutionary quantum computer will not only have an impact on humanity, but also on economies and geopolitics. Therefore, the new technology does not only offer opportunities for entrepreneurs, but also for countries: nations previously lagging behind, can suddenly become global players, while others risk losing their technological, economic and geopolitical edge. Consequently, the entire developed world has thrown itself upon the new technology and the global race has started as a result.

From the previous technological revolutions (semiconductors and internet), the United States retained most of the successful companies. Many of these tech giants are currently investing in quantum, but national laboratories and universities are conducting research too. Due to the strong reputation of its universities and the financial strength of its tech multinationals, they attract foreign talent to the US and open laboratories in cities with concentrated talent abroad. Entrepreneurs are active too: startups, amply funded by the large amount of private capital present in America, are working hard to develop a quantum computer. The US government actively supports these businesses: by placing government orders, the *Buy American Act* (enabling the US government to support American startups and enterprises) and the establishment of a quantum ecosystem, it is contributing to America's technological strength.

China, too, has plunged fully into quantum. Whereas *Time Magazine* wrote in 2000 that China would never reach the technological level of America, the country has turned the situation on its head in just 20 years: with tight five-year plans, a concentration of research efforts and huge investments, China is working decisively towards a leading position. China's tech giants are also joining in: Alibaba, Baidu and TenCent, already successful in artificial intelligence, are investing massive sums in quantum and building their own laboratories. As a result, China has reached a leading global position: a recent report by *Harvard University* concludes that the country is now on par with America in several technological areas and has even overtaken America in the fields of artificial intelligence and quantum internet.

While Europe does not have the venture capitalists that America has, nor the concentrated approach of China, nor the big tech that both America and China possess, it does have excellent research institutes in various areas of quantum technology. Most academic publications have come from Europe, but in terms of patents, Europe does not do equally well.

The European Union has invested billions in the new technology since 1999, and also individual countries have made vast sums available for research, development and the creation of a startup ecosystem. The Netherlands has built one of the best, and to enhance its success, it is imperative that scaleups possessed with the vision and ambition for market leadership get more capitalized, allowing them to attract more talent, conduct more research, and gain a strong position in the market. It will increase

a company's value too, making it a tougher acquisition target for foreign companies and enabling them to acquire others instead. To achieve this, Europe will need to establish more venture capital in the *deep tech* sector.

To accelerate, Europe must convert its scientific papers into more patents and increase internal cooperation. In 2021, The Netherlands and France have taken the first step by signing a cooperation agreement for the development of quantum technologies. Then, there is a real chance that new developments occur side by side and the first quantum computer will be achieved by common global effort.

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