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S-CON

(Solvey Congress)

"28th Solvay Conference on Physics: The physics of quantum information"

Background Guide

Dear scientists,

Welcome to the first edition of the Solvay Congress committee. I am Abril Cetina, and at this year’s conference, I’ll be your director with the help of my scientific secretary, Angel Treviño, and my conference officer, Alma Lopez. It is our pleasure to welcome you to our committee.
Let me properly introduce myself. I am 17 years old, and I am a sophomore at La Salle. I aspire to become a film major after I graduate. During my free time, I do various activities such as pottery, painting, working out, writing, reading, and researching topics of my personal interest. I participated in a MUN as a delegate for the first time as a middle schooler. Then, a year later, in my second semester of high school I participated again as a delegate at the Historical Security Council. I've truly enjoyed the experience and opportunity of participating and have grown very fond of it.
This will be my first time as chair, and I am truly grateful for being trusted with this responsibility. I am working hard to make this year’s first Solvay Conference a great, refreshing, and unique experience for you and to help you expand your knowledge of modern topics surrounding physics and technology. Please don’t hesitate to contact me if you have any doubts or questions. I am thrilled to meet you and to be able to guide you at the conference.

Best of luck,

Abril Elina Cetina Campos
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COMMITTEE DESCRIPTION

A Solvay Congress (S-CON) is a series of scientific conferences initiated by the Belgian chemist Ernest Solvay in the early 20th century. These congresses are renowned for bringing together some of the most influential scientists from around the world to discuss and deliberate on various topics in physics and chemistry. The Solvay Congress serves as a platform for experts to engage in rigorous scientific discourse and exchange ideas.

Topic: "28th Solvay Conference on Physics: The physics of quantum information"

INTRODUCTION

Advancements in quantum optics and related fields have paved the way for significant progress in theoretical developments and practical applications of quantum information theory.

Quantum information theory shares some foundational ideas with its counterpart, which has led to the development of classical computers. However, it also introduces many new concepts and potential applications based on unique possibilities inherent in quantum theory.

In classical information processing, we use basic units called bits to carry and encode information. Quantum information processing, on the other hand, uses units called qubits. These qubits function quite differently from classical bits. While a bit can only be in one of two states (either '0' or '1'), a qubit can exist in an infinite number of states, all stemming from two primary states denoted as $|0\rangle$ and $|1\rangle$. This means a single qubit can represent an endless number of classical bits. Additionally, when we have more than one qubit, their combined states can hold correlated information in a way that is fundamentally different from classical bits. This particular kind of correlation appears as entangled states of the qubits.

In classical information processing, we manipulate the joint states of bits using classical logic gates. Similarly, in quantum information processing, we use gates. The states of qubits in a quantum register can be changed step by step by applying various quantum gates. These gates form a universal set, and there can be multiple possible sets of universal gates. A universal set comprises gates that act on a single qubit and others that work on the combined states of more than one qubit. By applying a predetermined sequence of gates to the initial data stored in the qubit register, we perform a program, which can be seen as the execution of an algorithm. This program takes the qubit register to a final state, providing data that may solve a given problem provided by the appropriate algorithm.

While this is the fundamental concept of quantum computation, which can theoretically outperform classical computation by a wide margin, qubits and quantum gates can also be used for other equally remarkable information-processing tasks. These tasks involve using classical and quantum communication channels to transfer classical and quantum information.

HISTORICAL BACKGROUND

In the early stages, the new regime in physics was marked by Max Planck's introduction of Planck's constant in 1900. Although very small, this constant indicated a departure from smooth, continuous behavior in the physical world.

While the concept of quantization was introduced in 1900, it took much longer for a comprehensive quantum theory to develop. The idea of discontinuity was a tentative first step and progress in reshaping.

The origin of this quantum journey dates back to a day on December 14, 1900. Max Planck was presenting to the German Physical Society about the spectrum of light frequencies emitted by a heated object. A few months earlier, he had introduced a formula based on new experimental findings. Now, with more time to reflect, he aimed to provide a physical explanation for it.

