MAXWELL

Electrotechnische Vereeniging

Issue 24.2 | March2021

PREDICTION, AN UNCERTAINTY

Interview with Dr.ir. G.R. Chandra Mouli
About EV Charging and load prediction

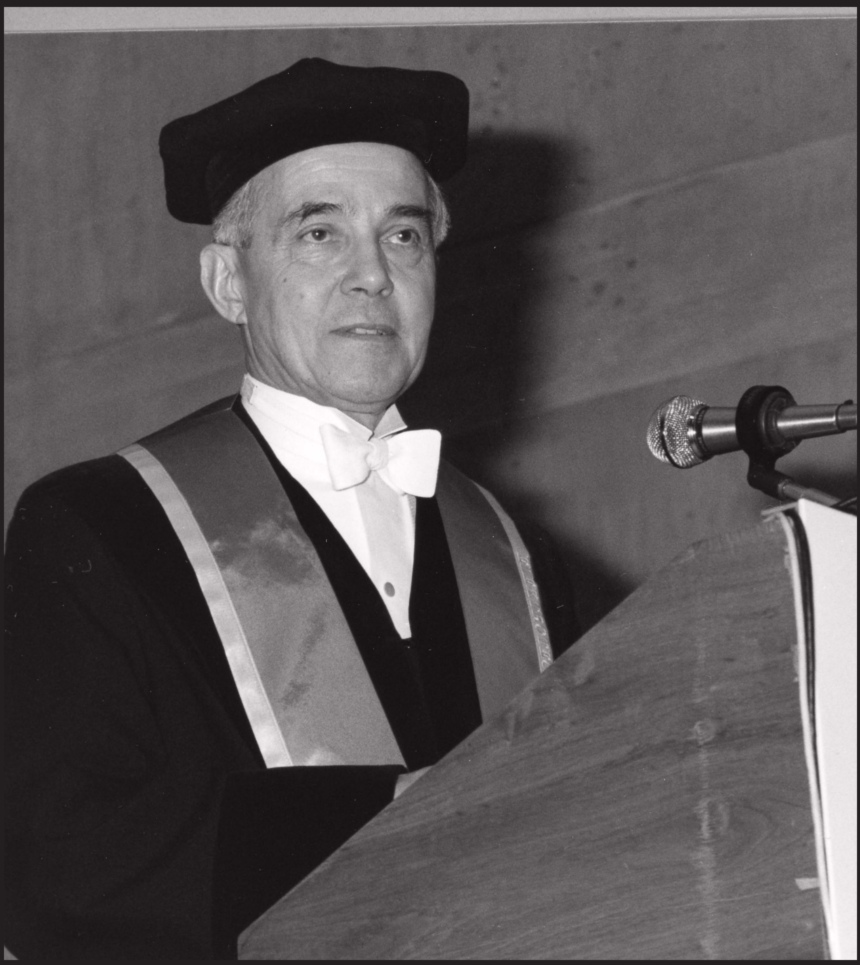
Black Hole Visualization
By Annemieke Verbraeck

What is Quantum Computing?
By Prof. dr. ing. K.L.M. Bertels

IN MEMORIAM

We deplore to announce that has passed away at an age of 96

Prof. ir. Hans van Nauta Lemke



Emeritus Professor and Rector Magnificus Delft University of Technology
Honorary Member of the Electrotechnische Vereeniging

* November 22, 1924
Palembang

January 10, 2021 †
‘s-Gravenhage

Since 1989 the Electrotechnische Vereeniging has had the honour of having Mr. Van Nauta Lemke as Honorary Member. Our thoughts go to all involved.

From the Board

Dear Reader,

Another Maxwell edition is published and thus another quarter has passed in this very strange time. It has been tough for all of us. We are all familiar with the circumstances, and we all would like to have a taste of our old lives again. Just for one day, to break free from the daily grind we have lived in the previous year to shake things up.

Some of us have discovered new hobbies, some of us have found a new love for being outside and some have enjoyed watching lots of movies with their housemates. The pandemic has made us more creative and forced us to discover new things we did not know about ourselves.

A year ago I was asked if I were up to the challenge of becoming a Board member of the Electrotechnische Vereeniging, and what an experience has it been so far!

When looking back on the past few months I see a lot of exciting activities, a lot of new committees and lots of students who are actively enjoying the ETV during these times.
This year has taught me and the rest of the Board to make the best out of a situation that did not go as anticipated because as we all know, this year played out differently than other years.

A few weeks ago, the EEMCS Recruitment Days have taken place, which to me was the most important event this year. It is something I was extremely excited about and I have worked towards since this year started.
Now this intense yet special week has passed, I have more varied duties which means there is room to work on new projects and coming up with fresh ideas to introduce our partners to the students.

Enjoy the rest of the year, and remind yourself to relax once in a while.

With excited regards,
Floor Walterbos
Commissioner of External Affairs of the 149th Board of the Electrotechnische Vereeniging

Dear Reader,

We have arrived at a new quarter. I don't think anyone would have been able to predict the current situation at the start of this academic year. EWI has been closed for a few months now, and probably will be for a bit longer due to fire safety issues. Luckily, there is light at the end of the tunnel, as experts expect the virus to be containable by this summer. This means that activities such as the first year weekend, the gala and Lustrum activities are just over the horizon. Keep your head up!
If you have any questions or comments regarding your studies, know that we work daily from our digital Board room on discord. You are always welcome to join us for a chat even if it is not study related!

With excited regards,
Tim Plantfeber
Secretary of the 149th Board of the Electrotechnische Vereeniging.

Colophon

Year 24, edition 2, March 2021

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Editorial

Dear readers,

Welcome to the second edition of the 24th Maxwell! The theme of this edition revolves around the role of electrical engineering in not only building, but also predicting, our tomorrow.

The power of prediction in the mathematical sciences, stemming from the understanding of probability together with access to massive amounts of data, has become a cornerstone of modern scientific applications. Unfortunately, in the public sphere, it has also given birth to one of the biggest modern misconceptions about science: that scientific outcomes are 'conclusive', whereas in fact, all scientific methods are essentially the understanding and art of 'uncertainty'.

For this edition, the Maxwell committee reached out to researchers who are working with prediction and uncertainty across diverse fields in electrical engineering – from black hole visualisation to quantum acceleration, to how data-based prediction is being incorporated into EV charging and the European power grid.v

We hope you will enjoy the articles we have brought together. A big thank you to all our contributors for sharing their experience and insights. I also want to express my gratitude to the Board and my fellow committee members, without whom this edition would not have been possible.

Natasha Birari

INDEX

The Hammer Computer

Kees Pronk

At the Study Collection, we were aware of a large machine (3.0 x 1.5 x 1.0 meters) standing in a dark corner. The origin and purpose of this machine had long been forgotten. Fortunately, an observant visitor was able to tell us where the device was built and who the designer was.
The device had been constructed around 1950 at the Nederlands Radar Proefstation (Dutch Radar Testing Station) in Noordwijk (now: Christiaan Huygens Laboratory in Katwijk) under the supervision of its designer ir. J. A. Hammer (figure 1). A brief description of the machine, as well as the author, is given in [3].
A literature study yielded two articles. The first article [1] is a report by Hammer at a scientific conference in France, expounding the scientific progress made by using this machine. In the accompanying survey article [2] more details of the machine are presented. After studying these articles and opening up the machine to examine its construction, gradually, a picture began to emerge of the purpose and structure of this analogue and mechanical calculator.

The construction of this machine started around 1950. To really know what we are dealing with, we must go back to that time to understand the development of radar technology and the construction of computers in those years. This whole exercise resembles technological archaeology: from the artifacts found, an image is formed of the operation of the machine, like a puzzle being slowly put together.

The Hammer computer was designed and built for a special purpose: the design and calculation of linear radar antennas. With radar transmission antennas, it is important to generate a beam of radiation that is as narrow as possible, without so-called "side lobes" (figure 2). Since the radiation pattern of a single antenna is relatively wide, an array of antenna-slots is used to achieve a narrow beam (figure 3). The total field generated by these antenna-slots is the sum of the contributions from all slots. Due to interference, the fields generated by the individual slots amplify each other in the antenna aiming direction and weaken each other in the other directions, thereby reducing the effect of the side lobes.

Rekenmachine van Hammer

Fig 1. Hammer's Calculator

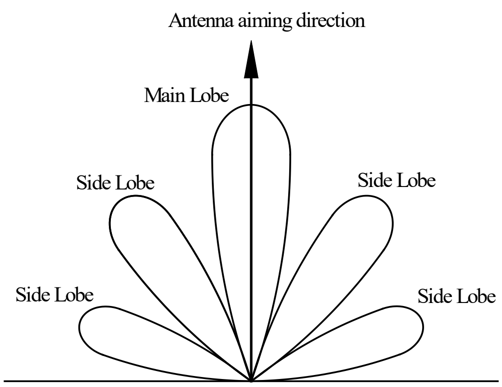

Fig 2. Radiation Diagram of a single antenna

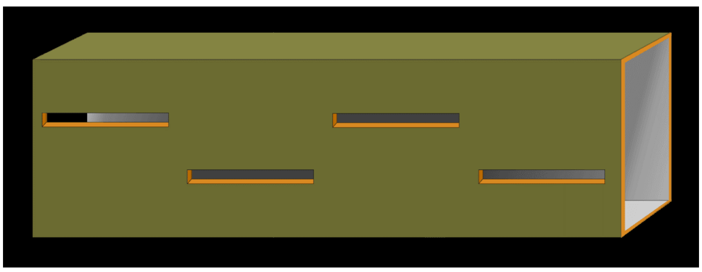

Fig 3. Example of a slotted antenna

The Design of the Computer

Hammer's computer is designed to perform two functions: (i) using up to 41 antenna slots, the machine calculates the field strength of the E-field, and (ii) starting from a prescribed radiation pattern, the machine calculates the needed contributions of the (at most 41) individual antenna slots. In other words, this unique mechanical / analogue machine simulates radar waves. The block diagram of the computer can be seen in figure 4. Whereas the frequency range of radar is around 30 GHz, here a frequency of 1000 Hz is used. The sine wave of 1000 Hz is presented to 41 parallel calculation channels via a signal distribution device These channels are numbered -20° .. 0° .. +20°. Each channel simulates one antenna slot.

