Theme: Continuous-variable quantum computing

WACQT | Wallenberg Centre for Quantum Technology

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Dear reader,

We now release the 5th WACQT newsletter and hope you will find it interesting. This time the theme article explains the concept of continuous-variable quantum computing.

So far this newsletter has been privileged information for our industrial partners and WACQT members. Since we put quite a lot of effort into these newsletters, we have discussed different ways to spread this knowledge further and to increase the visibility of WACQT. In discussion with our Industrial Advisory Board, we have therefore decided to make this newsletter public on our webpage after a grace period of one month. We hope that this will contribute to our goal of increasing the knowledge of quantum technology in Sweden.

From the 1st of January, Professor Anne L'Huillier from Lund University is new principal investigator in the WACQT management. I want to take this opportunity to welcome her to WACQT.

Per Delsing
Director of WACQT

Theme: Continuous-variable quantum computing

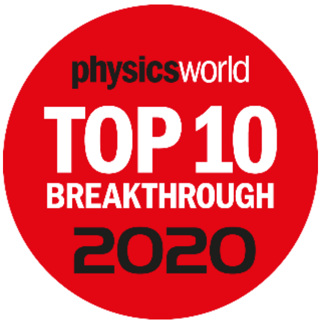
Dealing with errors is the most difficult obstacle on the road to large quantum computers. A rapidly expanding niche is therefore to encode the computational information in systems with a large (infinite) number of quantum states to achieve a built-in robustness against errors. Within WACQT, we are now increasing our efforts within this field, called continuous-variable quantum computing.

Theme article Continuous-variable quantum computing

WACQT news

Scientists "film" a quantum measurement

Measuring a quantum system causes it to change – one of the strange but fundamental aspects of quantum physics. The group of WACQT principal investigator Markus Hennrich at Stockholm University has been able to demonstrate how this change happens. The feat was selected as one of the top ten breakthroughs in 2020 by the magazine Physics World.

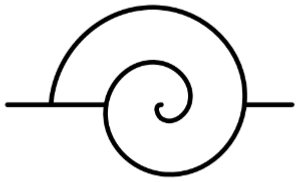


While the act of measurement usually forces quantum systems into definite classical states, the work of Markus Hennrich and colleagues showed that some measurements do not destroy all quantum information. By taking a series of "snapshots" during experiments on a single strontium ion, the team revealed that measurements are not instantaneous, but instead gradually convert superposition states into classical ones. Their findings shed new light on how quantum physics works, and might be used to improve error correction in quantum computers.

Read more in Physics World, at the website of Stockholm University, and in Physical Review Letters.

New architecture allows for universal continuous-variable quantum computation

In order to achieve a universal quantum computer that can be programmed to solve widely different problems, one needs a set of elementary quantum logic gates which can be combined to implement any computation. Such a set is called a *universal gate set*.



For continuous-variable quantum computing – a quantum computing approach in which information is stored in many different quantum states instead of just two different states in a qubit – there have been some proposals of universal gate sets, but none have been realistic to implement. But now, a team of WACQT researchers has theoretically shown how a universal gate set can be implemented in continuous-variable quantum computers based on microwave circuits. The key is to make use of a so-called superconductive nonlinear asymmetric inductive element (SNAIL) in the architecture of the quantum computer.

"Our results open the quest for continuous-variable algorithms based on few repetitions of elementary gates from the universal gate set," says theoretical physicist Giulia Ferrini who led the work together with Fernando Quijandría.

The experimental experts in continuous-variable quantum computing within WACQT, led by Simone Gasparinetti, are now considering implementation in the lab.

The work is published in Physical Review Letters and is also openly available as a pre-print.

Martinis becomes guest researcher at Chalmers

Professor John Martinis, world star within quantum computing, has accepted an invitation from WACQT to become a guest researcher in the quantum computing team at Chalmers. If not stopped by covid-19 restrictions, his visit is planned for this summer.

John Martinis was previously head of quantum computing hardware at Google, where he led the

team that built the first quantum processor that outperformed a classical computer. In 2020, Martinis resigned from Google and WACQT leaders Göran Wendin and Per Delsing, who are old friends of Martinis', saw the chance to invite him as a guest researcher.

