

QuSoft

Research Center for Quantum Software

ANNUAL REPORT 2021

WWW.QUSOFT.ORG





EXECUTIVE SUMMARY

In this annual report 2021, we present in detail all the activities that were undertaken within QuSoft and the results that were achieved.

The main take aways are:

- QuSoft is now a thriving community of 73 people coming together to work on excellent and innovative quantum research.
- QuSoft has actively contributed to bring quantum research to a national priority. This resulted in the award of €615 million for Quantum Delta NL in April 2021. This will also give a tremendous boost to quantum research in the Amsterdam ecosystem.
- Over 100 research papers were published by QuSoft and there were three successful PhD defences in 2021.
- QuSoft is a driving force behind multiple high-impact initiatives on a national scale, like: The Quantum Application Lab, Quantum Software Consortium, innovation hub Quantum.Amsterdam and diversity platform 'Women in Quantum Development'.
- On an international scale, QuSoft continues to expand its collaboration, e.g. in Quantum Leap Africa and the Turing Chair.

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INTRODUCTION ANNUAL REPORT

On behalf of all colleagues within QuSoft, we are proud to present the annual report for 2021.

QuSoft's mission is to develop new protocols, algorithms and applications that can be run on small to full-scale prototypes of a quantum computer. Here, we work together on radically new software and technology with world-changing potential. Based on the fundamental laws of quantum physics we aim to keep up our excellent track record in quantum computing and quantum information to explore and develop uses of quantum computers and other quantum technologies at large, for the benefit of society.

Quantum technology is labelled by the Dutch government as a key technology

because it is considered a potential game changer in many societal and economic sectors, including health, agriculture, climate, and safety.

This report presents a brief overview of what we achieved in 2021 in terms of research, collaboration and community building, education and outreach, and people and prizes. We are happy to report strong results.

We hope you will enjoy reading this annual report.

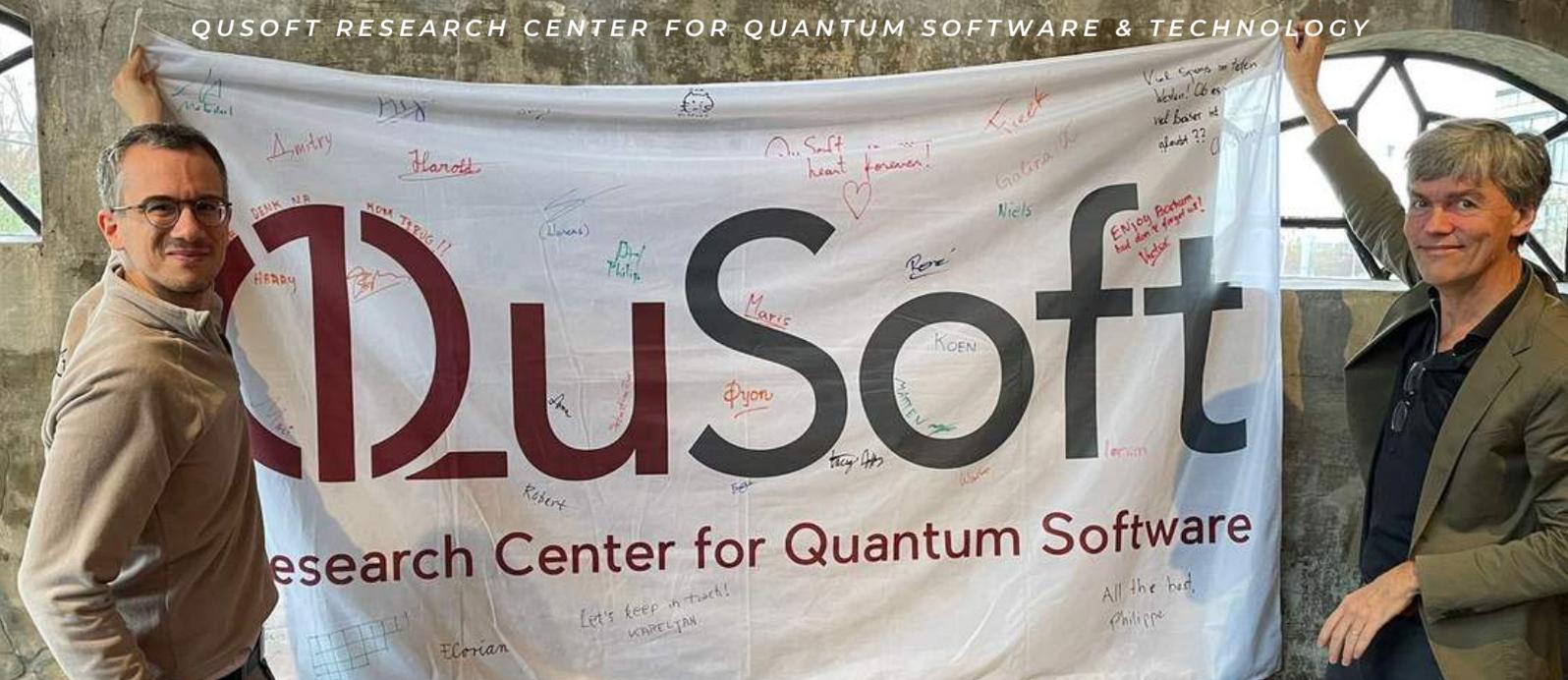
Victor Land & Yvonne Smit

FOREWORD BY DIRECTORS QUSOFT

2021 - A glass half-full. The second Corona year unfolded in a strange mix of continued stifle due to unavoidable measures and the beginnings of the return to normal academic life. Our 'home' conference QCrypt 2021 had to be held online, again, while some other conferences did return to in-person attendance. The successful celebration of 75 years CWI was a mix of on-line and in-person (social) events. PhD ceremonies were back in the Agnietenkapel and UvA hosted a festive day for the delayed in-person handing over of PhD diploma's awarded in on-line sessions during 2020. QuSoft open stage nights had to be delayed once again but the Gala van de Wetenschap did take place as a live event in the Internationaal Theater Amsterdam, featuring Spinvis and a swinging QuSoft delegation, in a quantum musical performance. Despite circumstances, QuSoft saw a continuing growth, welcoming several new colleagues in its midst. 2021 also brought the awarding of generous National Growth Fund support for the national Quantum Delta NL program, enabling a flurry of new initiatives at QuSoft, the Amsterdam quantum labs and the associated network organization Quantum.Amsterdam. All this leaving us fully charged for 2022 and years further ahead - a glass filled to the brim!