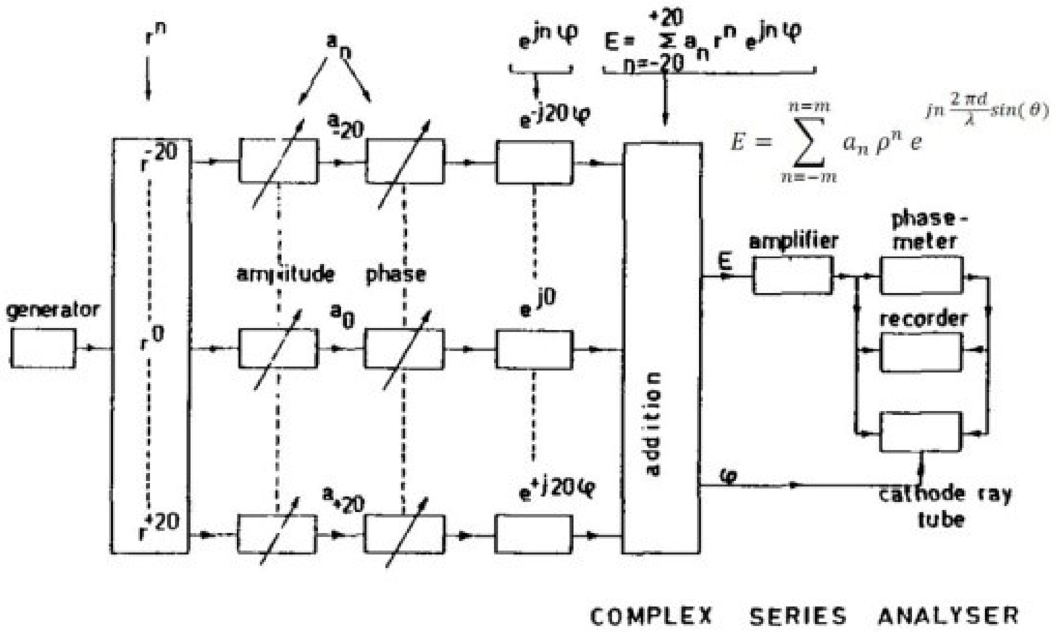

Fig 4. The block diagram of Hammer's machine. All calculations assume that the antenna slots are the same distance 'd' from each other

Fig 5. X-Y resolvers and the gear box. The positive resolvers rotate clockwise; the negative counter clockwise. The central resolver is stationary

To calculate the E-field the operator manually sets the amplitude and phase of each antenna slot on the computer. The amplitude for each channel can be set with a buffered 10-turn helipot.
Some more thought was put into setting the phase on this machine. Each channel is equipped with a so-called x-y resolver. The experimenter sets the desired value of the phase by manually turning the stator of the resolver. The rotor of each resolver is driven from a central gearbox with ratios 1: 2: 3: ..: 20. When the desired phase is set, the x-y resolver translates the mechanical angle between the stator and the rotor into two AC voltages [5]. Both, the resolvers and the gearbox, have been mounted on a very sturdy sub-chassis, so as to increase the accuracy of the computation. Figure 5 shows some resolvers and the gearbox.

The E- field is calculated for a large number of angles (θ = -30° , ... , + 30°) from the antenna aiming direction). The gearbox is driven by a central motor. This motor sets the angle θ from the aiming direction.
Using the formula

$$E = a_n \, \rho^n e^{-j\,n\frac{2\pi d}{\lambda}\sin\theta}$$

the strength of the E-field of the nth antenna slot is calculated. Subsequently, all field strengths are added together:

$$\sum_{-20}^{+20} a_n \, \rho^n \, e^{jn\phi}$$

The result is shown to the experimenter via an oscilloscope and/or a paper recording device (remember when paper recording was a norm?) as shown in figure 1. The addition of the signals is done via buffered amplifiers that use vacuum tubes. Figure 6 shows the bottom part of the electronic signal processing unit of eight resolvers.

The computer's second function of is calculating the amplitude and phase settings of the antenna slots starting with the prescribed E-field i.e. inverse processing. Towards this purpose, a so-called 'rootpot' is connected to the circuit [2]. The functioning of this part is based on finding the roots of the equation

$$\sum_{-20}^{+20} a_n \, \rho^n \, e^{jn\phi} = 0$$

Solving this equation using the 'rootpot' will give a number of complex roots. Although this part has been located in the machinery (figure 7), its precise operation is still unclear. Presumably the 'rootpot' is also used as the aforementioned signal distribution device.

Hammer's computer calculates the E-field in 12 seconds. Digital computers of that time (in 1955) needed 700 seconds for this calculation. The great developments that took place in digital technology later made this analogue / mechanical calculator from Hammer superfluous, and it was eventually donated to the Study Collection in Delft.

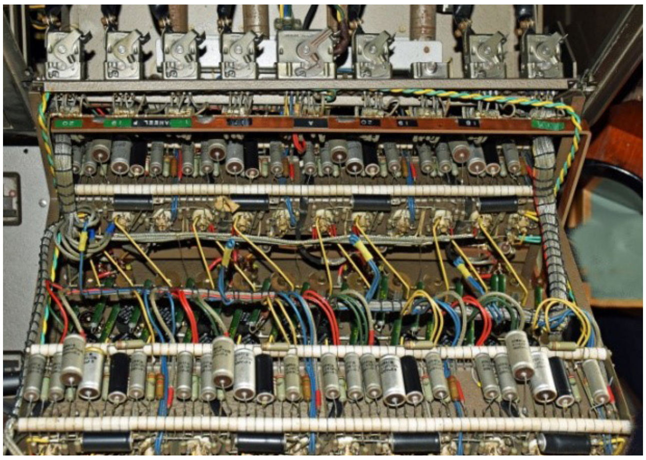

Fig 6. Electronics for signal processing of 8 resolvers

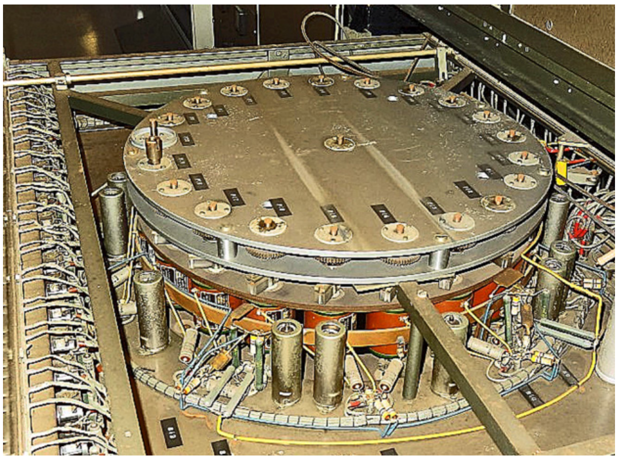

Fig 7. The Rootpot

Applications of Linear Radar Antennas

Various radar installations were constructed on the basis of experiments with Hammer's computer, both onshore and on frigates of the Royal Dutch Navy. Figure 8 shows an application of a linear radar antenna on the Dutch frigate zr. ms. Tromp (the black box on the stern, designed and produced by Thales in Hengelo). Of course, the most modern radar techniques have been used here. For more information on modern techniques, the reader is referred to [4].

Conclusion

During the Second World War, the development of radar technology in the Netherlands came almost to a standstill. After the war was done, it was decided that the Netherlands should start its own developments in this field. The Dutch Radar Test Station was established in 1947, and it started scientific and applied work on this subject. One of the developments was the creation of this analogue / mechanical computer by ir. J. A. Hammer in the years 1950-1955. It is remarkable that Dutch engineers were able to create this splendid example of electronic and mechanical design so shortly after the end of WWII.

Fig 8. zr. ms Tromp

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[1]The Evaluation of Diffraction Problems in Aerial Technology by Means of an Analyser for
Complex and Fourier Series, by: J. A. Hammer in: Principes fondamentaux: Équations de Maxwell, Principe de Huygens et Théorie de la diffraction en hyperfréquences (1956)

[2]Near Field Measurements and the Synthesis of Linear Arrays with Prescribed Radiation
Patterns: A Survey of some Early Work at the Christiaan Huygens Laboratory, by: E. Goldbohm (formerly professor at TUDelft) in: IEEE Antennas and Propagation Magazine, Vol. 35 No. 3, June 1993

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[4]https://www.museumwaalsdorp.nl/nl/radar-nl/radar-phased-array-onderzoek/

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tennas and Propagation Magazine, Vol. 35 No. 3, June 1993

EV Charging: Load Prediction, Smart Charging and its Impact on the Electric Grid

Interview with Dr.ir. G.R. Chandra Mouli

Aniruddh Kulkarni

Dr. G.R. Chandra Mouli is an Assistant Professor in the DC systems, Energy conversion and Storage group in the Department of Electrical Sustainable Energy. He has received his PhD from the Delft University in 2018 on the dissertation associated to the development of a solar powered V2G electric vehicle charger compatible with CHAdeMO, CCS/COMBO and designed smart charging algorithms. Dr. G.R. Chandra Mouli received 'Under 35 Innovator' award from the IEEE Industrial Electronic Society in 2019. Based on the specialization of Dr. G.R. Chandra Mouli, we discuss the future of the electric vehicle charging infrastructure. The 21st century has seen the new face of the automobile market: the electric vehicles. In 2010, the global count of electric cars was only 17,000. As per the International Energy Agency, the automobile market has seen a year-on-year growth of 6%, swelling the total count of electric cars to 7.2 million[1].

This exponential rise in the number of electric vehicles, raises an important question: Is the charging infrastructure developing at par with the vehicle technology? To this Dr. G.R. Chandra Mouli puts forth a perspective that this development of charging infrastructure is dependent on the country. Development of charging infrastructure means that, a balance is maintained in the ratio of number of vehicles to the charging stations. This development in the charging infrastructure var-

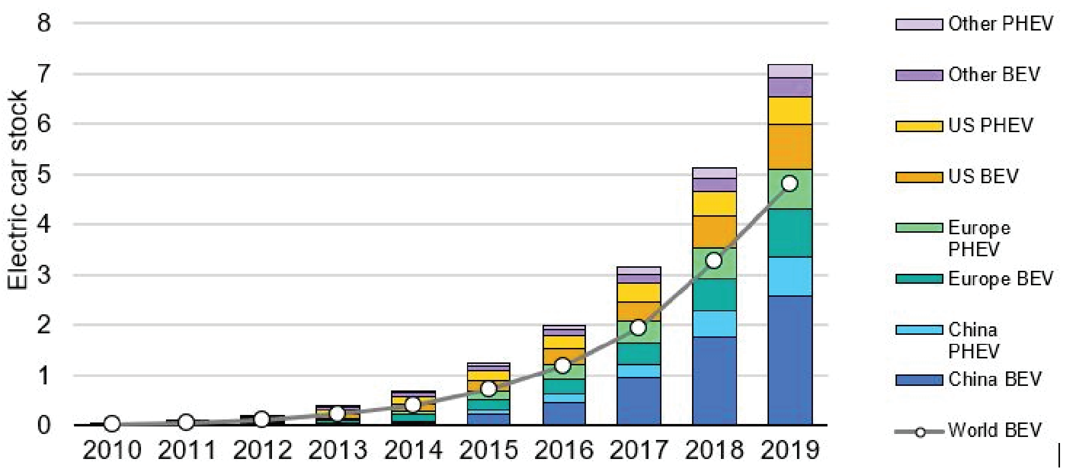
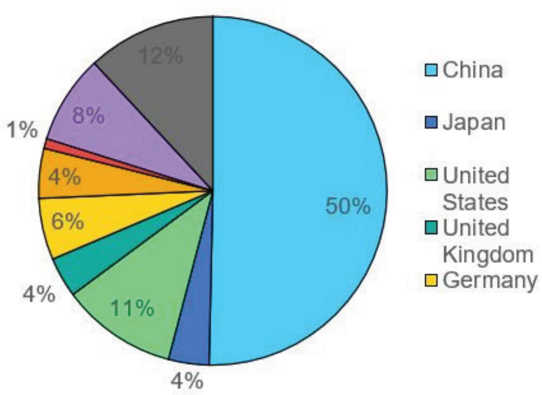


