SEI Cyber Talk (Season 2 Episode 3)

Perspectives on Quantum Computing: Education, Applications, and the Future of the Field

by Daniel Justice, Jason Larkin, and Andrew Matias Jonsson

Daniel Justice: I'm here today with Jason Larkin and Matias Jonsson. Jason Larkin is here as our project lead on our quantum computer project, and Matias Jonsson happens to be our new intern that's been working-- how long have you been with us today?

Matias Jonsson: I started yesterday.

Daniel Justice: Yesterday. So we threw him into here. We're kind of interested about how he got into quantum computing, where he wants to go with it, and what it's been like getting up to speed.

Matias Jonsson: So I am undergraduate physics major-- computational physics major at CMU right next door, and I've always found physics really interesting, since high school, and that's how-- I just kind of ended up in physics because I couldn't really see myself studying anything else, and it turned out to be the right decision, and I took a couple computational physics classes and then also a quantum computing class, and I discovered that quantum computing is kind of the opposite of most computational physics. Computational physics uses computers to do physics; quantum computing is using physics to do computers. So it's kind of a little mindset shift.

Daniel Justice: Hold on. Can we go back a little bit and talk-- what do you mean by it's physics to do computers?

Matias Jonsson: So when you're using computers to do physics, you're solving problems that you can't really do with pencil and paper. You're looking for very good approximations that are so good that it doesn't really matter that it's not quite the exact solution, that allow you to find the nature of certain problems and the solutions to certain problems much easier; and when you're doing quantum computing, as the world is moving in that direction, what I meant when I said "physics to do computers" is you're using the quantum nature of certain particles or bits of light to perform calculations using-- instead of using a computer chip to do the calculations, you're using the physical nature of the particle and the fact that it's in a quantum state. So anyways, then my advisor saw that I was interested in quantum computing and put me in contact with Jason here, and Jason helped me apply to the internship, and so here I am.

Daniel Justice: Oh, excellent. And actually, Jason, how did you get into quantum computers? Since quantum computing is such a cross-disciplinary-- you start seeing that people are coming into this field from different areas. So Jason, what's your background?

Jason Larkin: Yeah, so I got into quantum computing after I started working here at SEI, and we did our creation of internal projects. Quantum computing, of course, people have been seeing the progress that has been coming lately and the DoD itself is investing money. So I got in around that time-- I guess it was like a year, year and a half ago. At that point in time I had also had background in quantum physics, but this was from my PhD work and my training and my education. So I had sort of the quantum physics understanding lurking in the background waiting to be used again. I hadn't used it until when I did use it on studying quantum physics. So I was doing things like Matias is talking about, where you want to simulate reality, you want to simulate physics, and we've been doing that to this point on classical computers, which are very good and great, but there are certain kinds of problems in the physical world which don't map well onto classical computers or existing classical algorithms, and it's for those types of problems that we're trying to look at quantum computing to see if we can use them to help solve those particular problems. So I kind of knew quantum physics from my training and my background, and then it just sort of sat around for a while waiting for a use for it again, and then when I came here, now quantum computing is getting all this interest and there's funding going towards it to see if we can make it useful. So part of my own code got reactivated.

Daniel Justice: Yeah, right. So what previously comes back is not useful in restructuring that.

Jason Larkin: Yep.

Matias Jonsson: So I have something I wanted to add to what he was saying, is the interesting thing about quantum computing is that some of those problems that Jason was mentioning that don't map well onto classical computers, they don't map well because there's basically too much information happening-- being transferred around in these wave functions, which doesn't mean much to someone who doesn't know quantum physics, but the point is there's too much information being passed around by these particles in a quantum system for our computers to actually simulate. Like there's no computer large enough on the planet to do these calculations. So instead of using a regular classical computer to do the calculations, we let nature itself just compute it, because these particles-- I mean, they're calculating their own state, right? They just exist in a state and when it changes, nature does the calculations for us, and that's kind of what quantum computers are doing.

Daniel Justice: To clarify, before you took your quantum computing class, did you know quantum mechanics?

Matias Jonsson: So I took a quantum physics class. All the physics majors have to take one, and there's a couple more that I have to take senior year.

Daniel Justice: From your perspective, do you think that you need quantum mechanics in order to learn quantum computers? Do you think that it helps but isn't necessary? What's your feeling on it?

Matias Jonsson: So quantum computing is kind of the intersection of three fields. It's the intersection of physics, math, and computer science, and you can-- to have an understanding of every nook and cranny of it, you really kind of have to have a background in all of them. But I think to really apply certain abilities such as being able to write bits of code for a quantum chip, you don't really need the physics background because it's really-- one of the CMU computer science professors described it as it's basically classical computing with just one extra ability. And so if you just have a decent programming background and you are able to do some math, some linear algebra matrices, you should be able to at least grasp not necessarily the reasons for why quantum computing is the way it is-- that's more the physics-- but at least the applications of how to use it.

Daniel Justice: And actually let's back up a second. How's the math? Is it really hard? Is it attainable?

