CLOUD REALITIES

CR104

Quantumania part 2 with Catherine Vollgraff Heidweiller and James Goeders, Google Quantum AI

Capgemini

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[00:00:00] Done that once or twice. Yeah. We'll do, we'll do a full 90 minute episode on religion and philosophy in Uh, yes. Fantastic.

Welcome to Cloud Realities, an original podcast from Capgemini. And this week we are checking back in with our colleagues at Google Quantum AI and getting an update on what's gone on since the last big episode we did on quantum called QuantuMania, last year. I'm Dave Chapman. I'm Esmee van de Giessen and I'm Rob Kernahan. and I am delighted to say that rejoining us, uh, for this episode is Catherine Vollgraff Heidweiller, Quantum AI PM at Google, and also rejoining us, actually, because James joined us when we were at Google next. Very recently. We've got [00:01:00] and James Goeders, Head of Product for Google Quantum AI.

Catherine James. Good to see you. How are you? Great to see you. Very well. Hello. How are you? Thanks for having us. Oh, welcome back, both of you. It's great to see you and James, I believe it is very early on Friday morning where you are too early. It is, it's it's early here in Santa Barbara, California. But I'm excited to, to talk with both of you, all three of you this morning.

Well, thank you so much for, uh, for making it, it's such an ungodly hour. It's much appreciated. And uh, Catherine, I believe you are in London. Yes. Yes. It's nearly weekend here. I'm looking forward to, uh, what's next. Yeah, very good. Very good. And obviously, um, EZ and Rob are here. How are you guys? You good? Uh, I'm fine David.

It's Friday completely blue. Skies rather strange for where we are and I'm looking forward to enjoying the weekend. So moods and spirits are high. Yes, I have the same. And it's actually been full moon, so I'm still on the, on the same high energy. Oh, [00:02:00] do you get energy from Full Moon? Hmm. That we've had?

This is, I think she's secretly werewolf. That's what we've just discovered, isn't it? Yeah. I mean, that is literally, you've basically just declared on the podcast, not secretly. A full moon gives you energy that basically makes you a are wolf. Yep. Yep. That's not, well, there you go. Right. Even gonna on that bombshell.

Yep, yep. I'm embracing it. Why not? What's confusing you this week, Rob? Right, David. This week education has a bit of a problem and it's not sure how to tackle it. Um, so it's got more than one, hasn't it? Well, yeah, but you know, uh, AI. Students, mm-hmm. Are rather inventive and creative and they're finding a way to get round things.

And they're starting to struggle with students using AI for coursework in lectures, all sorts of stuff, right? 'cause obviously you've got a tool out there. It's very, very powerful. We've seen a massive advances around it. And so all the coursework basically is being, is a lot of AI's being used in the coursework.

It's [00:03:00] homogenizing it. It's not properly testing the individual. So what they're doing is they're wondering how to fix that. So they're moving more back to more of an exam-based system. So put them in a room, no technology with a pencil off you go answer the question, right? But for certain people, coursework is much better 'cause it proves them in a different way than those who may struggle with exams.

And so the education balance and what's going on is how do we deal with students using ai but actually proving that they've got a capability to be able to give them a certification to say, you are good at X, Y, Z, 1, 2, 3. I'm confused about where education's gonna go, because actually, if you continue to use AI and education like it is and it's being abused by the students, then you're not properly educating them.

They're finding an easy path, and that easy path may not prove their capability. So this is a show in, this is a show in its own right. Um, but I've been thinking about this quite a bit actually, because, you know, I've got kids who are 13 and 15 going through the education process. Like what, what would it make sense that they did?

[00:04:00] Now I wonder whether you remember, we had Dave Snowden on the show. We've had him on a couple of times, but he was, um, who could forget those episodes? David? Yeah. They, they're dense, that's for sure. They, they're thinker difficult episodes. Yeah. To not comprehend, but yes. But he, he made the observation about AI in.

In education, which I think is happening in the us. James, you may or may not have clocked this, but I, I understand that a number of the, sort of the high ranking schools are removing computers and information machines from the classroom because they're focusing their teaching on human critical thought and what it's going to mean to be a human in the intelligence age.

It is like how you differentiate because information, retaining information, regurgitating information is no longer going to be a competitive skill because, you know, AI machines are gonna be able to do that far faster than, and more effectively probably than the humans. So it seems to me that the education, I think we should, I, I've never been a huge [00:05:00] fan of highly vocation education, so I, I, my sort of cod take on it is the major sort of.

Bedrock, classical subjects, the sort of sciences things like maths and basic languages and um, stuff like philosophy and history, just taught in a classical way, which is teaching, problem solving, looking at human patterns, looking at human behavior, all of those sorts of things. I don't think they're ever going to not be relevant.

And, and I've seen recently a few little things pop up on things like, you know, Instagram reels and things like that of, of sort of people talking about this exact subject and saying stuff like, those are the sort of subjects that people should focus on. So that's sort of where my head's at. The other thing that occurred to me as you were talking through was, are you just making a similar sort of complaint, albeit far broader than the introduction of [00:06:00] calculators into, into mathematics?

So, so, but this is the thing, right? So education understood then the calculator was a valuable tool. They were ubiquitous. It integrated it in system. So is it, is it, and this is part of the confusion, is it that education needs to modernize itself for the new tools that present themselves to us? Yeah. Yeah.

As opposed to raging against the machine and saying That tool is unfair. Shouldn't be using it, go away. And is it the old guard not becoming, you know, just, just. You know, not accepting that this tool that is new to us is here to stay and it's not going away, so we better integrate it. I think it's time to, to, to make that shift, you know, 'cause who's deciding what kids should be learning?

And I think a lot of, in history, a lot of educational systems we're the ones deciding these are the talents and these are the skills that they need. But it should be, I think it should be completely the other way around these days. Well, I was at a re at a recent, uh, school event for my 13-year-old and looking at kind of options that they were gonna take.