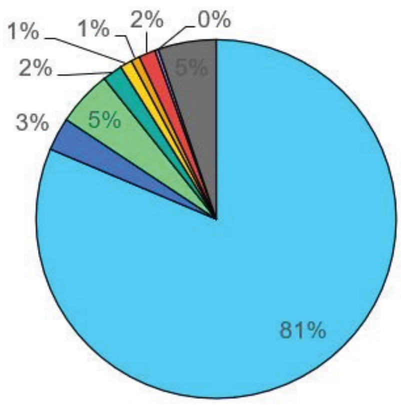
Fig-1: Rise of EV market from 2010 to 2019 ies by geography. According to the International Energy Agency, the global figure for installed chargers were 7.3 million in 2021. There are a few countries which have more vehicles than the charging infrastructure. Figure-2 shows country-wise distribution of number of charging stations built. This imbalance results in an increased waiting time for users to charge their vehicles or to commute to large distances due to unavailability of nearby charging stations.

The charging infrastructure can be categorized into two types: The first type of charging station is a long duration charging station i.e., chargers located in offices, public charging stations within the city etc. Such stations are meant for fulfilling the daily charging requirements of EV owners. The second type of charging stations are meant for fast charging. These stations are located on highways and routes of long-distance travel. Some of the industries making progress in installing and operating charging stations are Fastned, Ionity, Tesla Supercharger, EVgo.

The load experienced due to charging EV's has much higher magnitude than the conventional loads. Hence, the impact on the electrical grid will be much higher when the EV-charging is taken into account. Most of the present distribution electrical grids are not capable of handling such kinds of loads. For reducing this impact on the grid techniques like "Smart Charging" have come to existence. Smart charging aims at managing the supply and demand of the EV charging, by establishing protocols/algorithms to the way the users charge their vehicle and control the way in which battery of an electric vehicle is charged/discharged. This is one of the focus points of the Department of Electrical and Sustainable Energy. One of the techniques that Dr. G.R. Chandra Mouli confers is Congestion Management. This in other words is the efficient management catering to the peak demand of the load. The peak demand cycle occurs at fixed durations in a 24-hour cycle. Congestion Management deals with spreading out the time during the peak load hours throughout the 24-hour period such that the energy consumed remains the same but the power reduces for the peak load time intervals. An alternate method is to install locally generated renewable charging stations. This will be effective in sense that there will be less impact of the load on the grid.



Publicly accessible slow chargers 598,000



Publicly accessible fast chargers 264,000

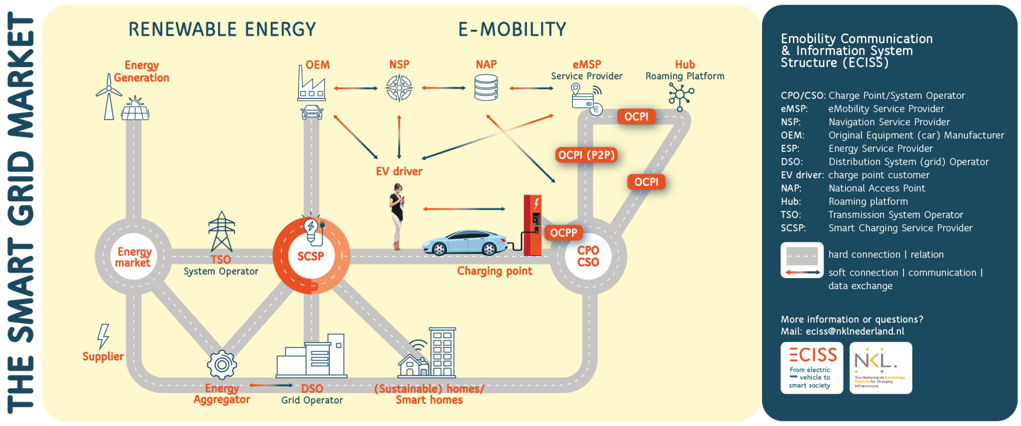
Fig-2: Global distribution of publicly available charging stations Publicly accessible fast chargers 264,000

Aggregator based Charging: -
One of techniques of smart charging is the aggregator-based charging. Aggregator based charging is one of the techniques which involves the contribution of the whole EV ecosystem. The EV (electric vehicle) ecosystem consists of several key components: the car manufacturers, the charger manufacturing industries, industries that install and operate the chargers, individual entities that provide the charge controlling software. The

energy market players such as energy producers and suppliers, companies responsible for supply-demand balance and the distribution system operators also a part of the EV ecosystem.
An individual EV owner/user does not have any idea of the total load experienced by the grid at certain point of time. Hence, from a customer centric view the control of charging is not possible. Based on the user behaviour,
there are certain durations in a day in which most of the EV's of a particular region will be charging. This will result into a surge of the load on the grid. These intermittent surges of load during the peak demand duration have to be distributed in order to reduce adverse impact on the grid. To accomplish this distribution there will be some potential entities in the future, who will be responsible to cluster the data and provide a prediction of load, spread out in a 24-hour cycle. These entities are called "Aggregators."

The primary function of an aggregator is to acquire the charging demand of every individual EV user. This charging information is dependent on the user profile by collecting information such as arrival time, parking time. Out of the whole EV ecosystem, any entity can take up the role of an aggregator. Independent entities can also assume the role of an aggregator. Multiple aggregator companies are present in the ecosystem which collect the data of a set of users for predicting and controlling a part of the load. Collectively, this data presents the total load profile at a national grid level.

To acquire the data of individual charging demand, the aggregators use different charging protocols. Some of the charging protocols used by the aggregators are Open Charge Point protocol, the Open Smart Charging protocol. For example, the e-mobility service provider handles the financial transactions related to charging. This financial transaction reflects the details comprising of duration of charging, location of charging etc. However, some charging stations are not included in the aggregator supervision. The load at such charging stations can be accounted for as uncertain load. Hence, the net load prediction is made by observing the charging pattern of EV owners and extrapolating the data.
The load due to EV charging is a long duration load imposed on the grid as compared to the conventional loads, which are switched frequently. Due to the prolonged time for charging, there will be an overlapping in the loading conditions i.e., due to multiple users charging their vehicles in the same time duration. Once the load profile is built based on integrating individual charging demand, in the same time duration. Based on the grid congestion and available sources such as renewable charging, different pricing schemes can be devised. The cost for charging is determined based on the optimal power consumed versus time profile for every individual vehicle. Hence, one of the possible methods is to decrease the loading during peak demand is to increase the price charged per unit



Traditional wide beam communication systems vs next generation system with dedicated for users power consumed (cost/kWh).

Despite the smart charging techniques, there are multiple factors determining the loading on the grid such as EV penetration, grid features, rated charging power of vehicles, charging behaviour pattern etc. Based on the EV penetration the peak load for grid has been calculated. Research has shown that a 10% market penetration of EV would result in an increase of 17.9% in daily peak demand while a 20% market penetration would result in an increase of 35.8% in daily peak demand [2]. This data concerns with the grid loading conditions. For an individual, the maximum demand will increase by 18% from every 10% increase in houses with EV's [3]. The impact of this increased load will be more prominent on the distribution network than the transmission network. Most of the distribution network have an installed capacity to operate at higher load conditions, there are some networks present which operate near to the peak load. Such networks, will undergo overloading condition. This issue can be resolved by increasing the installed capacity.

The above situation describes that the grid will certainly need an upgrade in the power capacity to satisfy the growing demand of EV charging. However, upgrading the grid will require a significant investment. Hence, Dr. G.R. Chandra Mouli believes that the future of charging infrastructure will turn towards an optimal solution which combines the smart charging techniques and the upgrade in electrical gird.

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1. IEA (2020), Global EV Outlook 2020, IEA, Paris https://www.iea.org/reports/global-ev-outlook-2020

2. K. Qian, C. Zhou, M. Allan and Y. Yuan, "Modeling of Load Demand Due to EV Battery Charging in Distribution Systems," in IEEE Transactions on Power Systems, vol. 26, no. 2, pp. 802-810, May 2011, doi: 10.1109/TPWRS.2010.2057456.

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Black Hole Visualization

Annemieke Verbraeck

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A surprising amount of black-hole articles
It seems every week I find a new article on my feed concerning new and surprising discoveries in space. Many of these are about black holes, although that might be just me, as Google must think I am obsessed with the phenomenon after searching for the Black Hole Wikipedia article hundreds of times during my research. Even though black holes are surprisingly simple - some of them can be defined with only one parameter – their influence on their surroundings is not easy to grasp. Despite my background in Astronomy, I often found myself double checking the basics to make sure my implementations and definitions were correct. If my Astronomy BSc taught me anything, it is how easy it is to make mistakes dealing with complicated physics formulas that cannot be verified in an experiment on earth.

From Astronomy to Computer Graphics
Another thing the Astronomy BSc taught me, is that those physics formulas were a bit too abstract for me and a lot more present in the study than the pretty Hubble Telescope imaging of deep space. This realization led me to pursue a master in computer science with a specialization in Graphics at the TU Delft. For my masters project, the professor of our group, Elmar Eisemann, immediately knew what I was going to spent all my time on. He saw the movie Interstellar, skimmed through the paper about their black hole visualization, and concluded that their simulation was not optimal, at least in terms of speed. With my astronomy background, I was the perfect candidate to fully understand all the formulas in the paper and work out a smarter and faster solutiovn. I am now in my third year of my PhD at the Computer Graphics group, and only this October did we publish a paper on our findings. As it often goes in research, at first it is more difficult than expected and at the end there is always some code to improve and some functionality to add. The end result was worth all the work however as we received an honorable mention for best SciVis paper at the Vis 2020 conference.

Taking a trip to a black hole
The easiest is to start the explanation of our research with a little thought experiment to describe our setting. Imagine yourself to be a wealthy tourist on one of the first spaceship trips. The guide starts talking excitedly, as you are approaching the grand finale of the tour, a real Kerr black hole. Unlike Schwarzschild black holes, Kerr black holes are spinning rapidly, so the spaceship has entered a stable orbit around it, to prevent getting sucked in. After all this travelling you know that space is a very empty place, so while you are close to the black hole, all the stars and galaxies are almost infinitely far away. So

far away in fact that if you would make a simulation, they could be approximated by existing on a celestial sphere with infinite radius around you and the black hole. The big question now is of course, what do you see when you look out the window? What do you expect to see?

