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Faculteit Bedrijf en Organisatie

How will quantum computing affect the computing environment and its applications?

Lukas Marivoet

Scriptie voorgedragen tot het bekomen van de graad van
professionele bachelor in de toegepaste informatica

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Co-promotor:
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Instelling: —

Academiejaar: 2019-2020

Tweede examenperiode

Faculty of Business and Information Management

How will quantum computing affect the computing environment and its applications?

Lukas Marivoet

Thesis submitted in partial fulfilment of the requirements for the degree of
professional bachelor of applied computer science

Promotor:
Martijn Saelens
Co-promotor:
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Institution: —

Academic year: 2019-2020

Second examination period

Preface

Samenvatting

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Abstract

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1. Introduction

De inleiding moet de lezer net genoeg informatie verschaffen om het onderwerp te begrijpen en in te zien waarom de onderzoeksvraag de moeite waard is om te onderzoeken. In de inleiding ga je literatuurverwijzingen beperken, zodat de tekst vlot leesbaar blijft. Je kan de inleiding verder onderverdelen in secties als dit de tekst verduidelijkt. Zaken die aan bod kunnen komen in de inleiding (Pollefliet, 2011):

- context, achtergrond
- afbakenen van het onderwerp
- verantwoording van het onderwerp, methodologie
- probleemstelling
- onderzoeksdoelstelling
- onderzoeksvraag
- ...

1.1 Problem Statement

Uit je probleemstelling moet duidelijk zijn dat je onderzoek een meerwaarde heeft voor een concrete doelgroep. De doelgroep moet goed gedefinieerd en afgelijnd zijn. Doelgroepen als “bedrijven,” “KMO’s,” systeembeheerders, enz. zijn nog te vaag. Als je een lijstje kan maken van de personen/organisaties die een meerwaarde zullen vinden in deze bachelorproef (dit is eigenlijk je steekproefkader), dan is dat een indicatie dat de doelgroep goed gedefinieerd is. Dit kan een enkel bedrijf zijn of zelfs één persoon (je co-promotor/opdrachtgever).

1.2 Research question

Wees zo concreet mogelijk bij het formuleren van je onderzoeksvraag. Een onderzoeksvraag is trouwens iets waar nog niemand op dit moment een antwoord heeft (voor zover je kan nagaan). Het opzoeken van bestaande informatie (bv. “welke tools bestaan er voor deze toepassing?”) is dus geen onderzoeksvraag. Je kan de onderzoeksvraag verder specifiëren in deelvragen. Bv. als je onderzoek gaat over performantiemetingen, dan

1.3 Research objective

Wat is het beoogde resultaat van je bachelorproef? Wat zijn de criteria voor succes? Beschrijf die zo concreet mogelijk. Gaat het bv. om een proof-of-concept, een prototype, een verslag met aanbevelingen, een vergelijkende studie, enz.

1.4 Structure of this bachelor thesis

De rest van deze bachelorproef is als volgt opgebouwd:

In Hoofdstuk 2 wordt een overzicht gegeven van de stand van zaken binnen het onderzoeksdomein, op basis van een literatuurstudie.

In Hoofdstuk 3 wordt de methodologie toegelicht en worden de gebruikte onderzoekstechnieken besproken om een antwoord te kunnen formuleren op de onderzoeksvragen.

In Hoofdstuk 4, tenslotte, wordt de conclusie gegeven en een antwoord geformuleerd op de onderzoeksvragen. Daarbij wordt ook een aanzet gegeven voor toekomstig onderzoek binnen dit domein.

2. State of the art

2.0.1 General explication of quantum computing

There are a few advantages that quantum computers have over any classical machine, to understand them we will have to introduce a couple of explanations.