"Scaling up to above 20 qubits is one of the most difficult steps in building a large quantum computer. Martinis already did this at Google, and I believe that his knowledge and experience can be really useful to us," says Per Delsing.

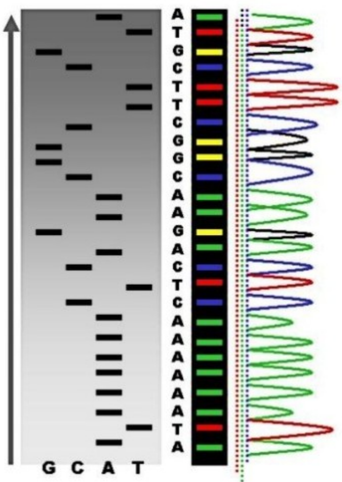
Martinis nowadays works for Silicon Quantum Computing (SQC), an Australian startup company that develops a quantum computer based on silicon. SQC was founded by Michelle Simmons, a renowned quantum physicist who was named "Australian of the year" in 2018 for her work in quantum information science.

Collaboration initiated with leading European metrology institutes

The recently started quantum metrology project *Frequency-structured materials for enhanced optical frequency references*, led by Martin Zelan at RISE and Lars Rippe at Lund University, are in contract negotiations concerning a Horizon 2020 EU grant for a project about a new generation of ultrastable lasers together with several partners, including the national metrology institutes in Germany (PTB), France (SYRTE), and Italy (INRIM).

"We think this connection to the major metrology institutes in Europe will be very beneficial for this first WACQT-supported quantum metrology project," says Stefan Kröll, principal investigator in WACQT.

Expanding quantum computing into medical sciences



An example of the results of automated chain-termination DNA sequencing

An important task within quantum computing research is to find real-world problems which are beyond the reach of regular computers, but that a relatively small quantum computer can solve. WACQT researchers are already exploring possible quantum advantages within chemistry, logistics and machine learning. In close collaboration with Sahlgrenska Academy, WACQT now expands into working on quantum algorithms for gene sequencing and life science as well.

WACQT has already recruited a PhD student, Hanna Linn, who has a physics background, and Sahlgrenska Academy is about to recruit a PhD student with a medical-science background. The two doctoral students will work together in exploring how quantum algorithms can be used within genomics for diagnostics, prediction, and prevention, having supervisors from both WACQT and Sahlgrenska Academy.

"This is a new application field for quantum computing. Some scientific publications have started to appear recently, and now is a good time for us to get going," says Göran

Johansson, theoretical quantum physicist who will be one of the supervisors.

Expert on ultrashort light pulses becomes new principal investigator

The WACQT management has been reinforced by an additional principal investigator: professor Anne L'Huillier. She will coordinate research within quantum sensing, together with Stefan Kröll, Katia Gallo, and Markus Hennrich.

Anne L'Huillier is head of the Attosecond Physics group at Lund University. Her research focuses on the generation of extremely short light pulses and on the study of ultrafast quantum dynamics. Within WACQT, she leads a project on controlling atomic matter on attosecond timescales.

"Anne L'Huilliers group has long been at the forefront of laser-atom physics, and brings important expertise to WACQT regarding time-resolved spectroscopy and control of the dynamics of quantum systems," says Göran Wendin, senior advisor and principal investigator in WACQT.

In collaboration with researchers from several Swedish universities, they recently managed to follow the dynamic process when an electron's spin – its rotation around its own axis – controls how an atom absorbs light. Read more about the study at Lund University's website or in the scientific publication in Nature Communications.

WACQT leader elected member of the Royal Swedish Academy of Sciences

Professor Göran Johansson, one of the principal investigators in WACQT, was elected member of the Royal Swedish Academy of

Sciences (KVA) in January 2021 – an honourable recognition of his achievements within science.

As a member of KVA, Johansson will take part in the Academy's work to promote the sciences and strengthen their influence in society. The Academy acts as a consultative body to the Swedish government and parliament, creates public opinion, awards prizes and arranges lectures, and appoints the Nobel laureates in physics and chemistry.

Within WACQT, Johansson leads theory efforts in quantum computing and simulation. He is also director of studies of the Swedish Graduate School in Quantum Technologies and head of the Applied Quantum Physics Laboratory at Chalmers.