Real image versus Simulation

The first thing that now pops into your mind is probably the image of our simulation (Fig.1) that made you interested in this article in the first place. Had you not seen it however, it might be the image of an existing black hole that was constructed last year from telescopic data, or it might be a simulation, like the one of Gargantua, the black hole in Interstellar. A large team of researchers worked on its depiction - one of which is the famous astrophysicist Kip Thorne - to make sure it was a very precise and physically accurate simulation. While this research produced IMAX quality imagery, a CPU farm was required for rendering, and for some frames this process took up to 100 hours.

Obviously it will take a while before we can go on touristic trips to a black hole, so until then we have to be satisfied with simulations, but not everyone has a CPU farm at their disposal. Our approach therefore aims to produce a high-quality interactive simulation that can be run on your own computer in real time, to come a little closer to that experience of looking out of the window of the spaceship.

I will explain step by step how we achieve this, but before that, we first must understand why visualizing a black hole is not straightforward and why it took Interstellar so long to render these frames.

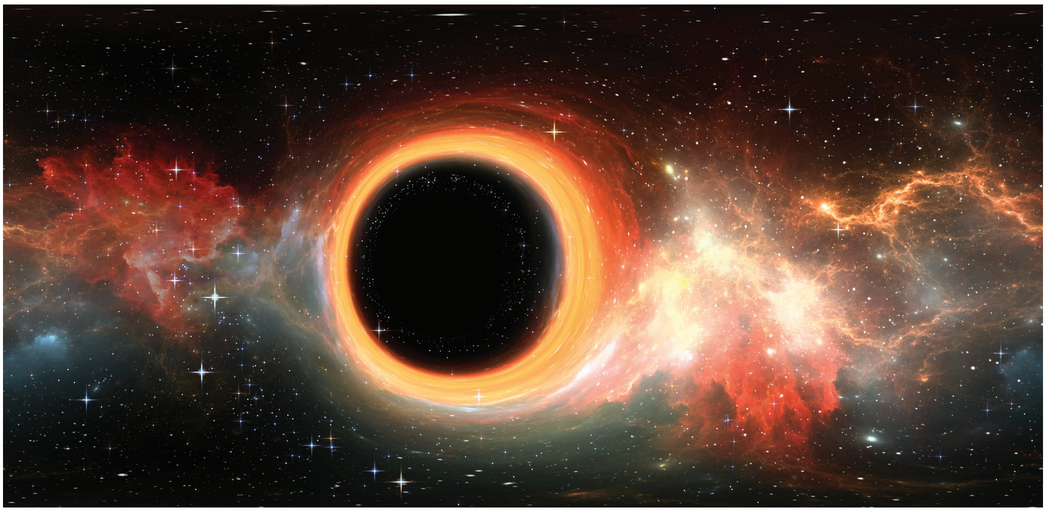


Fig 1: Result of the simulation

Infinite Images

As mentioned before, black holes influence their surroundings. The presence of a massive body like a black hole deforms space-time, and this affects everything that gets close to it, even weightless particles like photons. Let us imagine following the light rays originating from a far-away star until they hit your eye. As you can see in Fig.3, due to the presence of the black hole, the rays do not follow straight lines, but take curved paths through space. As we only detect the photons when they reach our eyes, we expect the star to be located in the direction where the photon arrived from. On top of that you can see that different light rays from one star follow different paths to your eye, which means photons from the ame star come in at different angles, and thus show you images of the same star at different locations in Fig.2. To make it even more crazy, the multiplying effect happens an infinite number of times. And then some light rays do not reach your eye at all, as they are trapped by the black hole and cannot escape. This results in the black portion in imagery of black holes, called the shadow. Looking at it from this way, saying that we aim to visualize a black hole is not accurate at all, as the only thing we see – or not see – is how it influences space around it.

Light always takes the shortest path

Making a virtual world and depicting it as accurately as possible on a computer screen is what computer graphics research is for. The most basic approach uses the physical principle that we can observe an object because there is light that hits the object, and then bounces from the object into our eyes, enabling us to construct an image of it in our mind. We invert this principle to get images from a virtual world onto a screen. To find out the correct color for each pixel we trace a light ray back from the viewer, through the pixel, into the virtual scene, to see what object it hits and if the object is illuminated. However, these scenes are usually in an earth-like environment, where light rays follow straight lines, and we can in general expect objects to be located at the direction we observe them in. For our black hole case, we do take a similar approach, where we start at the viewer and trace rays through the pixel back to the Celestial Sky to see what star or galaxy it hits there. Due to the presence of the black hole however, this ray will be curved, and can only be traced through space by performing a numerical integration of a set of differential equations based on the spacetime metric. This ray-tracing integration is very costly, and an interactive simulation is not feasible when having to trace lots of these rays. This means there are two things we had to do: making the ray tracing faster, and doing less of it.

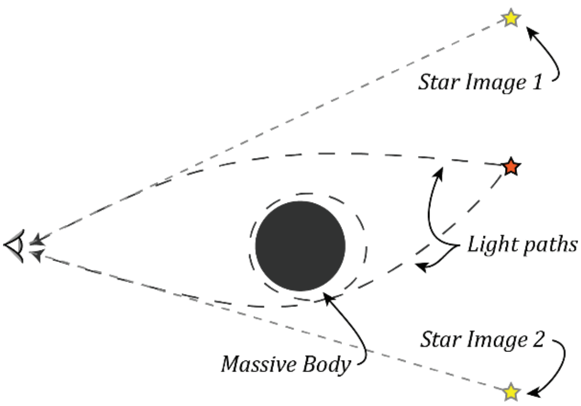


Fig 2: Due to the presence of the black hole, we see multiple versions of the same star at different locations.

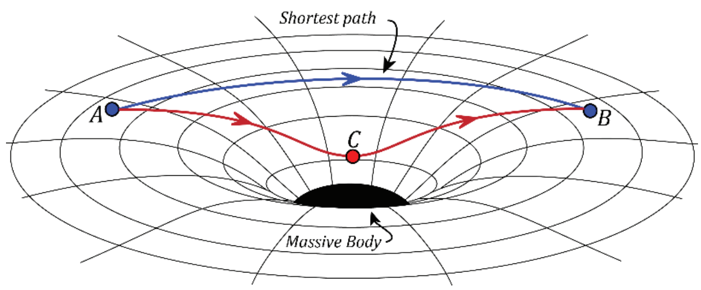


Fig 3: Light rays will always follow the shortest path from A to B.

Stellar Problem

The researchers depicting the stellar sky behind Gargantua quickly found out that their initial method of tracing one or multiple rays per pixel resulted in a completely black image. The reason for this is that the stars are defined as point lights and hitting this exact point with a traced ray is almost impossible. While larger objects like galaxies can be projected onto a 360-panorama map that covers the celestial sky (Fig.5), stars are much smaller lights than even one pixel. The solution for their missing stars was not to trace single rays, but elliptical ray bundles. Every bundle starts from a spherical area around a pixel, gets traced back through space and ends up as an elliptical area on the celestial sky (Fig.4). All stars in this area could then be integrated to determine the final pixel color and brightness. The elliptical ray bundle equations are even more complicated than single rays however, and thus take even longer to compute.

Step 1: Faster Raytracing

Our first step to achieve speedup is to use the principle behind the complicated elliptical bundles, but do the actual tracing using single rays. We also work with an area, but one that starts as a square, the pixel itself. We then trace a ray through every pixel corner and end up with a polygonal region on the celestial sky, which we can integrate just like the elliptical area. As every corner is shared by 4 pixels, we get to trace an area at the cost of only one ray per pixel. With our polygonal regions we trade in a bit of quality for a lot of speedup.

In practice the integration at the celestial sky is nothing more than a check to see which stars and which part of the 360 panorama is included in the polygon, and then adding up their colors and brightness.

Step 2: Less Raytracing

For the second step of our speed-up, we use the fact that the distortion of the environment stays the same as long as we stay in the same place. For one such position, we only compute rays once, coming in from directions defined on a spherical grid all around us. Because the distortion is smooth, we can interpolate this generated grid to create images looking in any orientation and with different projections. This way, we can show what our eyes would see with their limited field of view, or show how everything around us deforms at once, with a 360 panorama like in Fig.1.

As you can see in Fig.5, the distortion is more severe closer to the edge of the black-hole shadow. A lot of rays are needed in those regions to correctly interpolate, but in less distorted regions, we can probably get away with much less. To decrease the number of rays even further, we construct an adaptive grid that refines more in areas with more distortion. To construct the grid, we start with large grid cells and use the amount of distortion to check if they need to be divided. The end result can be seen in Fig.6. Depending on the position of the viewer, the adaptive grid traces around 40 times less rays than the standard one.

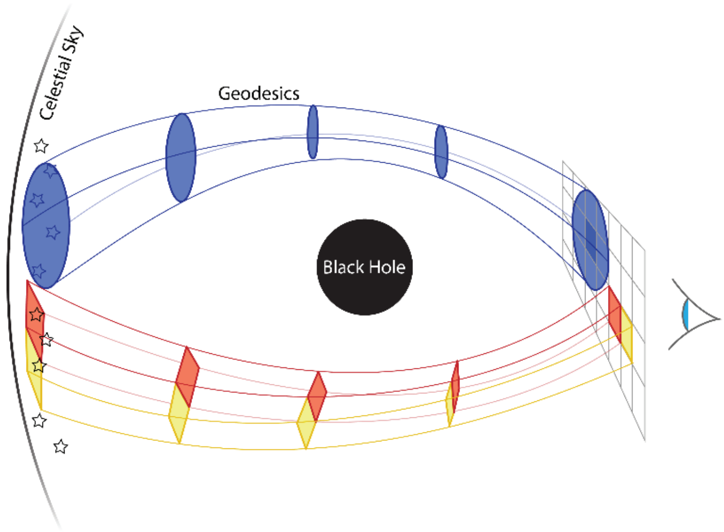


Fig4: Top: Elliptical ray bundles by Interstellar,
Bottom: Our polygonal ray bundles made out of single rays.