The first is *superposition*, it is the term used to explain how a quantum bit (Qubit) can be in multiple states at once. In classical computing we are able to represent 1 state at a time with the use of a normal bit, 0 or 1. In quantum computing this is different through the use of superposition, a qubit can be in both states at one point in computation. (Peter W. Shor, 2000) Effectively this means that quantum computers can exponentially gain computational space through only the addition of 1 qubit, while a classical computer would add bits to only linearly gain computational space. But this only counts inside the computation, because as we know a qubit will 'fall' in a single state as soon as it is observed/ measured. (Rieffel & Polak, 1998)

A practical example for a clearer understanding of the term. Suppose that we have a classical system where we have access to 4 bits of processing space, this would effectively mean that we are able to represent 16 different states. If we compare it now we suppose a quantum system that utilizes 4 qubits of processing space, if we take in accounts the use of superposition 1 qubit is able to represent 2 classical bits. Meaning that we now have access to 16 computational space in classical bits, which also means that we have 65536 different states to represent.

$$Classical: \quad 4 \quad bits => 2^4 states \tag{2.1}$$

$$Quantum: \quad 4 \quad qubits => 16^4 states \tag{2.2}$$

Another really powerful tool for quantum computations is called *entanglement*. It describes the physical phenomenon that 2 particles can become entangled, meaning that ones state can directly influence the state of the other over an infinite distance. In our case, the particles represent the qubits that can become entangle which could mean that if 1 qubit is measured in a specific state and it is entangled with another qubit, it means that we are able to know the state of the other qubit *without* measuring it. Think of the possible utilisation in communication in between devices and/ or networks that this physical phenomenon could introduce.

Decoherence is also a term that forms a big issue right now for further advancements in quantum computing. Decoherence is the term that describes how a qubit can lose its quantum capabilities over time or due to interference from the outside world, currently to achieve quantum aspects we need to cool down the quantum devices to around 0 Kelvin or -273.15 degrees Celsius. Only slight fluctuations of the near perfect conditions can mean that the qubits lose their quantum capabilities, which would mean that the eventual computation becomes useless. As of now the Sycamore processor from Google has achieved the largest amount of qubits (53) to be used for a computation with 'fighting off' the decoherence. With 'fighting off' we are referring towards the process of Quantum Error Correction (QEC), this is a process that tries to prevent the decoherence and interference between the qubits. This is as of now the main restriction on just expanding the number of qubits, because the more qubits are used in the system the more the system will be susceptible for decoherence and interference. (Cory et al., 1998, 10)

2.0.2 Practical fields of study using quantum

Security

A great concern with the rise of quantum computing has come up, people are believing that our current encryption system is easily breached by quantum computation. But indeed everyone was shocked when Peter Shor released his paper P. W. Shor (1994), which described a way to resolve prime factorization on quantum computers. A classical computer can easily find the result of a multiplication but finding the factors of a large number is an exponential computation for a normal computer. Shor's algorithm uses superposition and quantum Fourrier transform to resolve this exponential issue, meaning that it would suddenly become really easy to brute-force encryptions of data (e.g. RSA). (Rivest, Shamir, & Adleman, 1978) This could possibly mean that the praised mainframe environment would become a lot less secure. In reality however factorization of large numbers is not the only way that we encrypt our data. For example the AES algorithm uses multiple partitions of a key to encrypt its data, which would re-introduce the issue of exponential computation even when using a quantum computer.

(Daemen & Rijmen, 2000) (Amico, Saleem, & Kumph, 2019, 1)

In effect the introduction of quantum computing will most likely result in a much safer environment, because through the utilization of quantum encryption our data could even become impenetrable for quantum computers. When quantum computing will be implemented alongside the already existing mainframe applications, it will only strengthen its safety aspects and also the speed of these encryptions in mass.

Data

Physics and chemistry

Open source software

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3. Methodology

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4. Conclusie

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A. Onderzoeksvoorstel

The proposition of this Bachelor thesis, that has been checked by the promotor, has been included as an attachment to the full paper.

A.1 Introduction

A.1.1 Situating the subject

There has been a strong believe over the last 30 years that quantum computing can and will influence our sophisticated environment more than we think. In case of the mainframe environment it will maybe be the most influenced sector in *computer science*, because of its immense creation of data. Data will become or has already been the driving factor inside our societies, think of how much our daily lives are already controlled by data (e.g. online shopping, social media etc.). With the usage of mainframes we are able to create a sense of logic in this almost infinite pile of data. Now with *theoretical* utilisation of quantum computing, data can be searched more thoroughly and faster. (Grover, 1996)

If we are able to find and explore quantum applications for our current high-transactional business applications, a new wave of investment in research will open itself up. Which would obviously boost both fields at once. In this paper we will try and find these general applications that can prevail through the use of quantum technology.