And so obviously I, [00:07:00] we went through and had a look at each of the curriculums and the computer science curriculum. I had stuff like Python on it. It's like, I mean, really, really, you, you, it's like that's gonna be out mode. You're just not gonna need that as a skill. But if you, if you take a programming language, the concept of choice iteration and sequence, the three bedrocks of programming, I.

That's a powerful, I've just said, sorry, the system's just decided to do a thumbs down for me on the camera. Anyway, the, um, but those, those concepts are really important to understand the basis. So when it does turf out an answer for you, you can comprehend it. If you just get into the concept where you ask the machine, it gives you something and you don't appreciate how it works, then surely that's a failing.

And 'cause when it does break, how are you ever gonna fix it? This is why I'm confused, Dave. You can see the, you can see the conundrum. Have you, Jims, Catherine, have you got a, do you have a perspective? I love what you said about vocation using, uh, education. I, absolutely agree. It's, it's funny you brought up the calculator example. 'cause I thought the same thing. You know, many of us screw up with [00:08:00] teachers saying you're not gonna have a calculator your pocket. And now we have all of the world's information in our pockets and, you know, can look at that at any time. So, um, personally, I, I need comp, uh, software engineers who can code in Python.

So please keep that going. For right now, until the, uh, until Jim and I can write, uh, all of the software I need for my quantum computer, I'm gonna need engineers who can continue doing that. Fair enough that I, I like what Rob said. I still need someone who can debug it when the, the computer writes it incorrectly.

But I love what you said. I think we should really be thinking, especially higher education, higher learning around how to think, how to do problem solving and think critically. And, you know, the. Even as someone who's who stayed in the hard sciences, the, the liberal arts are what makes us people what, you know, that's our culture, that's our background, that's what we've done.

You know, I would hate that people aren't reading Shakespeare or, uh, you know, Faulkner or, you know, they, the great writers of, of the past and, you know, just knowing what it's like to be a human [00:09:00] right.

It, it would be great if we could see a shift in the way learning is done and we're not just going to college to get a job. We're, we're going to college to expand how we think and what we think about and all of the beauty that's in the world. Immensely. Well said. Immensely. Well, so I, so Rob, I think we sort it out.

I think we've cracked that one. Did we? I think we did. Sorry. I think we did. Yeah. Okay. I think we did. It was, it was actually quite a good exploration to say e education needs to modernize, but keep the humanity at its core as I summarize it. First time. That's good. Now we've fixed one for everything.

Fixed one. Yeah. Well we are so glad to have you guys back on. Last time around we had Catherine and one of Catherine's colleagues, Alex Deltoro, Barbara, uh, and this time around of course we've got, uh, we've got James stepping in and the episode we did last time around with you guys was quantum mania and we explored very far reaching [00:10:00] ideas of what Quantum is and where it might take us, um, as a society and you know, as organizations.

And you guys have had a busy year since then. Uh, the release of the Willow Chip, which is your latest quantum chip, there's sort of come out and it would be good to maybe start there. So James, why don't you just give us a bit of context on what's been going on, what Willow is. And, uh, we'll jump off from there.

Absolutely. And thank you for having me. So Willow is the latest quantum processor developed by Google. Quantum AI has 105 qubits and we, we believe best in class performance across many of the common, uh, performance benchmarks. We designed Willow specifically start to finish with error correction in mind.

Uh, and we're gonna talk a little bit more about what error correction means, but we didn't want to focus on vanity demonstrations with this chip. We really wanted to be pushing further on some of the hardest things in the field, tackling the engineering and the science that challenges that are necessary to actually make [00:11:00] sure everything's gonna work together as we scale up these systems.

Uh, and error correction really informed many of the aspects of our processes, how we thought about the chip architecture, the gate development, the calibration, the fabrication, each of those pieces, uh, because we wanted this to be our first demonstration of actually doing error correction in an integrated system.

So how close is Willow to like a production ready in the wild system versus like a, a next stage of r and d, would you say? Uh, still still a, a, it was a significant step in r and d, but still, still a step in r and d where, you know, there's a lot we needed to learn, but, you know, as someone who's been in quantum computing for, for almost two decades, uh, getting to this point where we've actually proven error correction can work on hardware, you know, has been a significant step.

We've been working towards, you know, for decades, uh, you know, since, since this was kind of theorized back in the nineties. So being able to actually push towards this show that we're gonna be able to scale these systems in the lab, [00:12:00] uh, is a very key step towards actually making it productionable where we can actually get it out to users and they can start working with it now physically, you know, kind of in, you know, kind of inches or millimeters.

How big is, how big is it? Uh, trying to speak to my, my non-US friends here. Uh, I'd say it's probably on the order of 50 millimeters by 50 millimeters. So, you know about two, two by two. These quantum chips are still fairly small now, obviously all of the components that go with that. Yeah, yeah. Uh, you know, the, they, the whole system, it's very large, but the actual quantum chip is still very tiny and it's 105 qubits.

I think I've got that right. Correct. Help us understand what that means in terms of how powerful is that. Well, so this was our first chip, uh, pushing beyond a hundred qubits. Obviously as we talk about use cases and, you know, actually doing real, uh, you know, pushing beyond classical boundaries, [00:13:00] we're gonna need thousands, millions of these physical qubits.

So 105 qubits in the grand scheme, still pretty small. But for us, being able to start incorporating and growing these systems, uh, was, was a key step. So it's, it's pushing on some of the boundaries. We're still able to fabricate, uh, these devices on a single wafer. Um, you know, we, we don't have to worry about things like that, but, um, it was a, it was a key piece for us as we can scale larger, so.

When we talk about these error correction codes, uh, you can think about it that we have to continue increasing the distance or the number of qubits we can connect together. And so by going to 105, we could do a larger distance code. Yes. Uh, which allowed us to get, uh, that better result. And so we want to continue scaling so we can continue running larger and larger codes, uh, and continue pushing on, uh, how, how good of a job we can do.

And, and I'm trying to get a sense of its processing potential. So have you got an example of, say, like a problem that a, a one qubit [00:14:00] chip would be able to solve and what you, what kind of problem you could solve with a hundred cubit chip? Uh, so one of the benchmarks we've been using, uh, even back since our 2019 early quantum supremacy days, uh, is this random circuit sampling or RCS experiment.