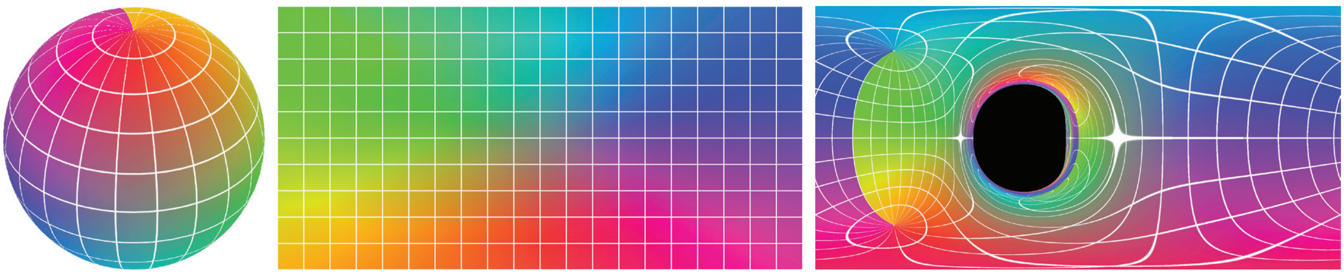


Fig 5: Left: Celestial sky map, Middle: Map as a panorama image,
Right: Distortion of celestial sky by a black hole, seen in panorama view

Interpolation

When constructing an image, we need to find the mapping from every pixel corner to its location on the celestial sky. With an adaptive grid, we have the mapping for each grid vertex to the celestial-sky location. Subsequently, we have to locate in which grid cell a pixel corner is located, and then interpolate the surrounding values of the grid to find the pixel corner's celestial-sky location. To better approximate the smoothness of the distortion and avoid artefacts, we use Hermite Splines for our interpolation method.

What about our trip around the black hole?

Now we can compute grids, but unfortunately even with all improvements it takes about half a second for all rays to be traced, so too long for interactive framerates. Luckily when we have the grids, we can render the images in real-time, by performing this step in parallel on the GPU. Our mission was however, to be able to feel like we are in a spaceship, travelling around the black hole. If for every position our spaceship is at, we have to wait half a second for a new grid, our implementation would not be very interactive. To solve this, we come to our last attempt at simplification and decreasing compute time; we aim to compute less grids.

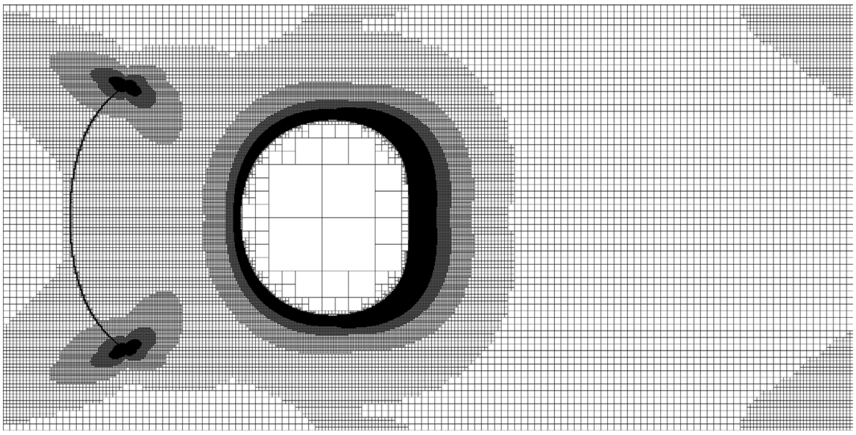


Fig 6: Adaptive grid in panorama view. Every intersection on this grid represents a light ray that has been traced back to the celestial sky.

Step 2.5: Less grids

To simulate movement, without having to recompute the grid all the time, we came up with a method to interpolate between grids at different positions. This is not as simple as it seems, if we look at the deformations between two grids, like in Fig.7, it is clear that one produces a larger shadow. If we would just lay them on top of each other and interpolate, there is a region in which one grid does not have any information to contribute. Without going into too much detail here, our solution computes the interpolated shadow and warps the two existing grids around it – making it possible to interpolate the grids at the same positions.

And of course, a lot more

This is not all functionality our method has, but it does outline the largest steps that enabled us to make a high-quality interactive simulation, while tracing only a fraction of rays compared to previous solutions. We also made sure to emphasize the aesthetics of the resulting imagery, we are from the Computer Graphics group after all! For stars we use a Gaussian filter to show their difference in brightness and added diffraction effects (Fig.8). While the particular pattern we use is an artifact caused by the vanes of a telescope, we are so used to see imagery of space like this, that it was a natural addition. We also include color and brightness changes induced by the black hole, as it influences the wavelength of photons passing by and creates other fascinating effects (Fig.9).

Looking back in time

When we observe space, we are looking back in time, as it takes quite a while for light from distant stars and galaxies to reach us. As I am very busy with a new project, the black-hole simulation already starts feeling like a thing from the past. It would be great however, to bring this software to an educational space. I would have enjoyed some of my astronomy lectures a lot more if the professors had shown me simulations like this!

Podcast episode with Annemieke Verbraeck
In The ProfCast, Marieke (PhD candidate Applied Mathematics) and Dave (communications advisor) talk to scientists who want to improve the world, who prefer to educate young people and who avre looking for that one spark. What drives them? Where does their fascination with science come from? And how do they dealv with all the hustle and bustle? In recent weeks they spoke with Annemieke Verbraeck, among others. Black holes are one of the most remarkable phenomena in the universe. But what do they look like? And how do you represent such a thing? Researcher Annemieke Verbraeck developed a new simulation based on the Hollywood film Interstellar. Professor Elmar Eisemann and Professor Alexander Verbraeck also speak in this episode.

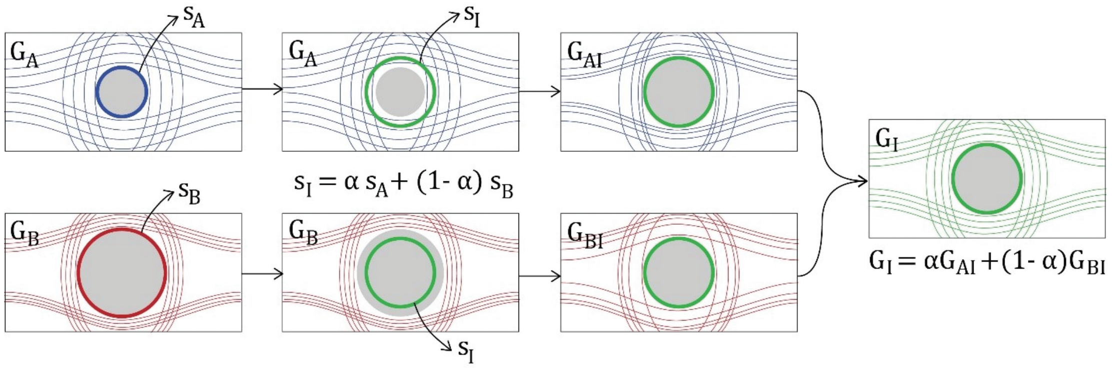


Fig 7: Interpolation between grids A and B to find grid I. The grids are warped around the interpolated shadow to make interpolation possible.

Fig 8: Star effects, from left to right: No effect, Gaussian filter, Trails to make movement go smooth between frames, diffraction, the image used to make the diffraction.

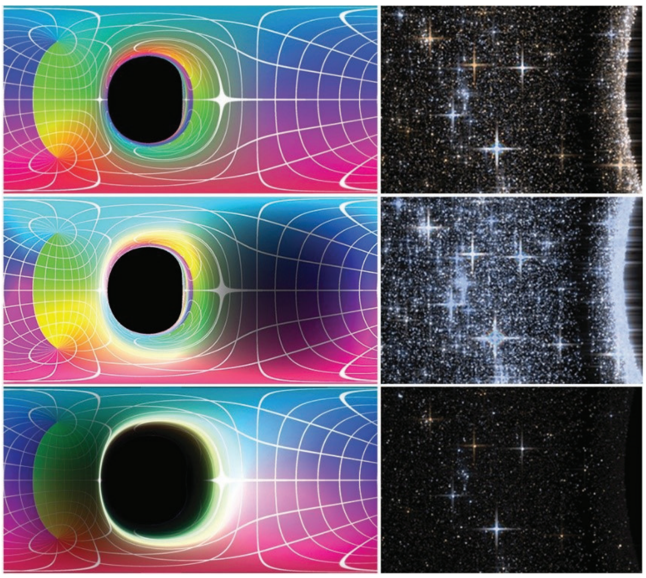


Fig 9: Effects on brightness and color: From top to bottom: No effects, Redshift effect, Lensing effect.

A Physicist who never lost her humanity

Aniruddh Kulkarni

The epitaph "A physicist who never lost her humanity" is attributed to the respected human being and great physicist Lise Meitner. In the year 1945, Otto Hahn received the Nobel Prize in Chemistry for the discovery of nuclear fission. However, Lise Meitner despite of being associated with the project for the whole of her lifetime, unfortunately did not receive the honor to be the recipient of the Nobel prize.

Lise Meitner was born in a Jewish family on November 7th, 1878 in Vienna, Austria. The primary education in Austria had been mandated by Empress Maria Theresa in 1775. Till the 1800's the reason that women are not competent enough was used as an argument to restrict women from entering universities. Starting from the year 1872, women were allowed to graduate yet they remained excluded from some specific universities due to the ideology. By the year 1901, this ideology was discarded and women were allowed to enter universities however some restrictions pertaining to the field of study still prevailed. Owing to these restrictions, Lise could only enter the University of Vienna in the year 1901. With Ludwig Boltzmann as her mentor, she entered the world of physics. Otto Robert Frisch once said that Lise Meitner made her vision of physics as battle for the ultimate truth, a vision that she never lost. Following her doctorate, she moved to Berlin in 1907, where she attended lectures by Max Planck. At University of Berlin, Lise Meitner started her research with radioactive substances along with Otto Hahn.

The beginning of the long-lasting collaboration of Lise Meitner and Otto Hahn started with research on Beta emission. Their collaboration prevailed for 30 years, in which they worked on radioactive substances and conducted experiments for obtaining isotopes of different elements. The results of their work were published in three major articles in the year 1908. The World war I started in 1914 and during this period Hahn served in the German gas service headed by Haber, while Lise served as X-ray nurse for the Austrian army. In 1917, they isolated the isotope of the element protactinium. In 1932, James

Chadwick presented a conclusive proof on the existence of neutrons. This proved to be as a stimulus to the research of Lise Meitner and Otto Hahn which investigation of the effects on neutron bombardment of nuclei.

In 1934 Ernico Fermi experimented with the effects of bombarding neutrons on elements for producing isotopes. The bombardment of neutrons of elements yielded isotopes of the element. However, one anomaly emerged during this research, which was the behaviour of element uranium. Upon bombarding neutrons on uranium there were several products produced as opposed to the definitive results yielded by other elements. This behaviour could not be explained. This puzzle only grew by the year 1938 which was a pivotal year for the scientific community in Austria, and shortly before World War II.