A.2 State-of-the-art

A.2.1 Prior knowledge

Inside the paper a couple of physics specific terms will be utilised. If you are not familiar with basic quantum physics notations and or terms, it would be highly recommended to read one or both of the following papers, (Rieffel & Polak, 1998) or (Peter W. Shor, 2000). For the general quantum notation that are used throughout the field, we refer towards Dirac (1939). It is also possible to read this paper as an informational piece without the implications of the mathematics and physics surrounding the subject. As previously stated the paper will not be going in depth technologically, because the scope is more focused on exposing the practical usages of quantum computing compared to classical computing or the combination of them both.

A.2.2 Recent developments

As of now Google has claimed to have won the *Quantum Supremacy race* (Arute et al., 2019) against IBM. They have realised this through the creation of their 54-Qubit quantum computer (53 functional qubits), that is able to perform a calculation exponentially faster than a classical system could ever hope to perform. In this case the *Sycamore* (Quantum processor) was able to perform a calculation within 200 seconds that could only be performed by a classical computer over 10.000 years (theoretically). Although it most definitely was an experimental calculation that has no real value in the business world, it does however prove the potential of quantum computing. It has been rumoured that IBM will release its counterpart of research in 2020. The fact that these 2 conglomerates are competing so fiercely will only further the technological developments in the realm of quantum mechanics. IBM has not been sitting idly either, they have released a paper regarding quantum algorithms applications. (Amico et al., 2019, 1)

A.3 Methodology

While the field of practical quantum computing is still in its infancy, there are a lot of different possible angles to approach the subject with. First of all we will be introducing the guiding principles of quantum computing, as to all start on the same footing. Then we will explore the realistic potential that quantum computing can offer for economic gain, especially for mainframe development. This will mainly be comprised of an extensive literature study that will set its focus on economic applications of quantum computation and thereby on the mainframe environment. Concretely the paper will use real-life economical batch data and will process this data through the use of quantum algorithms and classical algorithms. If there are any advantages in processing the nightly batch load by using quantum algorithms, it will become provable that quantum computing can also be extremely profitable. There will also be demonstrations of quantum computation software such as Qiskit by IBM (Abraham et al., 2019), Cirq by Google (McClean et al., 2017) and Q Sharp by Microsoft (Svore et al., 2018). Qiskit stands out because it is an IBM Python framework that solely offers the opportunity to actually execute your quantum circuits on real quantum devices as of today. (with limited qubits however)

A.4 Expected results

The paper will try and create a more concrete point of view on the possible features quantum computation can offer. Through the analysis of multiple papers, we are hoping to find certain points of contest. These points indicate the highly debated subjects within quantum computing and are therefore extremely valuable. We will be trying to locate and display the business potential within these points of conflict. Currently IBM has created an extremely stable and performant business environment with its mainframe, Z15 and its older versions. Anything that can/ will affect this stable business platform can form a great threat or opportunity to the way we currently create and process our data. To protect this stable platform, we will be trying to index all the threats and opportunities that come with the introduction of quantum computation in our current computational environment. The second part of the paper will be more software-orientated, where we will be creating an application that processes the typical nightly batch data. This application will be performed on the different quantum platforms an on a classical device. The paper will visualise these probabilistic and timing differences between results of the different software platforms and will try to show attention points with simulating quantum computers compared to effectively executing on one. Through the demonstration of quantum computation we hope that readers are going to be personally inspired to be creative with the new technology and start developing their first 'Hello World' with their quantum circuits.

A.5 Expected conclusions

We are expecting to *debunk* the more absurd ideas of quantum computing. (e.g. destroying all our encryptions and our society) Concretely, we are going to put the whole subject inside a more realistic 'future' vision. This will hopefully offer readers ideas of possible applications of quantum computation inside their departments (e.g. Chemistry, Economics, Astronomy etc.) Also With software being so readily available for the general public, we expect that quantum computing applications will be created exponentially faster than with the dawn of classical computing 70 years ago. With this train of thought, we are hoping that real economical value can be available within the next decade. By processing our example night batch load we hope to find this necessary business value. Frameworks like Qiskit will be developed further and more powerful quantum computers will be made available towards the public to boost the research in the subject. And with these thoughts we can be certain that interest in quantum computers will only increase in the future.

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