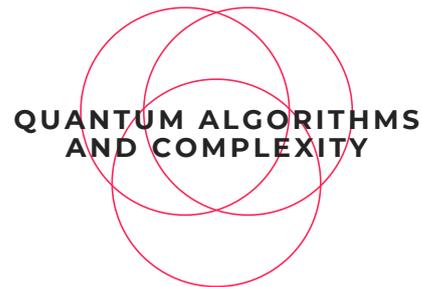
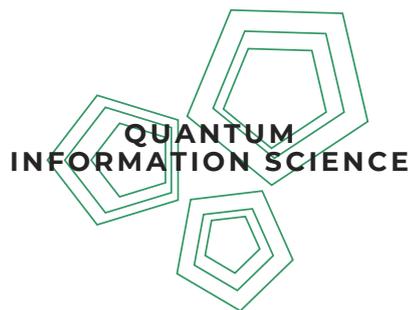
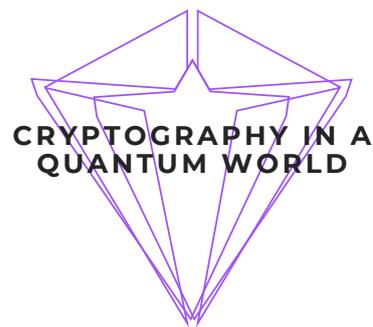
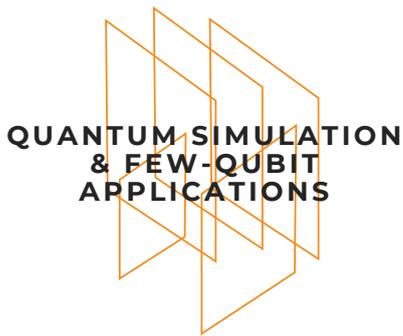
**HARRY BUHRMAN &
KARELJAN SCHOUTENS**





KEY ORGANISATIONAL DEVELOPMENTS IN THE LAST YEAR INCLUDE:

- In 2021 QuSoft added a new research line to its field of interest: "Quantum for Society and Business". In this research line, QuSoft works with companies and societal organizations to explore, discover and develop novel algorithms, applications and use cases – independent of the hardware they are to be implemented on. At the same time, the ultra-cold atom experiments offer unique opportunities to test actual applications in the future.
- In September 2021 the Memorandum of Understanding for the Quantum Application Lab was signed. Six institutions (CWI, UvA, TNO, the Netherlands e-Science Center, SURF, and TU Delft (on behalf of Quantum Inspire)) joined forces, together with IBM as a technology provider. The aim is to help organizations and companies start the development of quantum applications for quantum computing.
- Since 2021, QuSoft offers a certificate for MSc students at the University of Amsterdam. It is awarded to students that have demonstrated extraordinary commitment to quantum information science and have carried out their MSc thesis research project at QuSoft. Two students who had the honor to receive their certificate in December 2021 were: Chanelle Matadah Manfouo and Ricardo Rivera.



ABOUT QUSOFT

Researchers at QuSoft perform excellent, foundational and multidisciplinary research in the science domains of Physics and Chemistry, Mathematics and Computer Science, but also potential other research areas on the topics of quantum simulation, quantum information sciences and cryptography.

The overarching challenge for QuSoft is to harness the power of quantum information, through the study of quantum information science and the development of new protocols, algorithms and applications that can be run on small to medium-sized prototypes of a quantum computer.

The research at QuSoft can be divided into five lines:

- Quantum Simulation & Few-Qubit Applications
- Quantum Information Science
- Cryptography in a Quantum World
- Quantum Algorithms & Complexity
- Quantum for Society and Business

In the following chapter, research highlights per research line are presented. In 2021 more than 100 research papers were published by QuSoft researcher.

Also new collaborations with companies, consortia and community platforms were established in 2021 and old collaborations continued. These are shown per research line.

Quantum simulation and few-qubit applications

This research line addresses applications of small and medium-sized qubit platforms.



This research area addresses applications of small and medium-sized qubit platforms (10-100 qubits). In quantum simulation one uses such systems as analogue versions of quantum computers, allowing the study of problems in quantum chemistry and material science, among others. Few-qubit algorithms implemented on 50 or more qubits quickly become intractable for classical computers. This research line also addresses multi-qubit dynamics and quantum control, with applications in the design of quantum registers and in quantum many-body physics.

FEATURED RESEARCHER



/ Prof. Dr. Florian Schreck

QUSOFT COLLABORATIONS

/ Actual quantum projects

iQclock

A team led by professor Florian Schreck is developing a new type of clock, in which atoms are teased into a quantum state in which they actively emit light at an extremely precise frequency, which is what makes the clock tick. Such optical clocks promise to enable faster internet, improve robotic cars and facilitate subterranean exploration.



QuantStro

Within the QuART project quantum gases of strontium are studied. An alkaline-earth element that provides us with long-lived optically excited states, ultra-narrow optical transitions and a large nuclear spin. These properties make Sr uniquely suited for different explorations, applications and exciting research projects.