In 1938, the annexation of Austria into Germany took place which is referred to as the "Anschluss." During this political union, many scientists were dismissed or forced to resign. This became a reason for many renowned scientists to emigrate, Lise being one of them. Lise moved to Stockholm where she took up a post at Manne Siegbahn's laboratory. This was the place where she collaborated with the noted scientist Niels Bohr. However, Lise and Otto Hahn remained in touch during that time. In December, Otto Hahn and Fritz Strassman conducted experiments which was on the process of 'bursting of uranium' which later came to be known as the nuclear fission reaction. However, the results of the experiments turned out to be unusual. Lise and Frisch articulated the results using the "liquid drop model" of the nucleus, that the uranium nuclei split into elements Barium and Krypton. The term nuclear fission was first coined by Otto Frisch which explained the 'bursting of uranium' and resulting release of an immense amount of energy. This result provided a conclusive proof that all the elements beyond uranium in the periodic table could not exist in a stable state. The results of the experiment were presented in Naturwissenschaften in 1939.

The explanation of the empirical results provided by Lise and Frisch had a scintillating impact on the scientific community. Once there was conclusive proof that an immense amount of energy is released during the fission reaction, the idea of using nuclear fission reaction as a potential weapon emerged. The methodology of how an atomic explosion would take place, published by Frisch-Peierls, became the basis of the establishment of the Manhattan Project. Lise Meitner however turned down the offer declaring, "I will have nothing to do with a bomb!"

Lise Meitner contributed to the foundation of the nuclear fission reaction. Between 1924 to 1938, Lise Meitner and Otto Hahn were nominated for the Nobel Prize 19 times, 17 times for the field of chemistry and 2 times for physics. However, due to the Lise's emigration and intermittent collaboration with Otto Hahn, the Nobel committee did not consider the contribution made by Lise. This resulted in Otto Hahn winning the Nobel prize. This mistake by the Nobel committee was partly rectified when Lise Meitner, Otto Hahn and Fritz Strassman were awarded the U.S. Fermi Prize. The element "Meitnerium (Atomic Number 109)" has been named in the honor of Lise Meitner.

Master Student Column

Internship at SLAM Ortho

Jan de Jong

Jan is now a second-year master student in Computer Engineering. He started his bachelor's in electrical engineering 8 years ago right here in Delft, during which time he was also active in ETV.

Tell us something about yourself!
It has been some years since I have been an active member of this association. So, a brief introduction. I did a lot at the ETV, as well as a board year in my third year. During my year we also had the Lustrum year, so there were a lot of festivities going on. This year I am still doing the Board of Studies in Computer Engineering, so I'm still a bit involved, but I'm moving to Rotterdam and starting my thesis soon, so it's kind of the end of an era.

What do you like to do in your free time?
I've always been interested in technical stuff since I was a child - being into LEGOs, building things with my sisters and stuff. I really like the technical aspect of electrical and mechanical stuff, but also actually building things and working with my hands. I'm very happy I could make it come together into a study. I also liked swimming, and now I've picked it up again. And of course, being with friends. It was always a good time at the pub when it was

SLAMORTHOPEDIC

still open, but that's for another time maybe.

What was your motivation for doing an internship?
During the first year of my master, it was quite hard to find any interesting courses in the first quarter of the first semester. Therefore, I decided quite early on in the year that I wanted to do something other than CE courses for my free elective space. And, quite thankfully, this opportunity was presented to me during spring/summer: I was approached by a friend who works

at the company SLAM Orthopedics, to see if I was interested in doing an internship with them.

SLAM Ortho is a startup with its offices at the YES!Delft incubator on the TU Delft campus. They focus on surgical orthopedic drilling, and are developing an adapter add-on for a surgical drill that can automatically measure the drill depth in bones. This is used in plate osteosynthesis wherein a metal plate is fixated to the bones to stabilize a bone fracture. Their product drastically shortens the operation procedure and will also cause the procedure to be less error prone since the measurement step is automated.

Tell us a bit about your internship assignment.

My internship assignment was to design and prototype a portable receiver for the sensor adapter that they are currently developing. They had to show it to their clients and convince them to buy it, so it had to be awesome. The whole design loop was walked through and everything, from research into requirements to the final assembly, was touched. One of the most exciting things in my experience was designing and producing a custom SMD PCB. There is no such opportunity elsewhere in the CE study program.

Within a quarter it was possible to do all of these things, and in the end, a proof of concept for the portable receiver was delivered. For SLAM Ortho this meant that a lot of new information was gained, and further strategies could be researched.

Did you feel prepared for it?

I already enjoy building stuff, and also connecting the three domains of electrical, mechanical and computer engineering. But I didn't really have experience in building a PCB etc, so that was all new for me. I had to learn Fusion360, which is a program by Autodesk that you can use for fast prototyping for 3D . I learnt to actually make a board, although it wasn't a very hard board to make, but it had a good number of electrical components for a first board. There were also some challenges, and debugging is also a really important skill - very frustrating, but it can also be rewarding. There was a lot of software writing, and although I am a computer engineering student, this is one of my least favourite things.

It was a really friendly environment. I would like to see that in a company when I apply for a real job. If you want to really work in a team and get the best out of each other, you need to know each other - but that's also one of the things I've learned from my board year.

What was your favourite part about the experience?

It was an amazing experience, and one of the things I would never forget would be the ambience within a startup. The amount of freedom that is available to you is also quite a large responsibility. I learnt a lot about the design cycle, without everything being defined for you in an assignment by the TU. But because of that you can let your creativity thrive. And thus, you can really stay on top of next-generation ideas. I now really know what it is like to actually design electronics for a company.

Besides this awesome ambience, a very useful contribution to society can be made in the case of SLAM Ortho.

Do you have any advice for current students?

I would recommend everyone to do an internship in their master programme. It is very interesting how you can apply the knowledge from courses in such an assignment. You learn the translational step between all the theory, and its practical implementation and prototyping. Besides this, it also gives a good perspective on the dynamics in a company and how they differ from academia, so you don't end up going to work and not know what 'working' is, because you're in for a treat then.

With all of this being said, I'm very thankful for the opportunity I've gotten from SLAM Ortho and the TU Delft. I will soon begin on my master thesis project and will proceed to conclude my time here in Delft. And I hope you will all consider an internship as a part of your master programme.

Bachelor Student Column

Gijs Lagerweij, Third Year Electrical Engineering

Gijs is a third-year Bachelor student electrical engineering at the TU Delft. He has done an internship at Prodrive Technologies for his minor.

Why did you choose Electrical Engineering at the TU Delft?

To me Electrical Engineering was, and still is, a very interesting and broad discipline with applications in almost every aspect of our lives. I knew pretty early on that I wanted to do Electrical Engineering. It was a combination of the courses I liked during high school, as well as my hobbies. My father, who is also an electrical engineer, was always happy to help or explain things. His support certainly gave me a nudge in the right direction.

I chose to pursue this course of studies at the TU Delft because I liked this university best. I also visited several other universities, but Delft felt like the right choice to me, both in terms of atmosphere and in terms of the academic environment. Additionally, it was close to where I live.

Why did you choose to do an internship for your minor?

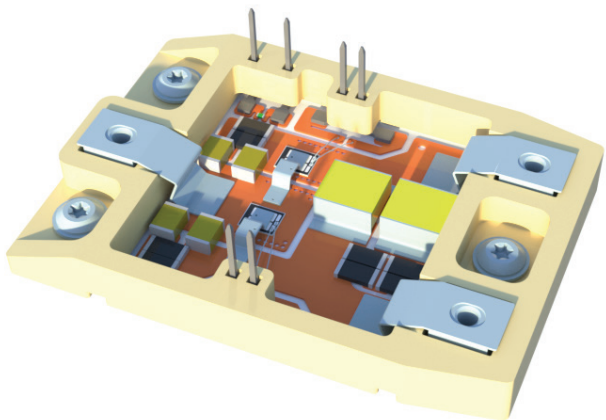
There are two reasons for that. Firstly, the TU Delft did not offer many minors in areas that interested me. Secondly, I wanted to apply the knowledge and skills that I have acquired over the years. (Work) experience is something that goes beyond what you learn at university, which is mostly theoretical. An internship helps you develop practical abilities, which is very valuable for your development as an engineer.

Do you think there is a large difference between studying and doing an internship?

Definitely. The goal of most courses at university is to give you a broad theoretical understanding of various concepts that belong to that subject, this is tested at an exam. During an internship, there is no exam, instead, your goal is to complete the project that is assigned to you. This typically involves theoretical elements such as a literature study and modelling, as well as practical elements such as design, testing, performing measurements, and analyzing the obtained data. Another very important aspect is documentation, which should help your colleagues understand the outcomes of your project after it is finished.

Where did you do your internship?

I did my internship at Prodrive Technologies located in Eindhoven. Prodrive is a technology company comprising over 1300 employees and is one of the fastest-growing companies in Europe. Prodrive designs and manufactures electronics, software, and mechanics, power electronics being the core competence, and is active in many different industries, such as the medical, industrial, automotive and semiconductor industries. Their capabilities include in-house production, assembly, testing and



life-cycle-management of electronic products and systems.

Can you tell us more about your project at Prodrive?

Within Prodrive, numerous products incorporate power modules and discrete semiconductor devices. These parts are off-the-shelf products which are typically not optimized for electrical and thermal performance in the specific application. This is especially the case for higher-performance WBG devices. Prodrive is now developing custom power modules using SiC MOSFETs in an effort to drive down converter costs and improve performance. These power modules provide a larger degree of flexibility in high-efficiency power conversion products. One way of optimizing the electrical performance is through the integration of various components (snubber, decoupling, gate driver, etc.) into the module.

The goal of my project was to completely characterize and verify the electrical and thermal behaviour of various custom power module configurations incorporating passive components. The assignment involved qualification of a test setup specifically developed to be able to characterize both the hard and soft-switching performance of any half-bridge, both discrete MOSFETs as well as *(custom)* power modules, development of a measurement procedure, as well as conducting the measurements. The electrical and thermal performance then had to be analyzed, after which I had to make a comparison between the variants. A number of custom power modules with integrated passives were also compared against discrete SiC MOSFETs in identical configurations.

The results of this investigation were quite promising. We observed an improvement of roughly 25% to 50% in steady-state thermal performance over the operating range when comparing the custom power modules to the discrete SiC MOSFET solution. By integrating decoupling and snubber into the module, we were able to achieve 75% lower undershoot and oscillation than with the decoupling outside the module.

We have also identified some limitations of the modules and potential paths for improvement. The general expectation is that, with the power semiconductor technology shifting from Si to SiC and GaN, the 'vertical integration' in terms of packaging will become more and more important for the company to be able to design power conversion products with high reliability, long lifetime and low cost/performance ratio.

How did you experience the atmosphere at Prodrive?

The atmosphere at Prodrive was very pleasant. It is quite informal, and you can talk to anyone at any time. My colleagues were happy to help and explain anything during my internship, either in the office or through a Teams call.

Did the coronavirus have an impact on your work?

Of course, but it was not as bad as it could have been. Working from home is unavoidable these days, but thankfully Prodrive responded very well to the virus. They implemented strict rules which allowed location critical work (e.g., lab and production work) to continue in a certain capacity. These rules allowed me to spend a significant amount of time on-site. Aside from some minor delays for ordering PCBs, components, etc., there was no significant impact on my project.