Read more:
Kvantfysiker invald i Akademien (kva.se)
Quantum physicist elected member of the Royal Swedish Academy of Sciences (chalmers.se)

Coming events

On 8–9 April, WACQT arrange an online workshop in Quantum Software and Optimisation. Please have a look in the WACQT calendar for information about all our coming events.

WACQT in the media

In WACQT Newsletter #3 we reported about WACQT's successful small-scale demonstration of a useful quantum algorithm. The results were published in Physical Review Applied during the autumn, and a press release was sent out by Chalmers just before Christmas.

The release resulted in media clippings in 17 countries and in WACQT researchers being interviewed both in the leading Swedish daily newspaper, Dagens Nyheter, and in the popular science magazine Forskning & Framsteg:

Chalmers kvantdator bryter ny mark – lockar Googles avhoppare till Göteborg (Dagens Nyheter)Så testades den svenska kvantdatorn med ett realistiskt problem (Forskning & Framsteg)

The technology newspaper Ny Teknik has published an article about a new mentoring programme for female researchers, organised by Women in WACQT together with the Chalmers network Women in Science: Nytt mentorprogram ska ge fler kvinnliga förebilder på Chalmers (Ny Teknik)

Read more about WACQT media coverage

Selected world-wide news

Quantum advantage demonstrated with photon-based quantum computer. A research team in China has demonstrated a quantum computer based on photons – particles of light – that outperforms even the fastest classical computers. In 2019, Google captured headlines when their superconducting quantum computer in three minutes solved a problem that would take a supercomputer at least three days. The Chinese team is now second to achieve so-called *quantum advantage.*

But in contrast to Google's demonstration, the problem was not only solved faster by the Chinese quantum computer than on a supercomputer – it is judged to be virtually insoluble for any classical computer. The problem, called the boson-sampling problem, may have potential practical applications in graph theory, quantum chemistry and machine learning, according to the research leader Jian-Wei Pan.

"It is clear that photonic systems are in the race for demonstrating scalable implementations of quantum computers. Also, the Chinese implementation of boson-sampling is fully room temperature, which is a remarkable advantage compared to superconducting-based quantum computers. I am really excited about future developments of this field," says Giulia Ferrini, one of the principal investigators for quantum computing within WACQT.

Read more in Nature News, Scientific American or in the scientific publication in Science.

Quantum engineering can further improve timekeeping. Atomic clocks known as optical clocks are the most accurate and stable timekeepers. Two quantum-engineering approaches could improve the performance of optical clocks even further and extend their applications, as described in two studies published in Nature.

The first approach is to surpass the limit to clock stability set by quantum fluctuations by using the quantum phenomenon called *squeezing* (explained here). The second is a method to prepare a highly coherent ensemble of a large number of clock atoms, which enables a high-performance clock operation.

"Optical clocks operate with up to 16 digits precision or more. Such a performance requires overcoming close to unimaginable challenges. It is extremely inspiring to see the sophisticated novel methods and ideas that come up in order to push this precision and accuracy even further," says Stefan Kröll, principal investigator in WACQT.

Read more in Nature

Chinese scientists have created a large-scale integrated quantum communication network. Chinese scientists have established the world's first integrated quantum communication network, combining several metropolitan networks connected by optical fibre backbones on the ground with two ground-to-satellite links. The network covers a total distance of 4,600 kilometres and is used for distribution of encryption keys, so-called quantum key distribution, among users across China. The team leader Jian-Wei Pan states that their work shows that quantum communication technology is sufficiently mature for large-scale practical applications, according to a press release from University of Science and Technology of China.

The integrated network uses trusted relay nodes to repeat and forward the signals, both within the ground-based network and to connect with the satellite links – achieving secure quantum key rates up to around 50 kilobit per second, currently limited by the time window

of the orbiting satellite used in the experiments.
“These ground-breaking experiments take quantum-secured optical communications one step closer to the realistic prospect of implementing a worldwide network by effectively combining large-scale fibre and free-space technologies,” says Katia Gallo, principal investigator and coordinator of efforts in quantum communication within WACQT.
The integrated quantum network is described in a scientific publication in Nature.