QuART

QuSoft and SURF joined forces in a one-year partnership. Operating under the name QuART, the collaboration will reveal what quantum computing can do for meteorological ray tracing. Using the properties of a quantum computer allows access to faster and improved weather models.



RESEARCH HIGHLIGHTS QUANTUM SIMULATION AND FEW-QUBIT APPLICATIONS

- Juan Diego Arias Espinoza, Matteo Mazzanti, Katya Fouka, Rima X. Schüssler, Zhenlin Wu, Philippe Corboz, Rene Gerritsma, Arghavan Safavi-Naini, Engineering spin-spin interactions with optical tweezers in trapped ions, arXiv:2103.10425, Phys. Rev. A 104, 013302 (2021)
- Jordi R. Weggemans, Alexander Urech, Alexander Rausch, Robert Spreeuw, Richard Boucherie, Florian Schreck, Kareljan Schoutens, Jiri Minar, Florian Speelman, Solving correlation clustering with QAOA and a Rydberg qudit system: a full-stack approach, arXiv:2106.11672, submitted to Quantum (2021)
- Popular article in Nederlands Tijdschrift voor Natuurkunde about the National Agenda Quantum Technology by Kareljan Schoutens, Carlo Beenakker, Ronald Hanson and Servaas Kokkelmans
- Florian Schreck made, together with his Strontium Quantum Gases Group on quantum clocks & neutral atom quantum simulator/computer, a series of explainer videos about the research that they execute in the lab. You can find a selection here;
 - Their [lab tour videos](#)
 - [Nice video about their work from folia.nl](#) and a similar video by [Video by AD.nl](#) about our clock research for the general public
 - [iqClock overview video](#) about their Quantum Flagship consortium iqClock on clocks for the general public
 - 10 minute [talk on clocks during European Quantum Week](#) for an audience interested in quantum science
 - 45 minute [QuSoft lustrum talk](#) on their clock and neutral atom quantum computer research for QuSoft scientists and friends
 - 1 hour [Quantum Science Seminar](#) about their quantum sensing research for quantum scientists.

Quantum Information Science

This research line addresses the broad range of insights and questions that arise as soon as information is processed according to the rules of quantum mechanics.

FEATURED RESEARCHER



/ Dr. Maris Ozols



This research line addresses the broad range of insights and questions that arise as soon as information is processed according to the rules of quantum mechanics. Reasoning based on quantum notions such as superposition and entanglement leads to applications in computer science, mathematics, logic and physics that do not always need an actual physical device. Some successful examples: an optimal algorithm for matrix multiplication, solving problems in operator algebras and functional analysis, and error-correcting codes. In the realm of physics, quantum information can be used in the study of non-locality, quantum thermodynamics, condensed matter systems, and even the structure of space-time itself. This research line also addresses quantum network and communication protocols, and distributed quantum computation. We study quantum-classical systems as well as architecture, interfaces and control.

QUSOFT COLLABORATIONS

/ Actual quantum projects

ELSA

A team led by professor Joris van Hoboken (UvA), who is affiliated with QuSoft, does research on the intersection of fundamental rights protection and the governance of platforms and internet-based services. These Ethical Legal and Social Aspects (ELSA) are very important to QuSofts research as well.



QSC

Developing new quantum software, by exploiting the counterintuitive effects of quantum mechanics, requires a union of ideas from computer science, mathematics, and quantum physics. Therefore the Quantum Software Consortium (QuSoft, QuTech, Leiden University) is building a new research community in Quantum Information Science.



Quantum Quest

Together with the University of Amsterdam, QuSoft has set up a web class for high school students. During the Quantum Quest students will learn the basics of quantum computing. At the end of the 5-week course they will understand what quantum bits and quantum algorithms are, and what they are good for.



RESEARCH HIGHLIGHTS QUANTUM INFORMATION SCIENCE

- Christandl, M., Leditzky, F., Majenz, C. et al. Asymptotic Performance of Port-Based Teleportation. *Commun. Math. Phys.* 381, 379–451 (2021). <https://doi.org/10.1007/s00220-020-03884-0>
- Local simultaneous state discrimination (2021)
Christian Majenz, Maris Ozols, Christian Schaffner, Mehrdad Tahmasbi
<https://doi.org/10.48550/arXiv.2111.01209>
- Gross, D., Nezami, S. & Walter, M. Schur–Weyl Duality for the Clifford Group with Applications: Property Testing, a Robust Hudson Theorem, and de Finetti Representations. *Commun. Math. Phys.* 385, 1325–1393 (2021).
<https://doi.org/10.1007/s00220-021-04118-7>
- Farrokh Labib, Stabilizer rank and higher-order Fourier analysis, *Quantum* (2021) .
<https://doi.org/10.48550/arXiv.2111.01209>
- A converse to Lieb-Robinson bounds in one dimension using index theory
Daniel Ranard, Freek Witteveen, Michael Walter (2021) arXiv:2012.00741. Presented at QIP 2021 under the title "Classifying unitary dynamics with approximate light cones in one dimension"
- Joint quantum session in the Networks conference and QSC general assembly
Jop Briët, Harry Buhrman, June 2021
- Quantum computing for HEP and GW: Nikhef & QuSoft workshop
Michael Walter (QuSoft), David Groep (Nikhef), September 2021

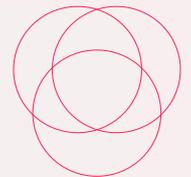
Quantum algorithms and complexity

This research line focusses on the development and investigation of new quantum algorithms.

FEATURED RESEARCHER



/ Dr. Stacey Jeffery



Which computational tasks are amenable to quantum speed-up? This research line addresses this fundamental question and develops and investigates new quantum algorithms. This activity is focused on the many-qubit regime, where full-fledged error correction and fault tolerant computation becomes possible. Important research questions are the verification and debugging of quantum algorithms – the very nature of quantum computing preempts methods known from classical computer science and calls for fundamentally new strategies and protocols.