What did you like the most about doing an internship?

I really liked that I was able to completely focus on a subject that interests me. The internship gave me the time required to dive into the subject and create some good, useful results. Usually, you do not get this amount of time at university, where you touch upon many parts of a subject, but never really dive deep into the details, at least during the Bachelor.

At the same time, I also enjoyed the cooperation between disciplines. It seems every discipline has its own perspective and working together can give rise to interesting discussions and new insight.

What is Quantum Computing?

Prof.dr.ir. K.L.M. Bertels

Prof. Bertels moved to Portugal to continue working on the quantum computing challenges. As a full professor in Porto, he is in the process of setting up a European quantum computing research centre to which already multiple universities or research groups are participating. The current members of the initiative are the University of Porto (P), ENSTA, in Brest (F), CEA in Grenoble and Paris (F), the Politechnical University in Valencia (E) and the University of Leuven (B). The goal is to work on various accelerator topics and to expand the tools for the different layers. QBee is a company that was created to develop several quantum accelerators and will be active at the international level. To this purpose, QBee will continue working on the tools and algorithms that will be needed once a quantum computational accelerator can be made.

The content of this article needs further research, but is based on prof. Bertel's latest research and recently published article, and remains his intellectual property.

Introduction:

There is growing interest in quantum computing as the new computational direction in which we can keep on building ever stronger computers. In the remainder of this article, I will not talk about a quantum computer but rather a quantum accelerator [1] as up to this point, I have not read a good article about what
a quantum computer is. However, what an accelerator is, is quite well understood by the semiconductor world as almost every computational device is built on transistors used to construct a co-processor that will substantially speedup the overall computer. So, every word in this article refers to a quantum accelerator, which in principle will operate on the quantum mechanical principles of superposition and entanglement.

Given the recent insights leading to e.g. Noisy Intermediate-Scale Quantum (NISQ) technology as expressed in [2], we are much more inclined to believe that the first industry-based and societally relevant application will be a hybrid combination of a classical computer and a quantum accelerator. It is based on the idea that any end-application contains multiple computational kernels and the properties of these parts are better executed by a particular accelerator which can be, as shown in Figure 1, either field-programmable gate arrays (FPGA), graphics-processing units (GPU), neural processing units (NPU) like Google's tensor processing unit (TPU), etc. The formal denition of an accelerator is indeed a co-processor linked to the central processor that is capable of accelerating the execution of specific computational intensive kernels, as to speed up the overall execution according to Amdahl's law. We now add two classes of quantum accelerator as additional co-processors. The rst one is based on quantum gates and the second is based on quantum annealing. The classical host processor keeps the control over the total system and delegates the execution of certain parts to the available accelerators.
Computer architectures have evolved quite dramatically over the last couple of decades. The first computers that were built did not have a clear separation between compute logic and

memory. It was only with von Neumann's idea to separate and develop these distinctly that the famous von Neumann architecture was born. This architecture had for a long time a single processor and was driven forward by the ever increasing number of transistors on the chip, which doubled every 18 months. In the beginning of the 21st century, the single cores became too complex and did not provide any substantial processing improvement. This led to the incorporation of multiple cores. The homogeneous multi-core processor dominated the processor development for a couple of years but companies such as IBM and Intel started understanding that heterogeneity is the right way forward to improve the compute power. GPUs and FPGAs are seen as natural extensions of the computer architecture, implying that the quantum accelerator would be a logical next step. In the quantum computing world, there exist two important challenges. The first is to have enough numbers of good quality qubits in the experimental quantum processor. The current competing qubit technologies include Ion traps, Majoranas, semi-conducting and superconducting qubits, NV-centers and even Graphene.
Since one of the first papers about quantum computing by R. Feynman in 1982 [3], research on quantum computing has focused on the development of low-level quantum hardware components like superconducting qubits, ion trap qubits or spin-qubits. The design of proof-of-concept quantum algorithms and their analysis with respect to their theoretical complexity improvements over classical algorithms has also received some attention.

A true quantum killer application that demonstrates the exponential performance increase of quantum over conventional computers in practice is, however, still missing but is urgently needed to con vince quantum sceptics about the usefulness of quantum computing and to make it a mainstream technology within the coming decade. Recent world-news coming from, for instance, Google, should be interpreted in this context. The errors that these devices still produce are so big that it is very difficult to make any valid statement about their operational quality. Improving the overall status of the qubits is challenging as these suffer from decoherence that introduces errors when performing quantum gate operations. It is only when the quantum physical researchers overcome those challenges that the quantum accelerator will be a widespread adopted solution. It is important to understand that any quantum accelerator that will be developed in the next 5 to 10 years will have the layers as shown in Figure 2. The second challenge is to formulate at a high level the quantum logic that companies and other organisations need to be able to use high-performance accelerators for certain computations that can only run on the quantum device.
This requires a long-term investment in terms of people and technical know-how from companies that want to pursue this direction and reap the benets. We

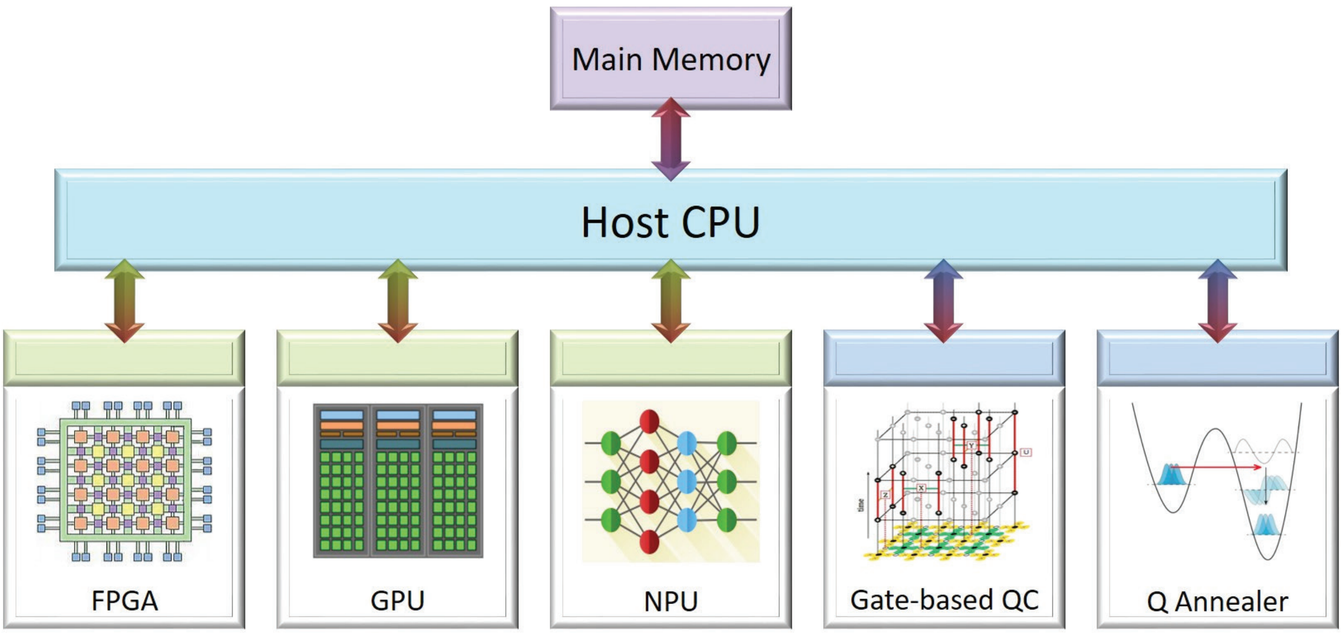


Fig. 1: System architecture with heterogeneous accelerators

will implement and test the industrial or societal applications for which the required quantum logic can be executed using the full-stack, evaluated and tested on a quantum simulator, running on a supercomputer. It is important to emphasise that the qubits are called perfect qubits that do not decohere or have any other kind of errors generated by them. With the emergence of huge amounts of data, commonly called big data, it is understood that this paradigm is not scalable to super-large data sets. The key factor is the huge amount of data that needs to be processed by multiple computing cores which is a very tough problem to solve. The data communication between the cores is a very dicult programming problem and the data management problem is substantially slowing down the overall performance.

Based on our group's research since 2004 [1], an important concept that we have been implementing in the quantum computing world is the implementation of a full stack for a quantum accelerator. The basic philosophy of any accelerator is that a full stack needs to be defined and implemented. The last 10 to 15 years have shown a large number of accelerators that were developed as part of any modern computer architecture. It always consists of the same following layers: it starts at the highest level describing the logic that needs to be mapped on the accelerator. Examples are video processing, security, matrix computation, etc. These application-specific algorithms can be dened in various languages such as C++ or Fortran. In the case of FPGAs, these algorithms are translated into VHDL or Verilog. In the case of GPUs, the language is often formulated using mathematics or other libraries and translated by the compiler to an assembly language that can be mapped on the GPU-architecture. Especially in the case of FPGAs, there is no standard microarchitecture on which the VHDL or Verilog can be executed. Such an architecture needs to be developed for every application that needs to be accelerated. The final layer is a chip based implementation of the micro-architecture combined with the hardware accelerator blocks that are needed. We use the term 'accelerator' as it is very unknown how to dene a quantum computer. The term 'Perfect Qubits' refers to the need to currently overcome the challenge that the current, experimentally produced qubits have, meaning very high error-rates and very short coherence-times. Supercomputers will be used to test any execution of the quantum algorithm and the simulator will be capable of addressing all the computational features that modern supercomputers can have, which will primarily consist of the memory resources that are available to represent the qubit states.