And so with that, uh, you know, it. To be fair, it is a little bit of a contrived example where we've, we've built a benchmark where we wanted to see could we beat a classical supercomputer at anything. Uh, you know, I would love to beat a supercomputer at something that actually impacts our lives, but Right.

You know, these early days we need That's right. So this, this 105 qubit device allowed us to perform an experiment in the random circuit sampling better than, uh, even the frontier supercomputer that we have here at Oak Ridge National Lab. So we, we were able to perform a calculation in about five minutes, uh, that would take, uh, 10 sillion years, which [00:15:00] is a number that is so my outrageous that I, I have trouble even picturing it, but I mean, if I, I basically, I'm saying we can do a calculation on this 105 qubit chip that would take.

Orders of magnitude longer than the age of the universe on our very most powerful chip. And now I'm sure there are gonna be detractors from other companies or other quantum hardware providers who would say, ah, but you know, the whole reason it's faster is because they, they picked an experiment that, of course would run faster on quantum and, you know, they're right.

Uh, but it this same experiment when we did it in 2019. You know, the, the great thing is that as. Quantum chips get better, our classical chips get better as well. And the people writing the algorithms for these classical computers, you know, the computers we use every day get better. So the, the demonstration we did in 2019, the classical computers are getting better and better.

So they're starting to catch up. So we wanted to show, without a doubt, nope, with the willow chip, you can now do this. You know that there's no chance that the classical computers are gonna catch up [00:16:00] anytime soon in that particular area, that very niche area of computing. Yeah, I mean, uh, I think it's fine that you chose something that was, that would kind of lend itself to that chip.

Right? 'cause that's what you're trying to test in the first place. Uh, exactly. Perfectly valid from my point of view. I mean, and it's, it's horses for courses, isn't it? With digital and quantum. It'll probably be a fusion somewhere in the future, won't it? So we'll still use digital, uh, and we'll use quantum.

So it's the, what's the best for the. The thing we need to solve and we'll mix mode it. Um, or, or at least that's how I see it. I mean, is, is that, would you characterize it or do you see a point where quantum will get to such a level that actually digital would be minimized in the ecosystem? So that, that's a very great point.

Uh. Quantum computers. I, I am a true believer. I, I think they're going to change the world. It's gonna be amazing. But quantum computers are never going to allow you to watch cat videos or do spreadsheets or do all of the amazing things. I thought you said it were gonna be useful, Joe. [00:17:00] Unfortunately, we probably won't be doing, uh, quantum computer podcasts, uh, on the quantum computer.

So we're, we're absolutely gonna still use our, our classical and our digital computers. Um, and, and you, you nailed it, Rob, that it's the combination between the two. So quantum computer is, is not gonna be useful unless you have that. That very powerful classical computer tied to it. So we're gonna have to do lots and lots of the computtion classically.

And actually our goal is gonna be to do as little of the computation on the quantum computer as possible. Uh, because even as fast as our devices are, there's still gonna be a lot slower than we can do things classically. So as you're having to do a lot of this error corrections, you're having to feed forward, uh, the results that you can do the, uh, the, the next step of the calculation, you're gonna end up having to see these hybrid systems where you're tied back and you're, you're doing lots and lots of classical calculations, a little bit of quantum, and then zoom back to the classical computer.

And, and you mentioned in your description of the chip, what was notable about it was error [00:18:00] correction. So just wanna go, uh, into that, the next level down on, on what is error correction specifically in this case, and why is it such a critical breakthrough? I. Absolutely. So as we're building these, these systems, and you know, you mentioned that the willow chip has 105 qubits.

Those are 105 noisy physical qubits. They're actually the qubits that we've patterned onto the chip in our fabrication processes. And what we did with the willow chip was we tried to design, or we were working to make a single logical qubit. And so with the logical qubit, what you've done is you've encoded all of those physical qubits into a, a single protected qubit that we refer to as that logical qubit.

And so in classical computing, in, in the computers we're using right now, our laptops, the errors in those little transistors are, are very, very small. So we might have one error in 10 to the 15 operations. And [00:19:00] so you're not gonna see, you don't need the error correction there. We, we have it underneath to kind of protect the memory, protect the wave, or storing the data.

Because my quantum computer chip, the qubits that are inside of that are so noisy, we see an error roughly one every 1000 operations. Oh, right. Okay. And so if I need to run. A hundred million calculations, but I'm gonna have an error. Every 1000 calculations. What we're trying to do is we're trying to encode all those physical qubits, protect it so that we are correcting those errors as they occur so that it doesn't break down my computer as I'm trying to run a calculation.

Uh, so what quantum error correction, A simple way to think about error correction is, can I use lots and lots of noisy qubits that, that have re reached a certain level, this threshold that I was talking about, where as I add more qubits, the error actually gets better. So up until we had the willow demonstration, as I [00:20:00] tried adding more qubits to do my error correction, the errors were getting worse.

So I, I wasn't seeing any benefit from quantum error correction 'cause my, my noise had not reached a level where we could actually correct for it. But with Willow, for the first time ever, as we scaled the system bigger, as we went to larger and larger grids of these noisy physical qubits, we were able to actually.

Decrease the errors exponentially as the system got bigger. And so that was the, really the key result is you're now seeing you, we've gone below this threshold that, you know, mathematicians and computer scientists had, had described years and years ago of now we're finally seeing the, uh, the benefits.

We're finally able to take advantage of that error correction. So, Catherine, before we go on to talk about some use cases and, uh, and, and the potential impacts of where we're up to, just, just cast out a little bit for us. What's, what's the next steps in, in, uh, in design and development? Uh, yeah. So the next [00:21:00] hardware, or perhaps rather a system milestone that we're working towards is what we call a long lived logical qubit.