QUSOFT COLLABORATIONS

/ Actual quantum projects

QuART

QuSoft and SURF joined forces in a one-year partnership. Operating under the name QuART, the collaboration will reveal what quantum computing can do for meteorological ray tracing. Using the properties of a quantum computer allows access to faster and improved weather models.



Toyota

In a joint research initiative with QuSoft, Toyota, UvA and VU, the aim is to explore potential usage of quantum computing for research and development. The project will run for two years and its focus is to study photocatalytic systems on quantum computers.



Bosch

Bosch and QuSoft have joined forces in a two-year collaboration. The goal is to examine how quantum computing could benefit this multinational. Lines of research include quantum computing's potential applications in design processes and artificial intelligence, as well as the technology's capacity to speed up optimization processes.



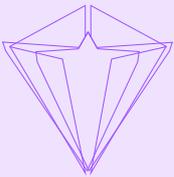
RESEARCH HIGHLIGHTS QUANTUM ALGORITHMS & COMPLEXITY

- Joran van Apeldoorn, Sander Gribling, Yinan Li, Harold Nieuwboer, Michael Walter, Ronald de Wolf. Quantum Algorithms for Matrix Scaling and Matrix Balancing. ICALP 2021: 110:1-110:17
- Simon Apers, András Gilyén, Stacey Jeffery. A Unified Framework of Quantum Walk Search. STACS 2021: 6:1-6:13
- Harry Buhrman, Subhasree Patro, Florian Speelman. A Framework of Quantum Strong Exponential-Time Hypotheses. STACS 2021: 19:1-19:19
- Harry Buhrman, Bruno Loff, Subhasree Patro, Florian Speelman. Limits of quantum speed-ups for computational geometry and other problems: Fine-grained complexity via quantum walks. To be presented at QIP'22.
- Yanlin Chen, Ronald de Wolf. Quantum Algorithms and Lower Bounds for Linear Regression with Norm Constraints. To be presented at QIP'22.
- Ronald de Wolf organized a QSC session at the Netherlands Mathematics Congress (NMC'21).
- Stacey Jeffery is part of the World Economic Forum Global Future Council on Quantum Applications
- Stacey Jeffery co-chaired the QIP Program Committee: QIP is the most important conference in theoretical quantum computing. As co-chair of the PC, she helped the chair coordinate the program committee and make the final selection of which talks are accepted to QIP. She held this role for QIP 2022, but most of the work happened at the end of 2021.
- Stacey Jeffery was chair of the Lorentz Center Informatics Board. With input from the members of the Informatics Board, Stacey Jeffery selected the informatics-themed proposals that will be granted Lorentz Center workshops. She held this role as of the end of 2021.

RESEARCH LINE

Cryptography in a quantum world

This research line looks into secure communication techniques that allow only the sender and intended recipient of a message to view its contents.



This research line is double-edged. One edge, known as post-quantum cryptography, is the development of cryptography that is difficult to break for attackers armed with large quantum computers. The goals are to improve existing schemes for this, to develop new efficient quantum-safe protocols and to analyse attacks that can be run on large quantum computers. The other edge, known as quantum cryptography, is the design and investigation of protocols that solve cryptographic problems that involve quantum data and quantum communication.

FEATURED RESEARCHER



/ Prof. Dr. Christian Schaffner

QUSOFT COLLABORATIONS

/ Actual quantum projects

QLA

QuSoft started an exchange program with Quantum Leap Africa (QLA), which is a newly founded research institute in Kigali, Rwanda, closely linked to AIMS, the African Institute for Mathematical Sciences. In this program QuSoft hosts Master students to work under the guidance of QuSoft researcher on their thesis.



ABN AMRO

Since October 2019, QuSoft and ABN AMRO have been working together on the DisQover project. Future quantum computers may be highly suitable tools for processing and monitoring financial transaction data. In this collaboration, both parties are exploring the potential of quantum computers in finance.



WIQD

WIQD (pronounced "wicked") is a professional network for quantum technology enthusiasts from industry, academia and policy. Its mission is to bring together women in quantum in the Netherlands, and beyond, for support, networking, and community growth. WIQD is funded by QuSoft, QuTech, Quantum, University of Leiden, and Quantum Delta NL.

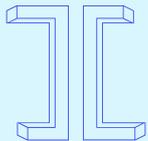


RESEARCH HIGHLIGHTS CRYPTOGRAPHY IN A QUANTUM WORLD

- A. Broadbent, S. Jeffery, S. Lord, S. Podder and A. Sundaram (2021). Secure software leasing without assumptions. Proceedings of the 19th International Conference on the Theory of Cryptography (TCC 2021)
- The organization of QCrypt 2011 was headed by Serge Fehr from the CWI crypto group and Leiden University and by Christian Schaffner from QuSoft and UvA. QCrypt 2021 is the 11th edition of the yearly international scientific conference presenting last year's top results in quantum cryptography.
- Popular article in FD by Christian Schaffner: "Wanneer kraakt de kwantumcomputer onze wachtwoorden?"
- Podcast for BNR digitaal - Interview with Christian Schaffner: "ALGORITMES VAN DE OVERHEID WORDEN VOOR ONS OPENBAAR GEMAAKT".
- Podcast for BNR 'De Technoloog - Interview with Christian Schaffner: "QUANTUMSOFTWARE, EEN PRIL VAK DAT EXPONENTIEEL KAN GROEIEN".

Quantum for Society and Business

QuSoft works with companies and societal organizations to explore, discover and develop novel algorithms, applications and use cases – independent of the hardware they are to be implemented on.



