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ETH Meets You in Davos
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Do you speak quantum?

As Quantum Computers make a stronger and stronger appearance in the mainstream news, young companies and start-ups have joined the race alongside the big tech giants and academic researchers to realize quantum computing. What does it take to create a quantum computer? What mysterious principles form the foundation of quantum computing? Moreover, which language will we have to speak to understand and communicate?

At the Institute for Quantum Electronics, ETH Zurich, several groups are pushing the boundaries of quantum information processing on a daily basis. We work on different platforms - some of the groups use single atoms in which they strip off an electron to make it into ions that they trap and manipulate using electric fields and lasers. Other groups use electrical circuits and microwave signals. Still others use defects in solid-state materials. All of institute's groups work towards implementing the necessary ingredients to create a functioning quantum computer. The race is still open as to the best platform, and many challenges lie ahead as we try to scale devices to a higher number of qubits. So far, the largest quantum computers have demonstrated the use of about 50 qubits, and researchers have been sweating to find a task that only a handful of qubits could achieve and that a classical computer could not. However, millions of qubits may be required for a truly useful computer. This year, ETH Zurich has launched a new master's degree program in Quantum Engineering to train the workforce who will turn this vision into reality.

R**ETH**INKING Creativity Exhibition Curator Simone Bucher van Ligten teamed up researchers from the Trapped Ion Quantum Information group led by Professor Jonathan Home with a group of young artists and interaction designers We Are Lucid, to create installations that provoke, inspire, and encourage visitors to step into a new quantum world, and to learn some of its language.

In "Do you speak Quantum?" we will guide visitors through these questions:

- Why all the fuss about quantum computers?
- How are quantum computers implemented?
- What do they actually do?
- How do they compute?

Upon entering the ETH Zurich Pavilion, visitors will be immersed in the world of quanta. As they take a walk through “The Qubit Forest,” they will marvel at a quantum error correction algorithm in action. Visitors will then stop at the “Particle Ballet” - a particle trap very much like the ones used by researchers in the labs – to view trapped particles illuminated by light. The trapped particles dance around in clever choreographies as the trapping parameters are changed. Finally, visitors reach the main room, where they encounter “entangled orbs”, a series of levitating spheres that turn together, as if they had been hypnotized. The orbs mimic the effect of entanglement on qubits. Entanglement is one of the main quantum physics resources that provide quantum computers with “super powers,” and allow them to perform hard tasks faster and better than classical computers. The centrepiece of the exhibit, the “pond of possibilities,” transforms visitors into a qubit allowing them to create ripples in the quantum landscape. As ripples propagate, they encounter other ripples and overlap, strengthening, or canceling, each other. This effect, called interference, is at the basis of quantum computation.

Exhibition Pieces

The Qubit Forest

At the entrance of the exhibition, the visitor will pass through two infinity mirrors that face each other. The exhibit piece create multiple images of the visitor, to give a sense of the multiplicity of realities that quantum objects explore. This destabilizing experience will mark the entrance for the visitor to a new world. The infinity mirrors represent one of the key principles of quantum physics, superposition. Superposition refers to a quantum object that is not only in one state, but can be in several different states at the same time. The quantum object exists in multiple states until measured at which time it resolves into one state.

Particle Ballet

As the visitor walks further along the corridor, he/she will be able to peer into the quantum world, by viewing a real quantum device from the laboratory through magnifying lenses. The device made of metal rods in which visitors can apply an electrical voltage to create a trapping configuration for dust and charged macro particles. The concept of trapping and manipulating individual particles such as atoms, ions, or electrons is pervasive in all quantum fields. With this simple installation, we want convey to visitors the power of isolating very, very, small particles that can be precisely manipulated.

Entangled Orbs

Two spheres, magnetically levitated, allow visitors to set one orb into rotation, the other orb, which is independent and disconnected from the first mimics the rotation. This exhibit piece represents Albert Einstein’s famous “spooky action at a distance” or “entanglement” - another core principle of quantum mechanics. When two particles are entangled, even if they are located far from each other, they are still mysteriously connected and react to the motion of the first. Entanglement is used in quantum computation, in order to transfer information from one qubit to another.

Pond of Possibilities

The quantum exhibit culminates with a centerpiece: a large tank filled with water, the "pond of possibilities." Conveying a key concept from quantum computing the pond represents how a computer explores many possibilities simultaneously and then makes a comparison using the effects of interference to “find” an answer. Visitors will play with the interference of water waves by selectively place obstacles, thus designing “algorithms.” Waves passing through different parts of the obstacle structure will reinforce each other and create small splashes, the position of which will select out of computation results.

The pond consists of a large (ca.1 - 2-meter diameter) round tank filled with water. Lights will illuminate the surface of the wafer in order to make the waves on the surface visible and clear. Actuators will initiate the waves with a certain frequency and amplitude. On the pedestal, knobs will allow the visitors to change the generation of the waves. In quantum physics, all quantum objects have an associated wave that represents the object. This means that quantum objects are everywhere, since waves propagate everywhere in space. When we perform quantum computations, we usually select a physical object, such as an atom or a photon. In the physical properties of these objects, such as the internal structure of the atom or the polarization of the photon, we can store information. Usually, bits, which are the building blocks of classical computers, can take either value 1 or 0. However, in quantum physics, we can select, for example, two internal states (state 1 and state 0), but the atom can also be in all Superpositions of these two states. One can think of this like in painting. We can have blue and red (zero and 1). In classical computers, these are the only two possibilities. However, in quantum computing we can mix the two colours choosing to have, say 30% blue and 70% red, to give a reddish violet (a superposition of blue and red). However, we can also choose to have any proportion of the two colours. This means we have many more ways to store information. From this stems the power of quantum computers. In quantum physics, everything is a wave, and that when we perform quantum computations, we manipulate waves and let them interfere with each other to yield a specific result.

References

- **Trapped ion Quantum Information group at ETH Zurich**: https://tiqi.ethz.ch/
- **We are Lucid**: https://www.wearelucid.ch/about_us
- **Ted Ed, “The high-stakes race to make quantum computers work”** by Chiara Decaroli
- https://www.youtube.com/watch?v=r_t96FqWE4M&t=4s
- **Ted talk “How do you build a quantum computer?” by Jonathan Home**
  https://www.youtube.com/watch?v=ArW8x1NpqGs&t=45s

For a general background

- **Scott Aaronson Paul Berneys Lecture at ETH, Autumn 2019**
  https://video.ethz.ch/speakers/bernays/2019.html

- **Why Google's Quantum Supremacy Milestone Matters**
  https://www.nytimes.com/2019/10/30/opinion/google-quantum-computer-sycamore.html

- **ETH masters in quantum engineering**
  https://ethz.ch/en/studies/prospective-masters-degree-students/masters-degree-programmes/engineering-sciences/quantum-engineering.html

- **IBM Quantum**
  https://www.ibm.com/quantum-computing/

- **Google quantum**
  https://research.google/teams/applied-science/quantum/

- **IonQ website**
  https://ionq.com/

Links to Bios / Publications

- Trapped ion Quantum Information group at ETH: https://tiqi.ethz.ch/
  Researches involved in the project: Chiara Decaroli, Maciej Malinowski, Celeste Carruth, and Christoph Fisher.

- We are Lucid: https://www.wearelucid.ch/about_us

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