Uh, James just mentioned how we, uh, how we encode a logical qubit, but this long lived logical qubit is really one abstract, nearly perfect quantum bit. And actually it's interesting, you're starting to hear companies across the quantum. Industry speak of building logical qubits. More and more often now, in fact, um, I was at a conference, uh, this week here in London where people from two companies proclaim they have tons of logical qubits.

So I guess in that context, people might wonder why our grand goal is to build just one logical qubit and why this milestone is so important and represents meaningful progress for the field. And the answer is that for this milestone, we define our logical qubit, quite ambitiously, essentially we define it to be the, the unit of computing that you will need to be able to run a fault tolerant algorithm on a quantum computer.

And most commercially valuable al algorithms are expected to [00:22:00] be in the fault term regime. Mm-hmm. So it needs to have fewer than one error per, uh, million computational steps. So yes, that's the big, uh, next hardware. Milestone. Of course, there's also lots of, uh, cool work in flight, in algorithm development, and in fact also at the point where hardware and application development efforts meet.

So I, we can talk a little bit about that as well, if that's, uh, if that's interesting. Yeah, yeah. Why not? And give us a sense of some timeframes, uh, as you're describing these things. How, how close are we to that million mark, for example? Um, so you mean to the mark where we have one error per million computational steps?

That's it. Yeah. Or a million qubits or million Both. Which I would find great coming from theory side. I'm afraid we'll have to tell people to stay tuned. Right. Gotcha. For the logical qubit, the long live, logical qubit. Gotcha. Um, well let's go on to then use case and impact James.

Mm-hmm. So these things in the wild and in the real world, what is it, what, where were up to in terms of them being leveraged and uh, and what do you think the major impacts are gonna be? No. Absolutely. So you know. I think it's been great, uh, over the last couple of years seeing more and more quantum systems coming online because we've, we've got a lot of, and, and I mean, across the industry, uh, you know, there, there are a lot of very smart people, you know, both at Google and, and other places working on applications.

But I think the key step is. Building the sandbox, ma making a, a place where [00:24:00] we can bring in the community to think about some of these use cases. And, you know, as we make our systems available, more people get access. I think they're gonna come up with new and exciting ways to use it. I, I think about it kind of like an app store, right?

Like if, if I build the app store, then smart people will come in and they can build, uh, useful apps for it. Uh, you know, not just us physicists trying to dream it up, but you know what, what might come from that? Um, because I, you know, we, we all have our inherent biases. I come from the, the science world. Uh, most of what I think about is how we can use quantum computers for physical demonstrations, right?

How we can better understand simulating physical systems. That's kind of what got everyone started building quantum computers. So how can we better understand how molecules work, how they interact, uh, you know, these, these different processes. And from there. You know, there, there's great optimism that we're gonna get, you know, by understanding these fundamental aspects of chemistry and physics, we're gonna be able to discover new medicines.

We're gonna design more efficient, you [00:25:00] know, batteries for electric vehicles, accelerate progress in fusion and, and new energy alternatives. And so that's where a lot of our focus has been internally with our theory teams and our application teams. Thinking about, as Catherine mentioned, these future fault tolerance systems where I'm, I'm not working with noisy.

Qubits, but instead, I have perfect qubits and I can actually simulate nature at a level that we can't do today or may maybe ever. Um, but we're also, I, I'm still very hopeful that we, we may be able to see some beyond classical applications in this noisy era we're in. Uh, you know, there, there was a lot of excitement built, uh, kind of in the, the 2018 timeframe when we first started getting systems online that maybe we could do something with noisy qubits.

And there's still hope there. Um, you know, our team is still pushing on that, especially as these systems are, are scaling up in size. But as Catherine mentioned, and I think our, our key point is it's probably gonna need to be an error corrected system. Hopefully it doesn't have to [00:26:00] be a million qubit, uh, error corrected system.

But I think at Google, we're, we're optimistic. We're gonna see something in the next five years, uh, that actually is transforming and is actually impacting the lives of people, uh, with the system we're building right now. One of the things when you go there, I I, which I love about quantum is all the use cases you talked about, there were essentially future humanity, like power mo, understanding molecules.

Are you crazy Medicine of humanity? I know David, it's, it's emotional for, but it's one of those things, it's like, it's like when you talk about it, it's all the things that we need. It's like this, this, this massive work towards it all is like, paints this really bright, happy future and I quite like often we'll get into the dystopian end of uh, yeah.

Breaking up Dave, I Emotion you need, I think. It's deeply positive. It's deeply positive, David, that's what you've got to look at. So I think it's worthy that because it's all for the [00:27:00] greater good, which I quite like. Yeah. And what's exciting actually is that a lot of these examples you just mentioned are in the kind of quantum simulation, uh, domain, which is in fact where many of expect of us expect the first wave of sort of major societal and commercial impact to happen.

So, you know, just in, in case, uh, there are some people, uh, listening for whom quantum space is a bit less top of mind, um, this is where you use a quantum computer to simulate and. Analyze a natural system and being able to do this well, unlocks all this great potential for progress in the development of medicines, batteries, materials required in industrial processes, you know, the design of fusion, uh, reactors.

And there's actually some really cool development, uh, there. Even within our team, we have an algorithms and applications research team that works loads on, uh, quantum simulation. So yes, for the, for the algorithm enthusiasts, definitely go and hit the archive, uh, and look up our most [00:28:00] recent, uh, paper on quantum simulation with some of squares spectral amplification, because yeah, it really speeds up algorithms, uh, hugely.

One area that's, you know, close to our heart that we haven't mentioned is there also is gonna be. Pretty big impact we think, uh, with ai. Uh, so I'll be, I'll be honest, when I, when I first heard this coming out, uh, maybe a year or so ago, you know, the, the fusion of quantum and ai, I thought, man, what other buzzwords can, can people cram in here?

Right? It's all one, show me all into one sentence. Yeah, exactly how, you know, quantum AI didn't make sense to me as someone working on, on, on the quantum computing side of the world. I was like, well, you know, a AI is taking data that exists and, and, you know, building these amazing models on the quantum side, I'm, you know, I'm trying to solve these future of humanity, uh, you know, physics problems.