Although quantum computers and a quantum internet are still in their infancy, more and more organizations and companies start to appreciate the potentially disruptive, game-changing impact of quantum technologies in their fields. In this research line, QuSoft works with companies and societal organizations to explore, discover and develop novel algorithms, applications and use cases – independent of the hardware they are to be implemented on. At the same time, the ultra-cold atom experiments offer unique opportunities to test actual applications in the near future. Current industrial partners include national bank ABN AMRO, BOSCH group, Toyota Europe, and ATOS. There is a close connection to the Quantum.Amsterdam innovation hub, as well as practical collaboration with partners like SURF, TNO, and the University of Applied Sciences Amsterdam.

FEATURED RESEARCHER



/ Dr. Koen Groenland

QUSOFT COLLABORATIONS

/ Actual quantum projects

ATOS

QuSoft and Atos joined forces in a collaborative course "Quantum in Business and Society". The focus is on developing new use cases, engaging business markets & the challenges and knowledge gaps that companies are currently experiencing.



Hackaton KLM

Together with the Air France/KLM TripPlanner team, QuSoft organised a hackathon to find out if the underlying algorithms of TripPlanner could be improved by using quantum principles. A quantum scientist teamed up with an Air France KLM employee to try and tackle this problem together.



Quantum. Amsterdam

QuSoft is the cornerstone and one of the founding knowledge partners of Quantum.Amsterdam. The main purpose of the hub is to boost the innovation and economic development of quantum technology by building a strong ecosystem and setting up collaborations between science and business.



HIGHLIGHTS SOCIETY AND BUSINESS

- Q.A public meet-ups:
 - Introduction to Quantum hardware & software
 - Quantum *Startups* in and around the Netherlands
 - €615 million for Quantum. Proposed, Approved, Action!
 - What do companies get out of Quantum projects today?
- Quantum.Amsterdam has a physical location at StartUp Village and is officially open for business from December 2021
- QC Training / Workshops
 - Workshop General Awareness QC truly started, given workshop various times
 - Hackathon QuSoft + KLM
- Outreach, active participation in various international conferences and exhibitions:
 - AI Summit London
 - CES Europe show in de Amsterdam RAI
 - AI Summit, Beurs v Berlage, Amsterdam
 - Q2B conference and exhibition (with QDNL), Santa Clara. US

INSTITUTE

69.6%

of QuSoft's affiliated staff are employed by the University of Amsterdam (UvA)



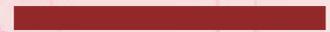
27.5%

of QuSoft's affiliated staff are employed by Centrum Wiskunde & Informatica (CWI)



2.9%

of QuSoft's affiliated staff are employed elsewhere



GENDER

79.7%

Male



20.3%

Female



NATIONALITY

50.7%

Dutch



49.3%

Non-Dutch





COMMUNITY BUILDING

Quantum technologies are complex. So complex, that no single research group or organization can realize the promise of quantum computing alone.

Collaboration is essential for innovation, and leaders from academia and industry are looking to work together to realize the promise of quantum computing.

In 2021, QuSoft worked hard on strengthening its community and quantum ecosystem.

 NEW WEBSITE: WWW.QUSOFT.ORG

 APRIL 2020: **1503** FOLLOWERS

APRIL 2021: **1975** FOLLOWERS

 APRIL 2020: **340** FOLLOWERS

APRIL 2021: **515** FOLLOWERS

 APRIL 2020: **368** FOLLOWERS

APRIL 2021: **708** FOLLOWERS

BUILDING A COMMUNITY

QUANTUM SOFTWARE CONSORTIUM

Together with CWI, Leiden University and QuTech, QuSoft is part of the Quantum Software Consortium (QSC). Developing new quantum software, by exploiting the counterintuitive effects of quantum mechanics, requires a unison of ideas from computer science, mathematics, and quantum physics. In order to achieve this move forward, forces must be combined. Therefore QSC is building a new research community in the Netherlands in Quantum Information Science.

For the year 2021 QSC organised its 5th & 6th General Assembly, the 3rd & 4th Junior Day, 2nd Quantum Training Days and on behalf the Talent and Outreach Committee, Doutzen Abma & Yvonne Smit (together with media company SOON) made an [explainer video](#) about QSC and Quantum Software. This video can be used for any popular science communication activities. Speakers from QuSoft who took part in this video were: Harry Buhrman, Galina Pass, Garazi Muguruza Lasa and Ivo Knottnerus



WOMEN IN QUANTUM DEVELOPMENT

WIQD (pronounced “wicked”) is a professional network for quantum technology enthusiasts from industry, academia and policy. Its mission is to bring together women in quantum in the Netherlands, and beyond, for support, networking, and community growth.

QuSoft colleagues that contributed to WIQD in 2021 are: Stacey Jeffery (founder), Yvonne Smit (chair Organizing Committee (OC)), Jana Sotakova (OC member), Subhasree Patro (OC member), Garazi Muguruza Lasa (OC member), Rima Schüssler (OC member) and Victor Land (Advisory Board member).

In 2021, activities were organized every month and a childcare pilot program started in December 2021 to help mothers attend quantum-related events and work activities. The program aims to remove an important barrier that prevents women from attending events or other work activities by providing funding for childcare.

BUILDING A COMMUNITY



QUANTUM LEAP AFRICA

We started an exchange program between QuSoft and Quantum Leap Africa (QLA), which is a newly founded research institute in Kigali, Rwanda, closely linked to AIMS, the African Institute for Mathematical Sciences. In 2021 up until now QuSoft hosted Crownie Ocha Eme.

She is currently an affiliate of the AIMS Ghana Research Centre, pursuing an MPhil degree in quantum computing at Quantum Leap Africa/ AIMS-Ghana, in partnership with QuSoft/CWI, Amsterdam. Crownie is under the supervision of Dr. Jop Briët and Dr. P.K. Osei.