Matias Jonsson: I mean, it's mostly linear algebra of varying sorts. There's parts of it that make more sense than others. I think the physics side of it, when you go into the physical realization of these devices, the math gets pretty nasty. But I think if you're just trying to write some code to try it out for yourself, it doesn't get too nasty. If you have some matrices background you should be okay.

Daniel Justice: Yeah, that's been my experience a hundred percent. And actually, Jason, to you, the same question. What kind of studies do you think that you have to have in order to go? Do you think that you need quantum mechanics in order to become a quantum computer programmer or engineer, or to further the field?

Jason Larkin: So I think there's definitely a diminishing return on studying quantum physics versus as quick as possible implementing some algorithm on a quantum circuit and executing it.

Matias Jonsson: Yeah.

Jason Larkin: In other words, I think over time you're going to see more and more separation from-- right now there's a lot of concern with device level and physics level behavior, and that's also because we have such small devices and they're so noisy and all that. As we begin separating and the number of qubits grows and the fidelities remain the same or get better, and eventually error correction is implemented and all that, you're going to see the abstractions and the people developing having to move further and further away from less of the physical stuff happening on the devices-- and so once you make that separation, I think there's a set of core stuff from quantum physics that you need to know but not much after that, and I think we've seen this, where if you just understand that there's this new type of state that is different from a classical state and there's operations within this state that you can create that are clearly different from classical computing, there's sort of that minimum set of understanding that you need, and I think once the abstraction level builds up high enough, that's the only stuff that you'll need to know. Like if you look at some of these performance analysis papers, they're not really knowing what the-- exactly how you make a qubit and exactly how you change its state and how you implement gate operations; it's about getting the number of gates down by orders of magnitude; it's about recognizing symmetries in the problem or strategies for optimization. And so I think we'll see it separate more and more, and then you'll just see people-- and you already are seeing people-- focusing on different levels of the stack and accepting the abstraction from beneath up to some level, but we don't need to know more than that. I think we're already seeing it and you're going to see more of it.

Matias Jonsson: In much the same way that when you're writing a Python code for some project, a class project, or if you're in school or for work or something else, you really don't need to worry about what's actually going on at the transistor level with the silicon chips, right? I mean, if you were working in hardware in electrical engineering, you might actually care a little bit more, but as the chips become larger and better developed and more stable, like he was saying, I think you're going to worry less and less about the actual quantum physics of what's going on and more and more about just applying it and just accepting the abstraction.

Daniel Justice: Actually talk about that. Your quantum computing career is pretty nascent-- it's just beginning.

Matias Jonsson: Yeah.

Daniel Justice: Where do you think you might end up? With a physics background, I would imagine maybe you'd want to look a little bit lower level towards actually that transistor level.

Matias Jonsson: I'm sort of up in the air on that. I'm not sure. For a while I was convinced that I definitely wanted to get a PhD in the physics side of it, but at the moment I'm kind of unsure because all levels of the stack are pretty cool. So I'm not sure if I want to limit myself to just one level of the stack.

Daniel Justice: And actually, we'll do a standardized intern question. You've got three, four months here. What are you hoping to get out of that? What part of the stack would you like to look at for the next three months?

Matias Jonsson: Oh, not the physics side of it. I did that last semester for a whole semester in a class. I'm looking forward to learning more of how to use basically the types of chips that are currently available to try and solve problems that are approachable in the near term.

Daniel Justice: Do you have any architectures or chips that you think are promising and not promising?

Matias Jonsson: I'm not up to speed enough. Jason is definitely a better person to answer that question.

Daniel Justice: Jason, do you have any favorite technology out there right now?

Jason Larkin: So I think it's hard to say because first, when you start writing down the number of different architectures, you get to a number like five or seven, or you can say neutral atom, trapped ion, to the transmon qubits, Microsoft's topological stuff, you still have annealers and annealing-- so when you sort of-- and you have the emergence of those architectures coming over the next few years. Some of those architectures only exist in lab form, in some prototypical form; other ones are available right now. You can go run a transmon qubit processor from a number of providers, right? There's multiple providers that will let you do that. And so I think we can talk about what exists in prototypical form; we can talk about when we might see it available to the public; but it is so hard to predict. That being said, there are definitely certain types of problems or certain things that certain architectures do better than others in terms of scaling, in terms of particular gate operations or architectures that promote locality or the connectivity is better or the noise scale is better, but none of that is very clear right now.

Matias Jonsson: Yeah, at the moment it's kind of like we're in the time when it hasn't been decided what the basis will be for creating these quantum chips. Like for a long time, classical computers were built on vacuum tubes. Well, first they were mechanical and then they were vacuum tubes, and then there was kind of-- vacuum tubes were not scaling well, and so silicon was kind of promising, and then someone figured out how to make a really good silicon transistor and it was over because the race was won, and since then there have been improvements made to the silicon transistor but no one's really questioned silicon's supremacy in classical computing. Now we're in that intermediate phase where no one's quite figured out which sort of physical manifestation is going to be the best for scaling chips.