How could that, that possibly be? But, um, you know, recently, and especially since I've come to Google and I've seen, uh, you know, some of these, this, this merger between the [00:29:00] two or, you know, the intersection, I, I do think that could be a, a very interesting place to play. And that's something I'm excited to see.

What we're gonna come up with. I wanna say that out loud actually, because we're still in the midst of, are we gonna use video with our podcast or not? But you can actually see you, you are glowing, both of you talking about this topic that, that's, you know, about quantum, for me it feels quite, you know, theoretical and I have no clue what we're heading towards.

But you know, the, the enthusiasm is very, yeah. It also makes me hopeful. Infectious. Yeah. I really have to agree that quantum AI is a really interesting space of, there are lots of, uh, cool touch points and they're really complimentary technologies and it's, it's funny to see that we're kind of. Coming at this from so many different angles because there's AI for quantum, you know, all about how can we use AI methods in our efforts to build quantum computers, but also quantum for ai.

So, you know, how can quantum chips be used to somehow [00:30:00] accelerate ai? Uh, and then also I guess the kind of purest interpretation of quantum ai where you're actually doing machine learning on a quantum computer. And we're seeing really cool progress in all three of these, of these areas at the moment. I was gonna go on to the, the nexus point of quantum and AI and what that's going to mean from an AI perspective.

So there's, there's obviously in the, in the world of ai, there's lots of talk about the, the speed of innovation, where it's going, it does impressive things today and it'll probably be even more impressive in 12 months time. But in, in your heads as you're thinking about this, what is applying quantum to AI actually going to do from an AI perspective?

So applying quantum to ai, there will be no doubt many ways in which we will do this. But some of the, uh, early ways in which we've discovered this should be possible, uh, is for example, providing classical models with data from quantum computers, which in some cases can really change the computational comput [00:31:00] complexity of your problem.

So this is kind of powering classical AI models with quantum data. Another cool example is for some distributed models, it's been shown that it's possible to achieve exponential reductions in a classical data transfer if you have a small quantum computer in the loop. So you could see this as kind of sending qubits between different parts of your classical compute infrastructure, allowing you to do inference much faster.

And when you, when you boil it down and compare it. To digital on a power level, is there a, is there a parity with the amount of energy required to process quantum or is there a big difference? 'cause we're talking about huge computational leaps, but does that come with a massive power? Obviously if I had to run the, um, the digital computer for septillion years, you know, that's a lot of power.

Needed more power in the universe. But is there, is there a parity? And as they're operating, the amount of energy they need is. Similar or not, I suppose it's an area I'm well in this quantum for AI case, that is certainly what you would be [00:32:00] looking at because if you are trying to achieve this exponential reduction in classical data transfer, or you're trying to, uh, really reduce the computational complexity, then you are basically reducing the, the compute that's required in the first place to, uh, to learn that that is a kind of like very exciting area of development.

But more generally, if you think about doing, um. Quantum machine learning on. So be doing machine learning on a quantum computer there. If you think about, uh, quantum data, so you'll probably, uh, have heard about lots of different sensors being developed, um, across industries at the moment to measure things, you know, from imaging sensors using hospitals or brain scans, chemical sensors which rely on spectro spectroscopy, sorry, goodness, um, et cetera.

And you can imagine that a quantum computer is, it's really native task for a quantum computer to learn from this kind of data. And whereas if you try to represent [00:33:00] that on a classical computer, you would need a huge amount of, of memory. As you think about digital, it's really inefficient way to process information.

'cause we boil everything down to ones and zeros, process it, and then boil it back up to an image or an audio or something that the human comprehends with quantum it, it processes on a a much more. Well, it's a completely different level, isn't it? Uh, and so I suppose that helps us well, B, but it's always interesting for the listeners to understand that sort of.

Difference in how it actually operates is able to do such so much more with such a smaller amount of resources available to it. Yes, exactly. And there's so many, um, exciting ways to, to leverage that, that are sort of constantly emerging from the research field, sort of hot of the press. So maybe as another example, you know, quantum computers could train certain neural networks exponentially faster than classical algorithms when the data follows natural patterns, like, let's say Ian distribution.

So this is even for cases where the distribution is provably hard in the, in the complexity, [00:34:00] complexity theory sense to learn with using the standard classical, you know, gradient based algorithms that people, that people rely on a lot. Does the, does the introduction of quantum into the world of AI move us faster towards a GI do you think?

Or are they, or are they not connected in that way? I would actually say that the introduction of AI into quantum moves us faster to building quantum computers because we use, you know, so many AI methods in our hardware development effort. Uh, many people will have maybe seen the, the Alpha qubit paper, which we, uh, came out with with a partner team in Google DeepMind.

And, you know, James has talked about error correction a lot. And decoders are what's in the error correction loop is what identifies the errors in the chip. And so what they did is they built this decoder, which is a, a recurrent transformer based neural network that land to decode the surface code really well.

Uh, and this is just one example. We do this, we do this really across the, the [00:35:00] team more and more. Amazing. Amazing. Um, James, I do wanna talk, trying to get my head around the nature of the deployment of Quantum going forward. We've talked a bit about how it's likely to be some form of hybrid with digital.

But does that mean that quantum is going to be a fairly niche technology, or is there a point where it can be deployed more, more broadly? Absolutely. So I think in the early days, uh, we're going to probably see it be much more niche where, you know, we're gonna make these systems available over the cloud and, you know, we're gonna allow you to tie your quantum workload into, uh, you know, a classical workload.

And we're trying to make that as seamless as possible. But I do think these, you know, we're, we're gonna be able to solve all of these problems that classical computers can't solve. Uh, but, you know, like I mentioned, the, the areas right now that we've identified where that advantage is, those are still pretty narrow.

And [00:36:00] I think at least in those early years of fault tolerance systems, we're gonna see. Very niche deployment where quantum computers are used in just a very small area where we can actually see value. Also, these systems are gonna be, uh, it's gonna be very much like the early days of classical computing where they take up entire buildings, right?