BUILDING AN ECOSYSTEM

QUANTUM.AMSTERDAM

Quantum.Amsterdam is both a network organization for the institutions on the Amsterdam Science Park involved in quantum technology development, as well as the Amsterdam hub in the national QDNL ecosystem. Starting as a small project in 2020, it is now a mature organization, with a management team of senior members at CWI and UvA, chaired by Christian Schaffner, and an executive team, consisting of Business Developer Maarten Wijdekop, Quantum Innovation Officer Koen Groenland, HvA/CWI Lector Applied Quantum Computing Marten Teitsma, Coördinator Communication and Impact Yvonne Smit and supported by Dimitri van Esch. As from December 2021 Q.A has an office at StartUp Village and is officially open for business!

Quantum.Amsterdam organizes workshops to make organizations and companies more aware of the impact of quantum computing, called the Workshop General Awareness Quantum Computing, as well as (Big) Meetups for the general public and for companies. The event of the year 2021 was de Big Meetup: €615 million for Quantum. Proposed, Approved, Action! Where Harry Buhrman and Giles Brassard spoke on behalf of QuSoft

QUANTUM APPLICATION LAB

In September 2021 the Memorandum of Understanding for the Quantum Application Lab was officially signed. And in March 2022, the Quantum Application Lab was founded. Six institutions (CWI, UvA, TNO, the Netherlands e-Science Center, SURF, and TU Delft (on behalf of Quantum Inspire)) joined forces, together with IBM as a technology provider. The aim is to help organizations and companies start the development of quantum applications for quantum computing. Maarten Wijdekop (Business Developer Quantum.Amsterdam), Victor Land (QuSoft) together with Mark Buningh (TNO) act as the management team for QAL in this phase.

The type of project ranges from first exploration of challenges and possible applications, via strategic roadmapping of quantum technology applications, to the development of (prototypes) of quantum applications, which can eventually be tested, benchmarked and run on quantum computing systems.

BUSINESS DEVELOPMENT

Since June 2021, Maarten Wijdekop is the Business Developer for QuSoft and Quantum.Amsterdam, and therefore focuses on making our academic research useful for business and applications at large.

Before, Maarten worked at TNO for 4,5 years as a business developer for their Photovoltaics groups in Petten and Eindhoven. He brings his experience to the Quantum.Amsterdam hub and enjoys working in the new quantum ecosystem. Some high lights of the past year include:

- Visiting the Quantum2Business conference in Santa Clara, and developing relationships with QC Ware, IBM and many other companies;
- Delivering high quality QC workshops for professionals and organisations who have to prepare for the QC Age, such as De Nederlandsche Bank;
- Engaging famous high-tech companies such as Toyota, ASML and Bosch in collaborative research projects;
- Organising and hosting QC Meetup events to interconnect and develop the Quantum community further
- Establishing the Quantum Application Lab (QAL) consortium with TNO, SURF, eScienceCentre and others where end-users can come to evaluate, develop and road-test QC use cases that could benefit their business proposition.

MAARTEN WIJDEKOP

Business Developer





HIGHLIGHTED EVENT: GALA VAN DE WETENSCHAP

The ninth edition of the Science Gala took place on Tuesday November 23, in a sold-out International Theater Amsterdam, with 'common sense' as the theme. Under the musical guidance of curator Erik de Jong, better known by his stage name Spinvis, scientists shared insights from their field on this theme with the audience. As always, New Scientist editor-in-chief Jim Jansen gave the presentation.

Quantum Intermezzo

Harry Buhrman takes the stage with a violin in his hand. The director of the pioneering research center QuSoft talks about how he and his colleagues are developing quantum software, and what the importance of this is. Under musical accompaniment of Stacey Jeffery and Maris Ozols, he demonstrates the principle of a quantum computer. Buhrman: 'What music is more than rhythm is the same as what a quantum computer is more than a classical computer'.

You can translate a rhythm into a series of zeros and ones. A 0 stands for no sound and a 1 for sound, as in the calculation of a computer it stands for whether or not there is a signal.

Just like the computing power of a computer, you can speed up and slow down this signal of zeros and ones. You can also create slightly more complex tunes by playing multiple rhythms in sync, just like you can do more complex computations by connecting computers in parallel.

Yet the musical depth of a classical computer remains limited. To really play a melody, you also need tones. Just as a tone is a sound wave that vibrates with a certain frequency, a quantum bit (qubit) is also a wave function with a certain number of vibrations. Only a single note is still not enough to create music. For this you need a harmony of several sound waves, just as you need a superposition of quantum particles for quantum calculations.

With a large applause Harry ended his performance, together with researchers Stacey Jeffery and Maris Ozols, with the song 'In Staat van Narcose' by Spinvis. And if you did not know how a quantum computer really works before, than at least with this performance you could now feel what a quantum computer can do more than a classical computer!

Gala van de Wetenschap

Every year, the Gala lets the best scientists take you through the most mind-blowing facts and discoveries. Besides Harry Buhrman, other big names such as Robbert Dijkgraaf, Iris Sommer and Henkjan Honing were also performing on stage.

QUSOFT EDUCATION (BSc)

Through the University of Amsterdam a variety of courses in the general area of Quantum Information are available. They range from introductory to advanced. By including some of these courses in your BSc study program, students can get ready for research projects (BSc or MSc theses) or for their future PhD studies in the field.

A BSc Quantum Information module can be followed as part of a BSc program in Physics and Astronomy, Mathematics or Computer Science. The details depend on the embedding BSc program.

