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Special Topics : Quantum Computers : Ignacio Cirac Interview - Special Topic of Quantum Computers

AUTHOR COMMENTARIES - From Special Topics

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Ignacio Cirac

From the Special Topic of Quantum Computers

In our Special Topic on Quantum Computers, the work of Prof. Dr. Ignacio Cirac ranks at #1 by cites and #2 by papers, based on 100 papers cited a total of 5,555 times. Prof. Dr. Cirac's record in Essential Science IndicatorsSM *from* *Thomson Reuters* *includes 194 papers, the majority of which are classified in Physics, cited a total of 10,551 times between January 1, 1999 and December 31, 2009. He is also a Highly Cited Researcher in the field of Physics.*

Prof. Dr. Cirac is Director of the Theory Division of the Max-Planck Institut für Quantenoptik in Garching, Germany. He also holds the title of Honorarprofessor in the Department of Physics at the Technical University of Munich, sits on the editorial board of several journals, and is one of the 2010 recipients of the Benjamin Franklin Medal.

Below, he talks with* ScienceWatch.com *correspondent Gary Taubes about his highly cited work in the area of quantum computers.

SW: What were you hoping to accomplish with your 2000 *Physical Review A* article, "Three qubits can be entangled in two inequivalent ways" (Dur W, Vidal G, Cirac, JI, 62[6]: art. no. 062314, December 2000)? What was the context of that research?

At that time, we were interested in understanding how to crack entanglement. If you think about quantum computation, not only quantum computing but applications that quantum mechanics might have in information technology, you see there's this very strange property of quantum mechanics that is key, and it's this property of entanglement. So it was very natural to try to characterize this property and quantify it.

This is what led us to that paper. People had thought before about how to characterize that property when you had two objects. We realized that if you consider three objects, then you find many new and interesting features. And that's what that paper is about.

Can you explain what entanglement is for those of us without a physics background?

Well, for somebody who's not a physicist, you can think of entanglement as a very special kind of correlation. When we have two or more particles, they will behave in a correlated way even though they don't communicate with each other. You measure something in one, and you measure something on the second one, and what you obtain is very much related to that first measurement. If you have three objects, then your third measurement is also related to the first and the second.

These correlations are called entanglement, and they don't exist in classical mechanics. And these particles, these qubits, can be atoms in different laboratories, for example. They have to be microscopic systems, so they really behave according to quantum mechanics. They have to be qubits so they have to have two possible values. Atoms have that property. They could be photons also, or electrons, or molecules—whatever microscopic objects that can have two values in this quantum mechanical way.

"I think we'll be able to do simulations that simply can't be done with normal computers..."

Why are two qubits insufficient, and what do you gain by moving to three?

Some of the applications that exist in information technology based on quantum systems require several objects, not only two. Of course the mathematics gets more complicated when you're dealing with more objects. People had studied two.

We decided to see what happens with more and more objects. So the first step was to take three. This is where quantum effects are very important in information.

What was the biggest challenge or obstacle you encountered in this research?

I'd say understanding how to properly formulate the problem, and then realizing that we could actually classify all possible properties of three objects according to one specific way, which is the one that gives you all the information you want.

That was the first challenge: to find the right question, in effect. And the second challenge, of course, was to solve it in practice.

What is it about this paper that makes it so influential? Why has it garnered so many citations?

Because later on people found applications for this three-qubit state, and then of course they used the properties derived from the paper for these applications.

What exactly are these applications, and did you anticipate them when you wrote the paper?

Well, methods for distributing secret information, things related to security in communication or protocols for doing digital signatures or whatever protocols that involve three partners. This is not quantum computation now, but quantum communication or secure communications based on quantum mechanics.

And, no, we didn't anticipate this connection. It was unexpected. It came later on. We were just studying the entangled properties of qubits, of more than two qubits, and then we later realized that the theory we were developing may have applications in other fields.

How did you decide where to submit or publish your paper? Why *Physical Review A* in this case, for instance, rather than *Physical Review Letters*?

There are some papers that have a significant amount of content, more than can be easily summarized in four pages. Even though the impact factor of *Physical Review A* is not as high as *Physical Review Letters*, sometimes it's better to write a long paper where you can explain everything in detail and publish it in a journal that will accept it than it is to rush and publish in *Physical Review Letters*. That's what we did here.

On the other hand, I think all of us are seduced by the fact that *Physical Review Letters* has greater impact and so we tend to submit there more often.

How have your research interests evolved in the decade since that paper came out?

> *"We were just studying the entangled properties of qubits, of more than two qubits, and then we later realized that the theory we were developing may have applications in other fields."*

I have been basically working on two different topics related to quantum information. One is related to this paper, further developing the theory of quantum information. The other is thinking about physical systems and how to build quantum computers from them.

During the last year, that first path has now evolved into many-body systems. The theoretical tools we've developed now can be applied in other fields of physics, specifically in condensed matter physics.

As for that second path, I've continued working with experimentalists, trying to build more robust quantum devices based on atoms, ions, electrons, and photons—on these microscopic systems.

What do you think is achievable in quantum computing in the next decade?

Maybe reaching something on the order of 50 or 100 qubits, and also making significant progress in the related field of quantum simulation. I think we'll be able to do simulations that simply can't be done with normal computers—simulations of condensed matter systems, in particular, that will allow us to study properties of magnets or magnetism, conductivity or superconductivity.

These problems are very hard to study with normal computers. I think with quantum simulators we'll be able to study these systems, simulate them, and understand the physics behind them.

Is there one goal in particular that you'd like to achieve in your research someday?

One of my major goals would be to develop theoretical tools that are useful in this context of quantum information, in building a quantum computer or quantum communication device, and in studying these many-body quantum systems.

Is there any fundamental or technological limit to the number of qubits that can be used in quantum computing?

There's no fundamental reason why we couldn't work with 100,000 qubits. It's a huge technological challenge, but I don't see any fundamental reason why it can't be done. Of course, it will take a very long time to get there. Technology doesn't advance as fast as we want.

What would you rate as your most difficult or trying professional moment?

Probably when I had to choose to move from Spain. I got an offer from Innsbruck and I had to decide whether to stay in Spain, where I'm from, or move to Austria. That was a very difficult decision. And it was difficult in the beginning, but later it worked out well.

Which of your professional achievements brings you the most satisfaction?

I'd say working with my collaborators, and particularly with Peter Zoller, who has been one of my closest collaborators for many years now.

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Ignacio Cirac's current most-cited paper in *Essential Science Indicators*, with 715 cites:

Dur W, Vidal G, Cirac JI, "Three qubits can be entangled in two inequivalent ways," *Phys. Rev. A* 62(6): art. no. 062314, December 2000. Source: *Essential Science Indicators* from Thomson Reuters.

Additional information:

Ignacio Cirac is featured in ISIHighlyCited.com

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