They cost a ton of money to build, and so then they cost a ton of money to access. Uh, and so in my mind right now, I, I'm seeing it very, very niche. But then I think about, you know, reading books about those early days of classical computers where, you know, someone's saying, oh, we're only gonna build five.

I only need three. We only need more than three. No one will ever. And so I'm sitting here going, you know, the voices of the past are echoing in my head saying, you're so narrow-minded. You, you can't see the future. And I, I love to think about a world where, you know, we're using it for all kinds of other things, but I, I think in those early days as we're, we're kind of figuring out what [00:37:00] we're using these systems for.

It's gonna be gonna be niche, and, you know, I'm gonna try and make them available to as many people as I can. Uh, but I, right now I'm questioning how wide that adoption's gonna be. And, um, but honestly I'm just really excited to build these systems, uh, that, you know, I, I'm a hardware guy. I wanna build a quantum computer.

I want to get it onto, uh, the net and I wanna get as many people accessing it as possible so we can start finding the use cases that I'm just not creative enough to come up with. Uh, you know, so that we can, you know, sa same as the, the, the, the folks building these back in the fifties and sixties, who never would've thought of, you know, cell phones or AI or any of those, those applications that we've come up with.

So, uh. I, I would love to, to be able to go a hundred years in the future and look back and, and laugh at myself at, at how I was, you know, not able to be creative. But, uh, my, my, my cynical position right now is, yeah, narrow to start dreams of, of big, wide adoption. But even if it is narrow, even if we're [00:38:00] only curing cancer and developing new drugs and new energy technologies, I think, you know, that's still quite the pretty good, the success Pretty good.

So we'll take, but it's that, it, it, it, it, it's that thing though, when you talk about the people who predicted like, we will need like seven computers in the future. They stood on a podium and said it with absolute and total confidence, which is always the, the hubris, isn't it? That says it. What you've just said there is, it's probably gonna be quite widespread, but I'm not sure.

So, you know, we'll see what happens. That's a, that's a much better way to say it than the confidence of the past that just the failure of imagination to see where it was going to go. So, yeah, I'm with you. We should look backwards and go, it's probably gonna be everywhere, but we don't quite know how. And then when, when you think about the, it's available to me as a consumer and I can go and get hold of quantum capability, what's that mean from a commercial aspect and sort of people using it for commercial gain or applications that then become saleable, et cetera?

I mean, what, where's the return on that? Because that'll start a whole new [00:39:00] flywheel process. Software. We go from research to commercialization and that'll, that'll create a massive lift. I mean, what's your view on, on that and when that might occur and how it might happen? So what we are looking at here is, um, really the point where hardware and applications development efforts meet, uh, I think the field is for a long time in trying to break through what you can, in a way think of as the, the ROI frontier.

I. Uh, we tend to call this the, the beyond classical computations. If you're Frontier, some people call it the sort of quantum advantage frontier, but this is where someone uses a quantum computer in the here and now to do some commercially relevant computational task, which is actually intractable on classical computers.

So this is where you can conceptually at least, uh, in a first flight sense of the term, uh, begin to benefit, uh, commercially from being a user of quantum hardware. Uh, because [00:40:00] we have quantum computers today, which in terms of raw computational power, and James talked about the, the RCS benchmark, which is a great way of measuring, you know, the kind of raw, uh, compute power of a quantum chip.

Um, and so in terms of in, in terms of this benchmark, we have quantum computers, which can outperform classical computers. To a really impressive, uh, degree. Uh, and we also have algorithms research results already, which point us to where we can get commercial value out of using quantum computers. But those tend to be, uh, for quantum computers of the future, you know, they need to be full tolerant.

They need to be really much larger than what we have now. And what we haven't quite seen yet is a publication of a result where someone actually performs a proof of concept con computation on a real quantum computer, which is beyond classical. Uh, but this is an active area of research that, uh, that I think is, uh, is moving fast and to, uh, [00:41:00] is a, is a space to watch.

I wanted to ask quickly, actually about. I think one of the scaling challenges, if I understand it, is to do with the cooling issue and Yeah, and the refrigeration. I wonder where you guys are up to with that and did Willow have any breakthroughs in terms of the level of cooling that it needed and, and how you think you're gonna crack that problem?

Because that, that to me feels like that's the, uh, that's the issue with, you know, computers as big as rooms, isn't it? A lot of it is to do with the cooling systems. So we certainly had to scale up the fridges in the context of scaling up the chip. I think that will continue to be, to be the case. There are, there are challenges on every level, level of the stack to, to solve when you are, um, moving on to the next generation of hardware.

But it's true that the, the Cryos stats, so these, these big refrigerators that quantum chips live in are a very, um, uh, expensive component of the, of the [00:42:00] hardware stack, right? And are challenging to, to scale. So we work with our, uh, supply chain partners, uh, sort of in a, in a co-development r and d set up.

And as we map out future chips, we need to also map out sort of future versions of this refrigerator and figure out, for example, are we going to build one huge refrigerator or are we going to try to, you know, have interconnect and, and have a more modular approach. And I think that from a sort of.

Research and engineering perspective. The answer really has not been, uh, found yet as to how we, how we're going to do this when we get to a very large scale. But at least, uh, we managed for the, for the willow chip. Yeah. And coming at it from a, a physicist standpoint, and I, I know it, it's sometimes frustrates our engineers here, but in, in my head now, I see those, some of these scaling problems, we're now able to push them off and, and I can think of them as engineering problems.

And so when they were physics problems, I was worried we might not ever be able to [00:43:00] solve 'em. Okay. But now that they're engineering problems, I have so much faith in our engineering team, I think, well, of course they'll figure that out. They'll, they'll figure out a way to, to get the cooling where it needs to be or the, you know, the different connections and the wires where they need to be.

So that's been a great thing here is, is seeing that some of these impossible physics challenges, we figured out how to solve those and now it's, now it's just, uh, the listeners can't see my air quotes, but it's just an engineering challenge, uh, that I feel very confident we'll be able to solve. It. I I love that you just go, yeah.