Planck envisioned a piece of matter, simplifying it as a group of oscillating electric charges. He then imagined distributing its energy in discrete units, which were proportional to the frequencies of oscillation. He labeled the constant of proportionality as 'h,' which we now express as $E = hf$, where E represents energy and f stands for frequency. The frequencies of oscillation determined the frequencies of the emitted light. Through a complex chain of reasoning, Planck's postulated formula was confirmed, now involving the same natural constant 'h.'

Then, in the 1927 Solvay conference, quantum theory was discussed by pioneers in the field, representing the pinnacle of the debate over the interpretation of quantum mechanics. This discussion was launched after the developments of matrix and wave mechanics. After the conference, the quantum mechanics community split into two camps: those who adhered to Niels Bohr and Werner Heisenberg’s position, known as the Copenhagen Interpretation.

There have been more recent significant advancements in the field of quantum mechanics, such as Google's demonstration of quantum supremacy in 2019, which marked a significant milestone in quantum computing, showcasing its potential to solve complex problems. Progress in quantum communication and encryption technologies also promises highly secure information transmission methods. Researchers have continued to push the boundaries of quantum entanglement and non-locality, testing our understanding of fundamental quantum phenomena. Additionally, developments in quantum sensing, metrology, and machine learning are showing promise in various practical applications. Ongoing debates in quantum foundations continue to explore the philosophical and conceptual implications of quantum mechanics.

CURRENT SITUATION

We are currently at a moment in history where we can create and precisely control complex states of interacting particles. These states are so intricate that our most powerful existing computers struggle to simulate them efficiently, and our current theoretical framework cannot accurately predict their behavior.

Technologies initially developed for other purposes, such as precision clocks and high-precision magnetometers, have been repurposed for coherent quantum information processing. These include ion-trap quantum processors, superconducting quantum processors, and systems based on photonics and single electrons.

At present, ion traps and superconducting circuits represent the most advanced quantum computing technologies. Ion traps utilize single electrically charged atoms as qubits, while superconducting circuits arrange approximately 100 qubits in a two-dimensional array. Both technologies have made strides in performing tasks challenging classical computers, demonstrating their potential.

Notably, Google's research involving the quantum repetition code and Quantinuum's success with a 7-qubit error correction code represent significant breakthroughs. These developments are pivotal because they lay the foundation for more reliable quantum computations, a critical aspect of the journey toward practical quantum computing.

Google's contribution focuses on the quantum repetition code, a method that utilizes up to 21 qubits in their Sycamore processor. It employs 11 qubits within a code block and an additional ten ancilla qubits for error syndrome measurement. This approach, while still not entirely a quantum error-correcting code, provided protection against dephasing errors. The key achievement here is the ability to carry out multiple rounds of syndrome measurement, up to 50 consecutive rounds. Each of these rounds takes about 1 microsecond, with most of the time dedicated to resetting the ancilla qubits for the subsequent measurement. Quantinuum's work, on the other hand, is focused on error correction for a 7-qubit code capable of correcting arbitrary errors acting on any one of the seven qubits. This experiment involved up to six consecutive rounds of error correction, with each round taking about 200 milliseconds. What is noteworthy here is that the cycle times in this experiment are considerably longer compared to the Google approach. This difference is primarily due to the architecture employed by Quantinuum, which involves transporting ions to specific processing zones for high-fidelity operations and sympathetically cooling their motional state. Along with these advances on the subject, multiple novel phases of matter have also been discovered by MIT scientists, such as "quantum spin liquid" and "discrete time crystals."

Despite these developments, there are still multiple things yet to be studied in the field, such as gate error rates. These errors, which occur during operations on qubits, remain too high in current quantum devices, including those used by Google and Quantinuum. Consequently, achieving higher fidelity in two-qubit logical gates through error correction remains a daunting task, and addressing gate errors is a critical hurdle in the pursuit of reliable quantum computation.

Scientists Box

Daniel Gottesman David Gross David J. Wineland Douglas Stanford Frank Verstraete John Preskill Misha Lukin Netta Engelhardt Peter Zoller Peter W. Shor Rainer Blatt Robert J. Schoelkopf Scott Aaronson

Guide questions

I. How can quantum computing help society to progress?
II. What are the fundamental limits of quantum machines?
III. What should we do to understand quantum gravity?
IV. What theories or contributions has your scientist contributed to the topic?

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