BSc program: Quantum Information (QI) module

A BSc Quantum Information module can be followed as part of a BSc program in Physics and Astronomy, Mathematics or Computer Science. The details depend on the embedding BSc program. In the BSc programs the course Introduction to Quantum Computing gives a first introduction to the subject. Natural follow-up to this are found in the table on the right

BSc program	Essential courses	Recommended courses
Mathematics	<ul style="list-style-type: none"> Quantumfysica 2 Introduction to Quantum Computing 	<ul style="list-style-type: none"> Quantumconcepten Advanced Quantum Physics Moderne Cryptografie
Physics / Astronomy	<ul style="list-style-type: none"> Introduction to Quantum Computing Advanced Quantum Physics 	<ul style="list-style-type: none"> Linear Algebra Moderne Cryptografie
Computer Science	<ul style="list-style-type: none"> Introduction to Quantum Computing 	<ul style="list-style-type: none"> Linear Algebra Quantumfysica 1 & 2 Moderne Cryptografie
Chemistry	<ul style="list-style-type: none"> Introduction to Quantum Computing 	<ul style="list-style-type: none"> Linear Algebra Quantumconcepten Quantumfysica 2



QUISOFT EDUCATION (MSc)

MSc program: The QuSoft Master Certificate

Since 2021, QuSoft offers a certificate for MSc students at the University of Amsterdam. It is awarded to students that have demonstrated extraordinary commitment to quantum information science and have carried out their MSc thesis research project at QuSoft.

This Master Certificate is specifically for students who are interested in a future career in Quantum Software and fulfills therefore all the required courses they need to do so.

Requirements for obtaining the certificate are:

1. Successful completion of three courses coming from at least two categories (read along to see what categories there are).
2. Attendance of three QuSoft seminars (you can find a schedule of all seminars at the bottom of this page).
3. Successful completion of a MSc thesis research project at QuSoft. (Please, go to our research lines to find a fitting supervisor).

A member of QuSoft will make the final determination about whether the certificate will be issued.

In 2021 the first two QuSoft Master Certificates were awarded to Chanelle Matadah Manfouo and Ricardo River.

Category 1

- Quantum Computing (8 EC)
- Quantum Information Theory (8 EC)

Category 2

- Bose Einstein Condensates (6 EC)
- Fermi Quantum Gases (6 EC, offered until 2021)
- Quantum Optics (6 EC)
- Quantum simulations with atoms and molecules (3 EC)

Category 3

- Quantum in Business and Society (3 EC)
- Comparable experience (such as a company internship, contribution to a teaching or outreach effort)

10. How many quantum bits do the currently largest quantum computers have?

- A. 1-10
- B. 10-100
- C. 100-1000
- D. 1000-1,000,000
- E. >1,000,000



**MORE EDUCATION
AND OUTREACH**



QUANTUM QUEST

The Quantum Quest is a web class for high school students from 16-18 years, organised by QuSoft, UvA and QSC. This course takes high-school students on a four-week adventure to learn the basics of quantum computing.

After a successful start in 2018, the course is also available for international students this year. Between November 5 and December 17, 47 highschool students discovered more about quantum entanglement and quantum circuits.

They are supervised by a team of teaching assistants led by junior teacher Mees de Vries.

The idea of the curriculum comes from Maris Ozols and Michael Walter. The aim of Quantum Quest is not primarily to introduce students to programming for the next generation of computers, but also to discover the kind of mathematics taught at the university.

NATIONAL QUANTUM COURSE

This course is intended as a solid introduction to quantum technologies (and all players involved) for the general public. It does not require any prior knowledge of mathematics or physics.

Everyone in society can follow the course online. Just like the national AI course (<https://www.ai-cursus.nl>) the principle is the same.

This initiative that started in 2021 by Quantum Delta NL and Jim Stolze should be finished in 2022. QuSoft contributed actively in the course and QuSoft researchers explained the quantum software and quantum sensing part. QuSofters who contributed to the course are: Koen Groenland, Stacey Jeffery, Christian Schaffner and Premjith Thekkepatt.



QUSOFT SEMINARS

Every Friday of the week Jop Briët and Subhasree Patro organised the, now well-known, QuSoft seminars.

Scientists from all over the world are invited to talk about their expertise in the field of quantum research.

These seminars are closed and only for a specific scientific audience. In this way all attendants feel the freedom to dive deeper into the material. Everyone is encouraged to initiate discussions that strengthen collaborations and provide new insights.

Many of the seminars were recorded and can be found on the QuSoft YouTube-channel.

A few selected international speakers are listed here:

Rahul Ilango (MIT)

Towards Hardness for the Minimum Circuit Size Problem

Ansis Rosmanis (Nagoya University)

Proving the Hardness of Inverting Permutations via Database Arguments

Srinivasan Arunachalam (IBM Research)

Positive spectrahedra: Invariance principles and Pseudorandom generators

Nick Spooner (Boston University)

Post-Quantum Succinct Arguments

Joseph Renes (ETH Zürich)

Belief propagation decoding by passing quantum messages

HONOURABLE MENTIONS & AWARDS

- Stacey Jeffery, senior researcher at QuSoft and part of CWI's Algorithms and Complexity Group in Amsterdam, is awarded an ERC Starting Grant of 1.5 million euro for research on Algorithms, Security and Complexity for Quantum Computers (ASC-Q). The grant helps ambitious younger researchers launch their own projects, form their teams and pursue their best ideas.
- QuSoft researcher & CWI phd student Jordi Weggemans wins Lorentz graduation prize. The prize was awarded by the Koninklijke Hollandische Maatschappij der Wetenschappen (KHMW)
- Quantum Delta NL, of which QuSoft is part, has been awarded €615 million from the Dutch Ministry of Economic Affairs and Climate Policy to power the advancement of quantum technology. This gives a tremendous boost to quantum research and development in the Amsterdam ecosystem.
- In December 2021, Christian Schaffner was appointed Professor in Theoretical Computer Science at the Informatics Institute at the University of Amsterdam. On Friday, 30 September 2022, he will give his inaugural lecture as professor in theoretical computer science.
- Michael Walter left QuSoft to start a new adventure. He was appointed as a Professor of Quantum Information, Faculty of Computer Science and CASA Cluster of Excellence. QuSoft wishes him all the best and certainly keeps on collaborating with Michael as an affiliated researcher.