So we've fixed the theory. Uh, just go and build it now. Chaps off your Exactly. It should be easy. Enjoy. Let me know when you come back and it's working. And some engineers like just steam pouring out. See going, oh my words. Yes. How are we gonna do that? But anyway, yes. I guess while we're on kind of fixing future problems, Catherine, let's talk a little bit about investment and effort.

So how does it, how does all of that work and, you know, kind of, how do you, how do you apply it in a way that kind of takes you forward in a, you know, a dial [00:44:00] moving way? I would imagine the amount of problems that you are trying to work through and think about, so many of them might end up being nory. So how are you, how are you pacing your way through that?

I would say that while we are in this r and d sprint where we have, you know, a small closed group of expert users rather than a, you know, a product with huge numbers of, uh, of users in the general pub, uh, public, we can be quite focused, uh, in our investment on, on the hardware development to get it as quickly as possible to, um, to a place where, um, the, the hardware is able.

To accommodate the kinds of applications which the user will really see an ROI from. But of course, we, um, uh, besides that also invest in applications and algorithms development. We have a, a great team working, working on that. And indeed, when you think about hardware development, that is really sort of system development that actually requires a lot of software engineering as well, uh, because [00:45:00] the quantum stack consists of a lot of hardware and software where layers.

And then on top of that, there's the product development. This is defining the gap between achieving a full system performance milestone and actually being able to make that useful to the world in the form of a compute capability and doing all the engineering work to, to close that gap. Uh, and then maybe finally, I guess, uh, it's, it's people and the broader ecosystem in this really emerging field, it's very important to do, I guess, workforce development and engage with the, the broader ecosystem.

Well, while we're still future gazing, and maybe just to bring the conversation to a close for at least this year and revisiting it this year, uh, uh, one of the things that always strikes me when we talk to you guys is you generally drop a couple of mind blowing quotes, like the one that you did at the beginning, James, around how, how much faster the, the chip was working than a traditional computer.

I wonder, like, as you are going through the work that you're doing, have you got a favorite one of those, [00:46:00] like a factoid about what Quantum has achieved that was, that surpassed your expectations or got to some crazy number, like the one that you just described earlier? Feel free to have a go at that, uh, in any order.

I think my favorite quantum quote, I do love the, you know, the fact that we're able to perform some of these calculations, uh, so much faster than, than any supercomputer. Of course, those are very fun. Yeah. Uh, but honestly, my, my favorite quantum quotes, uh, you know, go back to Richard Feynman, the, the person who first kind of theorized quantum computers, and, you know, it was, if you're going to try and simulate nature, then you know the computer needs to be.

Needs to be physical, right? We need to build, if you're gonna try and simulate a quantum sys system, the computer needs to be quantum. Uh, and you know what a amazing, uh, problem this is to try and solve. So though it doesn't have to do with the metrics [00:47:00] so much, and, and on our quantum systems here at Google, uh, just some of fine men's wisdom, uh, when it comes to the complexity of this problem and how fun it is to go after solving those very hard problems, uh, you know, ESMI was mentioning glowing.

It's true. This is my favorite thing. Uh, I don't tell the bosses, but I might do this for free. Uh, I just love working on quantum computing so much. Don't say no, no, no. That, that's my favorite thing, is you have this. You know it, Rob, you mentioned it too, like the, the amount that this could impact the world.

Uh, that's what gets me up out, out of bed every morning. It's just that this could be the key technology of the century, right? That this could change mankind. And so while it's not so much a technical thing, uh, that's really what, what gets me so excited. And also just thinking about how insane it is that quantum mechanics is real and that this is something that actually works.

'cause it. Even now, 20 years of thinking about it, it doesn't always make sense in my head. And so, you know, [00:48:00] the fact that the more you think about quantum mechanics, the less you actually understand, you know, the, the quotes like that. Those are the ones that have always stuck with me. Yeah. Wonderful.

Catherine? Um, I think perhaps the one that I find the most mind blowing is that to be able to create a kind of digital twin of our, of our own brains, and where will that take society and, you know, what does it mean even for the, for the human condition?[00:49:00]

Ez, what's on your mind? Yeah, I think it's something that we've already been touching upon throughout this conversation already talking about a fixed mindset with we only need seven computers. But if you talk about Quantum, and we just mentioned that we don't know all possibilities yet. Um, and we might even.

You know, looking into the future, we might be entering an era that we will never have all opportunities or possibilities in our heads because it's way above our head actually. Um, so if you look into engineers and product managers, they've been shaped by deterministic thinking. You write code, you run it.

If it breaks, you debug it, you trace it back to a root cause. But quantum computing forces us into a different reality, right? So not one outcome, but probability space, not certainty, but potential. And I recently read a piece in Harvard Business Review on teaching teams to think in probabilities. And that made me wonder, quantum isn't just a technological leap, it's a mind shift.

So how do you [00:50:00] build and lead teams around that? How do you onboard people into a world where answers are rarely final and logic is non-binary and maybe even broader? Does quantum also demand a new kind of leadership, one that embraces ambiguity and works with complexity rather than trying to control it?

What's your thought on that? Uh, so my job, I have to understand digital and digital systems, how they operate to be able to deploy 'em, right? And I still read up on quantum and it still makes my brain hurt. So I do think, I do think there's going to have to be a mindset shift, like you say, that says, I'm gonna have to think differently about the way you think about solving problems.

And that will be a big leap for loads and loads of people. So when we talked about the commercialization in the previous part, to get the commercialization working, it's going to be very clever people who think differently, who are going to get their first, isn't it in the community? 'cause the traditional, uh, sort of digital thinking need not apply from my perspective.

I absolutely agree. I do think it's a little bit of a mindset shift. I [00:51:00] think, you know, it, it's frustrating for those of us on the product side because we can't look at this like we do our, our normal products. It's, it's very hard to think I am engineering towards something where I can create the use case.

I can't start with the customer necessarily right now and work backwards because I'm still, I'm still laying the track as my train is going down, you know? And so I think it is, it is requiring, uh, a little bit of a shift in who our leaders are. You know, they, they have to have patience because they have to understand we're still figuring a lot of this out.

