Quantum Bit 2: QUANTUM INFORMATION AND COMPUTING

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[bass intro]

Leo - Hello, I'm Leonardo Guerini and this is the second Bit Quântico, which are our complementary mini-episodes, in which we address important issues, which for some reason or another we could not fit into the standard episodes of the podcast. In this Bit Quântico, we will talk a little about the new quantum technologies under development.

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> **Gabriela Barreto Lemos:** In fact, we are waiting for the great quantum computer, but, in a way, every computer we have uses, you know, quantum theory.

Leo - This is Gabriela Barreto Lemos, who is a professor in the physics department at the Federal University of Rio de Janeiro and a researcher in quantum optics. In Episode 2, we talked a little about the emergence of quantum theory and also about the technological development that it made possible, which is called the first quantum revolution. These advances were so great that they established several technologies that we have today, such as lasers, sensors, microprocessors and some medical equipment. But now we are on the verge of the second quantum revolution, which will include quantum computers, quantum cryptography and quantum sensors. Some of these things already exist today, but in a limited version.

Lu - Okay, in episode 2, Ingrid Barcelos talked about the little pieces of the computer, right, the transistor, which could only be improved and reduced to a very small size because of quantum… and now you talked about a quantum computer. Why isn't our computer today called quantum and, instead these developing ones are?

Leo - Well, what we discussed is that some components of the normal computer, which we have today, are designed and work because of our understanding of quantum theory. But these are just a few components. Just the hardware. The software, which are computer programs, has nothing quantum about it. As for the new quantum computers that are being developed, the idea is that they will work with quantum software too.

Lu - But what is quantum software? How can a software be quantum?

Gláucia - For us to understand this, let's first think: how do we communicate with each other? Try to think, how is the information reaching you at this moment that you are listening to us? Well, you're listening to a podcast, so there are sound waves in the air that are being picked up by your ears and that your brain decodes as words. If there was no air, you wouldn't be hearing anything. Furthermore, you are probably seeing several things in front of you, perhaps a sink that is no longer full of dishes, perhaps other people who are with you on the bus or in traffic. But you're only seeing this because there's a lot of light being reflected by these things... and then being captured by your eye. The bottomline is that we always need a physical medium that carries this information. In the case of listening, it is the air vibrating; in the case of seeing, it is the light itself traveling to you.

Leo - In fact, this type of observation led the German physicist Rolf Landauer to say a phrase that became famous: [echo effect] “information is physical”.

Gláucia - So, on the one hand, we always need a physical object to carry information, like air or light. On the other hand, we learned that the most fundamental physical entities that we know, such as photons and electrons, offer a range of strange behaviors, which are the quantum phenomena that we already mentioned in episode 2: superposition, entanglement, randomness... So isn't it possible to combine these two things and try to take advantage of these phenomena to transmit and process the information that is sent? This is how the field of quantum information theory was born.

> **Rafael Chaves:** And then, at the beginning, at the beginning of the eighties, this field of information theory was born, which is basically this idea of understanding what information is not from mathematics alone, but from physics, from the combination of these two things. And in particular, it allows for and also makes use of concepts from quantum physics.

Gláucia - This is Rafael Chaves, researcher and Professor of physics at the Federal University of Rio Grande do Norte.

> **Rafael Chaves:** So essential concepts such as superposition, entanglement, uncertainty principle, now take center stage in what information is, in how we define information.

Lu - And this is the field in which you and Leo work, right?

Gláucia - Right.

Leo - And in the same way that we can make use of quantum properties to encode and transmit messages, we can try to do the same with computing, and create software, or programs, that use these properties. So a quantum computer is a machine that can control photons or other quantum objects so well that it can represent the zeros and ones of traditional computing with them. Therefore, it has the advantage of having these other counterintuitive characteristics to assist in computation, such as superposition and entanglement. So it's not that a quantum computer would necessarily be more efficient than a classical computer, it's that it would have access to this range of phenomena that enable computing strategies that are not available to classical computers.

Gláucia - The researchers' current task is to transform this potential into a real practical advantage, such as: simulating chemical structures with greater precision for the production of new medicines, or even solving optimization problems that cannot be solved today.

Lu - And we're not at that point yet?

Gláucia - No. We are at the point where, for some very specific tasks, we have quantum algorithms that perform better than classical algorithms. But we still don't have complete quantum computers, advanced enough, to run the vast majority of these algorithms. Current quantum computers are still very limited in terms of computing capacity.

Leo - It's cool because we often think of science as a great generator of technology, but the opposite is also true. Science often fails to advance because there is a lack of technology and engineering techniques to handle experiments and simulations. This is the case with quantum computers. For example, research into quantum algorithms is already at a much more advanced stage than quantum hardware.

Gláucia - Well, with all this discussion, we see that quantum science goes beyond physics, right? In fact, you may have noticed that we here prefer the term "quantum theory" instead of quantum physics or quantum mechanics, precisely because these concepts that we have been discussing are not only found in physics, but also appear in quantum computing, in quantum information theory, in quantum chemistry…

> **MarceloTerra Cunha:** I think that one of the most important things at the moment is this approach via quantum information, it is to convey the idea that nowadays quantum theory is independent of physicists, right? It can walk alone, it has applications, for example in quantum computing, and it is no longer the exclusive domain of physics.

Leo - This is Marcelo Terra Cunha, mathematics Professor at Unicamp and researcher into the foundations of quantum theory. We have a special affection for Terra, because, in addition to being our interviewee and first-hand supporter here of our podcast, he was both mine and Gláucia's doctoral advisor, when he was still working at UFMG.

> **Marcelo Terra Cunha:** but in the final stretch of the twentieth century people realized the relevance of discussing quantum processing of information, this opens up space for many other disciplines to become interested in quantum, without necessarily being directly associated with specific physical phenomena.

Gláucia - In fact, not only does quantum theory go beyond physics, it is even expected that people will eventually apply quantum concepts without knowing details of the physics behind the process.

> **Marcelo Terra Cunha:** Nowadays it is reasonable to think of quantum computing professionals who do not know anything about what I mentioned [...] in the same way that there are classical computing professionals who do not understand semiconductor physics and this does not prevent them from buying equipment that works using semiconductors and someone developed this for them…

Gláucia - In other words, quantum physics is also knowledge at the service of other areas, and if you want to specialize in just one part of this great enterprise that is advancing quantum science, that's fine.

[congas]

> **Marcelo Terra Cunha:** For these people to be able to put into practice their abstract ideas and their algorithms built to solve the most varied problems possible. Including this one of letting us talk, each of us being in a different part of the globe.

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Leo - This quantum bit ends here, we'll come back in the next episode. Until then!