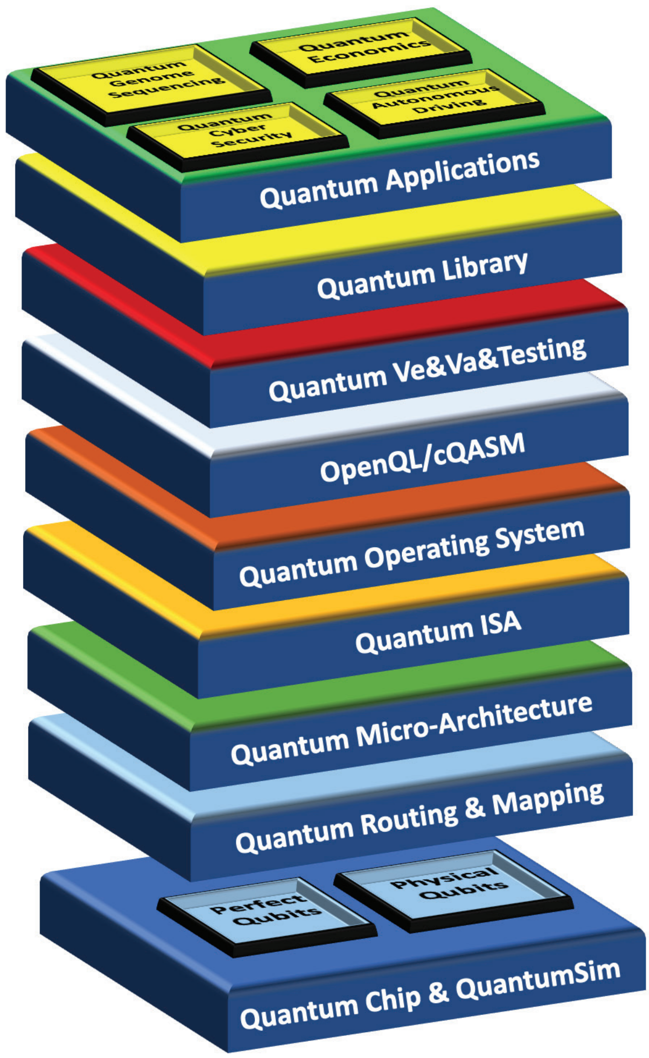


Fig. 2: Full-Stack with Perfect and Physical Qubits

Background:

One of the first proposals on quantum computing was written by R. Feynman in 1982 [3] which launched a world-wide research on quantum computing focusing on important low-level challenges leading to the development of superconducting qubits, ion trap qubits or spin-qubits. He formulated the use of quantum computers as an important scientic instrument to allow us to understand the quantum phenomena that quantum physics tries to understand. The design of proof-of-concept quantum algorithms and their analysis with respect to their theoretical complexity improvements over classical algorithms has also received some attention. However, we still need substantial progress in either of those domains. Qubits with a sufficiently long coherence time combined with a true quantum killer application are still crucial achievements on which the community is working. These are vital to demonstrate the exponential performance increase of quantum over conventional computers in practice and are urgently needed to convince quantum sceptics about the usefulness of quantum computing such that it can become a mainstream technology within the coming 10 to 15 years. However, we need much more before any kind of computational device can be developed, which ultimately connects the algorithmic level with the physical chip. What is needed involves a compiler, run-time support and more importantly a micro-architecture that executes a well-dened set of quantum instructions. An interesting and quite high-level kind of description was published in 2013 [4]. The authors describe their understanding of the blueprint of a quantum computer. They correctly emphasised the need to look at computer engineering to better understand what the similarities and dierences are between quantum and classical computing. As mentioned before, the most important difference is the substantially higher error rate that qubits and quantum gates (10e-3) have compared to CMOS-technology (10e-15). Guaranteeing fault-tolerant computation can easily consume more than 90% of the actual computational activity. The second dierence focuses on the nearest-neighbour constraint which imposes that two-qubit gates can only be applied if the qubits reside next to each other. The no-cloning theorem prohibits copying quantum states. The way that two-qubit gates are applied requires the two qubits to be sufficiently close to each other. They also describe a hierarchical layered structure but rather than defining these layers in terms of more computer engineering concepts, the schema is more expressed in terms of the different, relevant fields and research domains. Examples are Quantum Error Correction (QEC) theory, programming languages, fault-tolerant (FT) implementation and so on. There are also other mechanisms with undefined time costs that are necessary to make FT-quantum computing *(hopefully)* efficient and performing. Examples are state distillation for ancilla factories and the emergence of a wide variety of defects and errors, which all impose an additional burden on the micro-architecture and the corresponding runtime management. Depending on the application domain, the estimates of the number of qubits goes from relatively low, such as a couple of hundreds, to several billions. In conclusion, it is very important to have a young generation of scientists interested and involved in quantum computing. There is much more to be done than just the quantum physical aspects. If ever you are looking for an extremely well written and complete book on quantum computing, have a look at the Desurvire´s [5] where you will find everything to bootstrap your activities in the field. I hope this article will help you make a choice for your future life and the life of billions of other humans on earth.

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Possibly the D-Day

Simon Tindemans

On January 8th, 2021, the European electricity grid was the closest it had been to a large-scale blackout in 15 years. The fact that most people didn't notice anything was due to a range of risk-avoidance measures that were designed for precisely such an unlikely scenario.

The events of 8 January 2021

To be more precise, the disturbance affected the synchronous area of continental Europe, which spans from Portugal to Denmark and all the way East to Poland and Turkey. The electricity grid in this area is tightly integrated and operates with a single shared frequency of 50 Hz: the AC voltage signal you receive in the power socket is the same wherever you go in this region, which necessitates tight coordination to keep local disturbances from spinning out of control. On January 8th, there were large power flows from the South-East to the North-West of Europe, leading to heavy loading on high-voltage transmission equipment. In the early afternoon, overcurrent protection was triggered in a substation in Ernestinovo in Croatia, which caused the East-West power flows in that substation to be diverted to neighbouring power lines, causing further overloads and disconnections. Within a minute, this cascade resulted in the complete separation of the system into two parts (Fig. 1). Prior to the system separation, 6.3GW of power was flowing between the two regions – equal to one third of the Dutch power consumption on a cold winter night. The separation left the North-West area with a sudden deficit of power and the South-West with an equally large surplus. The imbalances caused immediate large frequency swings, shown in Fig. 2, which risked triggering large-scale system instability and perhaps a widespread blackout. Fortunately, automatic response services proved able to rapidly restore the system balance in each of the two subsystems, and they were reconnected approximately one hour after the initial event (evidence by the coalescence of the frequency traces in Fig. 2).

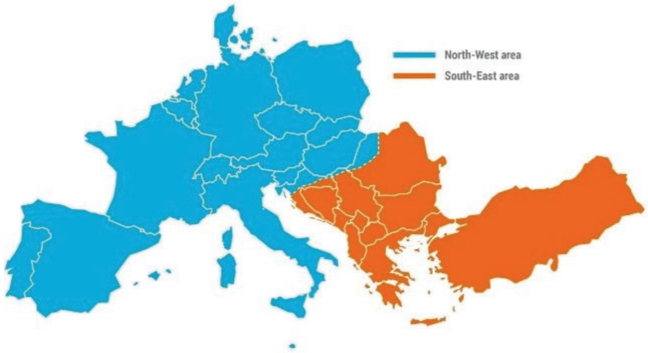
Risk assessment and the study of reliability

This recent event is an exemplary case for power system reliability assessment at the very large scale: accurately gauging the necessary amount of response service is essential to prevent blackouts. But did you know that most disturbances people encounter happen at the distribution network level, close to home? In 2019, Dutch electricity customers were disconnected from the grid for an average of 20 minutes, overwhelmingly caused by disruptions in the distribution network. Access to electrical power is essential in today's society, and power system reliability analysis is the study of the ability to supply this power to end users, both local and at the bulk scale. As a branch of engineering, it combines analysis (what are the weaknesses) with a focus on design (how can these weaknesses be addressed). It addresses a large variety of questions, including: "Is it wise to spin up the coal-fired power plant to compensate for a forecast dip in wind speeds?", "Is it worth investing in redundant transformers to

reduce customer outages?", "Do we need to invest in large-scale storage systems to deal with wind-still dark winter days?"
At the core of all such questions lies a risk assessment along the following lines. Firstly, consider all sources of uncertainty, identifying events that could interfere with the successful operation of the power system, such as lightning and squirrel activity (!). Secondly, consider the likelihood of occurrence of these events and the impact they would have if they were to occur, combining them (qualitatively or quantitatively) as risk = probability x impact. And finally, determine whether and how this risk can be mitigated.

Current challenges

As you can imagine, practical limitations in terms of data, modelling and computation ability mean that each of these steps is approximate. Historically, risk assessments were often qualitative in nature, for example by requiring a certain degree of asset redundancy. However, advances in sensing and computation mean



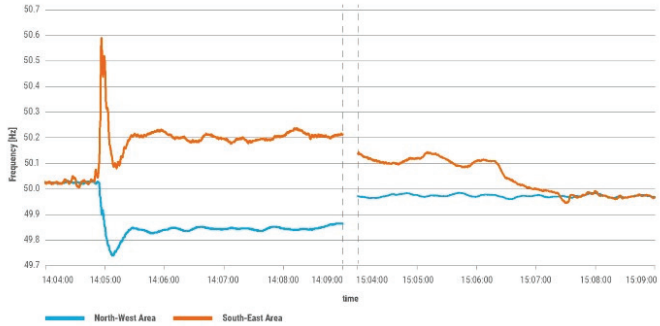


Fig.1: separation of the Continental Europe Synchronous Area on 8 January 2021. (ENTSO-E, https://www.entsoe.eu/news/2021/01/26/system-separation-in-the-continental-europe-synchronous-area-on-8-january-2021-2nd-update/; reproduced with permission)

Fig.2: frequency response during and after the disturbance. (ENTSO-E; reproduced with permission)

that the industry is evolving towards quantitative risk assessment methods. At the forefront of this development, research is done by electrical engineers in close collaboration with statisticians and computer scientists.
A selection of active research areas is listed below.

Weather and climate modelling
The importance of accurate weather and climate models is increasing. Besides direct impact of weather on network infrastructure (lightning, storms, etc.), it also affects the output of renewable generators. Moreover, the common practice of extrapolating the weather of the last few decades to the future is challenged by climate change. Finally, and perhaps surprisingly, space weather is gaining recognition as a subject of interest, because geomagnetic storms can induce significant currents in long-distance transmission lines.

Reasonable capacity payments
The rollout of large-scale renewable generation means that conventional gas- or coal-fired generators are slowly being phased out. Not unreasonably, this raises concerns about the security of supply: what can we do to ensure the lights stay on in the event of a Dunkelflaute, an extended period of darkness and little wind? In response, a number of countries are rolling out capacity mechanisms, where generators or batteries receive payments to remain "on standby" for such cases. But do we really need these schemes, and if we do, how much capacity should be purchased at what cost?

AI and machine learning
Last but not least, recent developments in AI and machine learning will fundamentally change the process of reliability analysis and risk assessment. In the short term, machine learning tools can improve the speed and accuracy of assessments that are currently done by system operators and planners, allowing them to tackle problems of previously unsurmountable complexity. In the future, hybrid intelligence will see AI agents working alongside system operators, learning from these operators and suggesting actions to them. Initial explorations of this approach are currently underway, also at TU Delft. These topics in reliability analysis are the focus of cutting-edge research and will be relevant for decades to come as the energy transition is taking shape.

Students who are interested in power system reliability analysis can learn more about it in two dedicated courses on the subject: Reliability of Sustainable Power Systems (EE3065TU, part of the minor Electrical Sustainable Energy Supply) and the MSc elective Uncertainty Modelling and Risk Assessment in Electrical Power Systems (EE4665).

About the author
Simon Tindemans is an assistant professor in the Intelligent Electrical Power Grids (IEPG) research group. With a background in theoretical (bio-)physics, he joined TU Delft in 2018 after working as a research fellow at Imperial College London. Simon teaches power system reliability courses (EE3065TU and EE4665) and leads the minor project
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