APPENDIX FINANCIALS

The structural funding for QuSoft is provided in part by UvA through the Quantum Matter & Quantum Information (QM&QI) Research Priority Area of the Faculty of Exact Sciences, and by CWI. Through it, tenure track researchers and junior research positions are funded, as well as support positions (including the QuSoft Institute Coordinator, the Coordinator Communication & Impact, Quantum Innovation Officer, as well as secretarial support). Furthermore, the office spaces, infrastructure and organizational support is provided for. The financial overview for 2021 is summarized in the table below.

Apart from this direct structural funding, some of the external funding is also included, such as funds through additional NWO, and EU Grants. Also, income and expenditures related to the QA hub are included.

QuSoft Budget turnover 2021 (CWI)

Benefits		Costs	
CWI basic funding	€352,000	Personnel costs Scientific staff	€1,010,000
External project funding (NWO, EU, PPS, etc.)	€888,000	Personnel costs Support staff	€120,000
		Housing expenses	€110,000
Total	€1,240,000	Total	€1,240,000

QuSoft Budget turnover 2021 (UvA)

Benefits		Costs	
QM&QI budget 2020	€547,000	Personnel costs Scientific staff	€1,066,125
Q.A Services (1)	€12,068	Personnel costs Support staff	€167,355
External project funding	€694,227	Personnel costst Outsourced staff (3)	€85,831
Extraction reserve(<2021) (2)	€145,848	Other expenses	€79,832
Total	€1,399,143	Total	€1,399,143
Grand total	€2,639,143	Grand total	€2,639,143

(1) This includes income from e.g. the Workshop General Awareness Quantum Computing provided to external customers.

(2) Over the first 5 years of QuSoft, not all budget was allocated, which was put in a Reserve.

(3) This includes hiring external support and project management personnel.

APPENDIX PHD DEFENSES 2021

Yfke Dulek

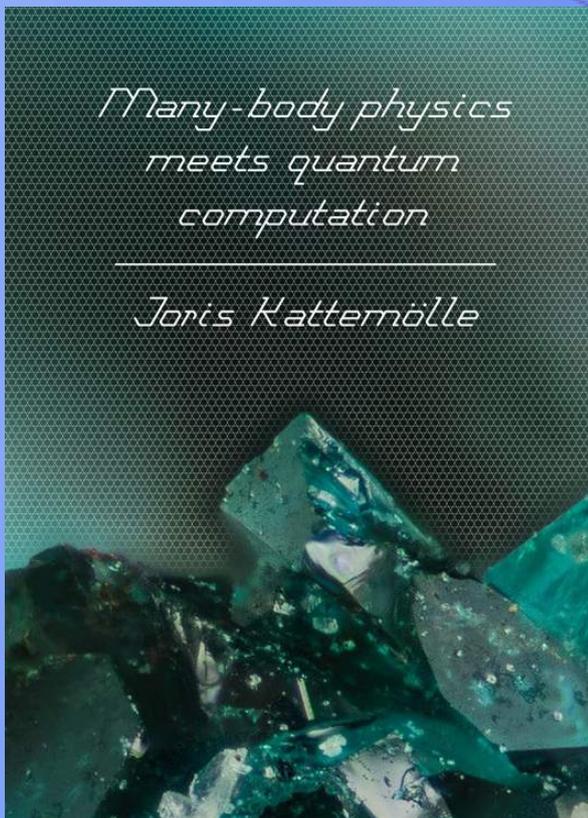
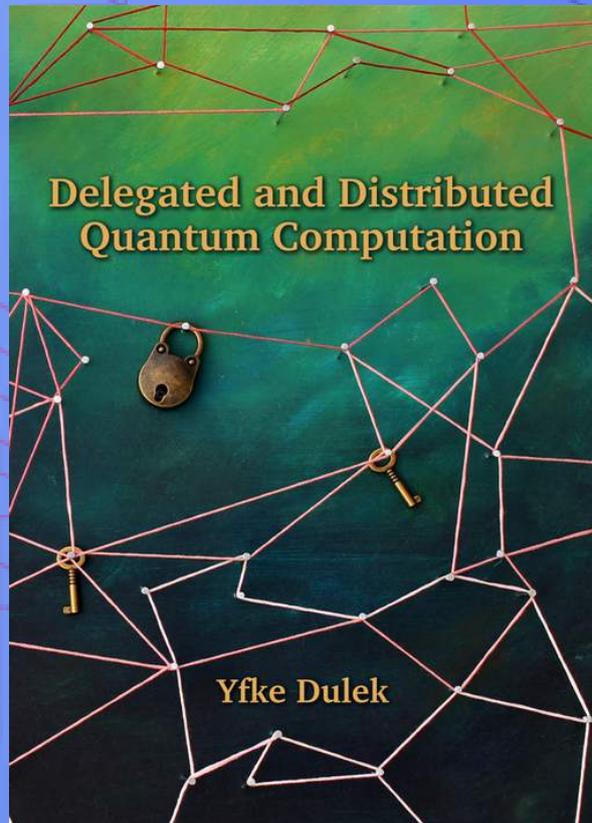
Defended her thesis 'Delegated and Distributed Quantum Computation' on January 15, 2021

Joris Kattemölle

Defended his thesis 'Many-body physics meets quantum computation' on June 23, 2021

Alvaro Piedrafita

Defended his thesis 'On span programs and quantum algorithms' on November 10, 2021



On Span Programs and Quantum Algorithms

Álvaro Piedrafita