Efficient quantum photon sources on a chip. Devices which can generate entangled pairs of photons of high quality and at a high rate are increasingly desirable as the field of quantum communication develops. Using a lithium-niobate resonator on a chip, a research team in the United States has now managed to achieve photon-pair generation at high rates, tens of megahertz, using only microwatt pump power. This is an improvement in efficiency by orders of magnitude compared to the previous state-of-the-art. The created photon pairs have also been shown to be in pure quantum states. The new photon source can become useful for example in quantum communication and optical quantum logic.
“Through an exquisite control of nanophotonic technology lithium niobate, the team at the Stevens Institute of Technology has managed to demonstrate a quantum source of outstanding performance. These exciting results pave the way for integrated quantum chips leveraging such ultrabright, high-rate and ultralow footprint photon sources together with the unique capabilities of lithium niobate nanocircuitry for ultrafast photon manipulation and quantum information processing in optical and microwave domains,” says Katia Gallo, coordinator of efforts in quantum communication within WACQT.
Read more in Physical Review Letters

New European supercomputer will promote hybrid quantum computing. The European Union and ten European countries, including Sweden, invest together in building one of the world’s fastest supercomputers. The supercomputer is to be completed in summer 2021 and will be located at Finland’s government-owned IT and data centre in Kajaani. It will be named LUMI, which means “snow” in Finnish.
The LUMI supercomputer will have a top performance of 552 petaflops per second, which is 39 petaflops/s faster than the currently fastest supercomputer, Fugako in Japan. LUMI will also be one of the world’s most advanced platforms for artificial intelligence.
"The LUMI project will greatly promote Nordic and European collaboration in computer and computational science. This includes new directions toward hybrid computing with quantum accelerators," says Göran Wendin, principal investigator and senior advisor in WACQT.
As reported in WACQT Newsletter #4, Chalmers recently participated in an EU application for hybrid quantum computation together with the LUMI project.
“Our application came second by a hair’s breadth, but we expect to get it financed in a second call during 2021,” says Wendin.
Read more about LUMI

Finland to build a quantum computer. The Finnish state-owned research institute VTT has commissioned the start-up company IQM to build Finland's first quantum computer. The hardware is based on superconducting circuits and the goal is to have a 50-qubit machine ready by 2024.
The Finnish state supports the project with 20.7 million euros and with additional funding raised by IQM, the total funding is 71 million euros.
“Finland has many skilled quantum researchers and IQM has hired a lot of people, but they are behind us when it comes to building

quantum computers," says Per Delsing, director of WACQT.
Read more at the VTT website

Xanadu and Amazon plan to build continuous-variable quantum computers. The companies Xanadu and Amazon recently made public their respective plans on how to build continuous-variable quantum computers, that is quantum computers in which the information is encoded into a large number of different quantum states, in contrast to just two different states in the more common approach based on qubits.
Xanadu's blueprint describes a continuous-variable quantum computer which uses photons as information carriers and has an architecture based on two-dimensional integrated photonic chips. According to Xanadu, their design is scalable, fault-tolerant, and enables room-temperature operation (however, the read-out requires cryogenic temperatures at the moment).
Amazon's publication presents an architecture for a fault-tolerant quantum computer with hardware based on a system of acoustic resonators coupled to superconducting circuits with a two-dimensional layout.
"Both road-maps are very serious outlines of how a fault-tolerant continuous-variable quantum computer could be designed," says Giulia Ferrini, leader of the theoretical efforts in continuous-variable quantum computing within WACQT.

France invests heavily in quantum technology. On January 21, the French president Emmanuel Macron announced that France will invest almost 2 billion euros over five years in order to become a top-three player in the world in quantum technology. The money will be devoted to quantum computing and simulation, quantum communication, quantum sensing, post-quantum cryptography, and related technologies needed for realising quantum technology, such as cryogenics.

According to the newspaper Le Monde, Macron declared that France needs to keep its talents, and also to keep certain technologies in order not to depend in particular on the two great international powers, China and the USA.
"It's a bit ironic that European countries are waking up this late. Europe was a world leader in quantum computing until 2010, but a lack of focused efforts from both the European commission and the member states allowed the USA and China to gain the lead at the engineering level. The most difficult part now is to get hold of the right people, as the market is presently vacuum-cleaned when it comes to young talent," says Göran Wendin, senior advisor in WACQT and project leader for EU quantum computing efforts 2000–2016.
Read more in Le Monde (in French)

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