Daniel Justice: So you think that if we could find, say, the quantum transistor, things would just-- it'll rapidly change overnight.

Matias Jonsson: Yeah, so I think-- I mean, my non-expert opinion is that if you find a stable, pretty close to room temperature, easy to manufacture sort of basis for creating quantum bits that are readily producible without too much effort, then I think the race will be won and whoever invents it will get rich and retire and then it'll rapidly become something that's commercials available.

Daniel Justice: I'm not sure that's the entire story of how the transistor came into being, but it sounds good.

Matias Jonsson: I'm trying to sum it up. I'm trying to sum it up, make it simpler.

Daniel Justice: Jason, did you have something to say?

Jason Larkin: Yeah, so we've referenced Martonosi before and other people like her who claim that-- it's pretty much like in the 1950s with classical computing. We don't know if a transistor is going to emerge as the dominant medium, and we'll know that in the next ten years I would say, maybe the next five-- who knows? But that's really the timeframe we're talking about. We're not going to get any sort of definitive answer into which is the technology which is going to scale and dominate, or really that one is going to scale and dominate, that it won't be multiple ones, and multiple architectures, each of which is well suited to some particular task-- like we might see a host of architectures that run some machine learning task really well; we might see a wide range that run different types of material science problems really well. I think that you'll probably see something more like that, that it won't even be one-- we won't even have a transistor, let's say, quote-unquote emerge, that it'll be multiple architectures, each of them-- because quantum computing already has a limited scope of what you're going to use it for. So it's not hard to think about within that scope there's multiple architectures doing their own thing. Like it's not clear to me that annealing isn't going to provide some advantage; it just hasn't shown anything definitive so far it seems. So I think we have to be open to all those possibilities, and we can be, because all this stuff is by and large being offered through the cloud and you can integrate with these components the same way you integrate with GPU now. You just call upon them when you need them, for most problems. I mean, there's other problems that don't fit into that paradigm, but. Yeah, as soon as the technology is available, because everything is cloud-based, or so much is cloud-based, we should get access to it sort of right away, so that the readiness of the technology, it transitions right away. As soon as the software and the hardware is there together and there's a benchmark, you're ready to go.

Daniel Justice: Matias, before you got into quantum computers, you probably had a preconception as to what they could do, and then by the time you started learning, and you're at the point now, you've probably changed that preconception. Was there anything ridiculous that you thought a quantum computer could do, and now you're like, "I can't believe I ever thought that"?

Matias Jonsson: So I definitely think the media sensationalizes it, because the word "quantum" just makes everything sound magical and--

Daniel Justice: Oh, it's amazing.

Matias Jonsson: Yeah, you throw "quantum" into anything and people believe it, right? They just say, "Oh yeah, quantum physics, yeah." I've seen some wild uses of-- whatever-- crazy things. Anyways, I definitely just kind of thought that they would replace classical computers, but that's definitely not the case. It's more like they will be used for certain specific tasks that are-- in which they will be hopefully orders of magnitude more powerful, but only for those specific tasks. Now, they're very important tasks, but it's not-- they aren't going to be generally useful the way classical computers are.

Daniel Justice: Yeah, that's perfect. It's a common misconception that I myself found myself falling into.

Jason Larkin: Small follow-up-- when did you arrive at that-- how long into learning about it did it take you to--?

Matias Jonsson: At some point early in last semester. Some point early in last semester when I was taking the class. It just kind of started making sense that this is not a general-- yeah.

Jason Larkin: So interesting, not too deep into a class you came to that realization.

Matias Jonsson: Yes, in part because of the class and in part because the class was making me get interested in just reading more on my own outside.

Daniel Justice: So it's not too hard to cut into the hype. It's just a little bit of education.

Matias Jonsson: Yeah. Don't exclusively read news articles about it, because many times journalists are trying to do their best to write about it but they don't necessarily have the background to not sensationalize it, and also sensationalized articles get clicked on more and read more. So they kind of have a duty to sensationalize it a little bit.

Daniel Justice: I guess my question would then be: Once it wasn't as exciting, it wasn't as sensationalized, why are you still--

Matias Jonsson: Oh, it is-- it's just as exciting. So the fact that it only has specific applications doesn't make it less exciting, it makes it more, because those specific applications are stuff that currently isn't doable. So they would change the way science is done in many ways.

Daniel Justice: Right, materials science, traveling salesmen, (inaudible) algorithm, breaking cryptography.

Matias Jonsson: And even all sorts of regular computational physics simulations that you need random numbers for. Like if you can generate better quality random numbers that are actually random and not sort of random by some formula, then you can get much better quality classical computational physics. So yeah, there's just some really exciting applications.

Daniel Justice: That's awesome. I'm glad to see you cut through the hype and you're still excited about it. You're still hyped even though you're through the hype. It's amazing. And I think with that, we're going to end. So I'd like to thank everyone for joining us today. For more information, please click on the links below and we'll be back later on and see what Matias has learned, and he's probably going to have more to say about some certain algorithms, perhaps QAOA. So thank you very much and have a good day.

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