And that, that can be tough. You know, we have a lot, a lot of very energetic folks, uh, leading these quantum companies. And so they have to have the patience of, let's make sure we do this right. Let's make sure we're not overselling where the systems are today. Because I think, you know, the, the global community is gonna look and say, quantum computers have been 10 years away for the last 30 years, so when are you guys gonna actually deliver something?

Uh, and then at the same time, you know, if, if that fatigue sets in or if we're not able to [00:52:00] meet, you know, what we've been saying we were going to do, I, I worry that, how does that change investments, especially as things like AI and other things are out there, other sexy things to invest in. So we have to be careful, we have to have patience, but we also have to push just enough that you have that little bit of heartburn that makes it tough to go to sleep at night because we can't get, uh, we can't relax too much.

So we have to continue pushing ourselves while having that patience to kind of, you know, I, I think it's a little bit of a shift from how tech is normally done, um, just because we're not sure where this is gonna go and we're not sure what it's gonna look like. Um, but it has so much promise that we can't stop.

So we have to keep, keep running, uh, but also keep our eyes open so we don't run into any trees. Yeah, absolutely agree. And perhaps this is something that you see, uh, more broadly in other areas of, of deep tech. Personally, I think if I was not working, uh, on quantum computing, I would probably be working on space in some way or other.

Right, right. And I imagine that people working on space, [00:53:00] uh, have precisely these same, uh, these same challenges where there's just huge, uh, uncertainties. You need to kind of. De-risk the science, de-risk, the engineering, do a lot of scenario planning in a pretty meaningful way where it can be that you have to do a huge pivot on your technical architecture if something scientifically is discovered that you maybe were not, uh, expecting.

Perhaps in a more literal sense though, about your, your, your, uh, regarding your question, where does this probabilistic nature of quantum computers affect our teams in reality and how do they cope with it? I find it interesting to see that at this stage, it's really not only the people building the chip and the software, which calibrates the chip and, and does the error correction that need to think about noise, but it's actually also the, the end users.

So the applications developers at the moment to be able to get anything useful outta the quantum chip need to really think about the [00:54:00] noise, the, the probabilistic nature of the, of the chip. And if they don't, then it's. It's not really possible to make it, to make it work for, make it work for you and usefully do something on it.

It's good to come at it maybe from a slightly different angle. And on your last point as where you were talking about increasing complexity and, and dealing with ambiguity and forms of leadership, I mean it's a good provocation. I think what I think leadership in its truest sense is dealing with complexity of human systems anyway.

Right? And I'm not sure what the quantum effect is going to be on that. So like, I guess the way I would try and pause the question is, if leadership is dealing with human systems and you put quantum into a human system, does that fundamentally change the nature of how the human system then operates?

Because I think as [00:55:00] the world has gotten faster and faster and faster and less knowable as we've, as we've gone forward, leadership has had to deal with increasing complexity anyway, hasn't it? Like you look at something like the FIN framework where it talks about moving from a sort of a complicated world into a, into a complex world, and in a complicated world, it was very noble.

You could maybe do a strategy that would be five years out. Now, if you did a strategy that was 18 months out, you're probably stretching what, you know, the what, what's predictably possible. I think we're even further than that now, right? Mm-hmm. It's, it's the same as what we sit with the seven computers.

We, I, I don't think our brains can wrap around the type of complexity that we're heading towards. I think you're right. I think, look, the, the, what, what that reminds me of is, you know, that there's a statistic about the human brain can only handle knowing something like 75 people. Or something like that.

And, you know, evolutionary, we've [00:56:00] kind of, we've grown up in sort of villages and then villages became cities and then it was, and then you were tracking news just through traditional networks and newspapers of what's going on on a global level. 'cause social media then has now made that real time and practically instant and you can see the impact that social media has on the human brain, can't you?

So I think you're right. I think, I think we are in that world of absurd complexity already. Oh God, I have no idea what Quantum's gonna do, Catherine. Is this distinction between complicated and complex? I've always found quite a fascinating one because, Hmm. It's good. I think quite literally complicated means that there might be many interacting parts, but actually, um, the system is still predictable.

Yes, that's right. Whereas a complex system, um, there you are dealing, um, with, with something that becomes very hard to, to predict over time. And so in a sense, what we need is to, to, to be really nimble and to adjust our [00:57:00] strategy and the way, uh, we sort of, uh, move the effort and the, and the teams forward as we go along.

I think, I think there's a fair bit of AI helping us with complexity as well. We already use it in basic tasks to solve complex issues and advances faster. So I think there'll be some fusion of human thinking and artificial thinking, uh, to, to remove complexity from the system. So we'll learn to use the tools at hand to make it easier for us to cope.

But you're right, you get to a co cog, well, cognitive overload occurs quite mm frequently in certain systems and, uh, we know it can be very that damaging. So I think it's the advance of tooling around us that we use to deal with it. Maybe as part of the answer, not the full answer though. You still have to understand how the system works at the basis level to be able to fix it when it breaks.

Good provocation is lots to think about in that. Um, now before we move on, I actually want to ask you a little bit of a wild card question, um, before we wrap up today. Uhoh run for the hills, everyone. Uh, run for the [00:58:00] hills. My connection is dropping. That connection is dropping.

What, Dave, you break it up now. Does the, does the, um, the nexus of quantum and AI make the possibility of us living in a simulation greater or lesser?

Well, asking for a vote. I'm asking for a interview. Well, I know your vote's gonna be Rob, but don't show your, don't show. Oh, we already live in a simulation. I'm convinced. Sorry. That's what, don't show your hand. It's a funny thing to ask. 'cause we, we recently had an offsite and towards the end of the night, this story, this question did come up.

Right? Right. And we had a couple of people, uh, pushing different ways and, you know, we're, we're kind of talking over it. And then one of our more senior scientists who, uh, you know, is very well respected, very intelligent guy, uh, stands up and goes, you know, you're all idiots. Uh, we're, we're not living in a simulation and stormed off to bed.

So, uh, emotions ran [00:59:00] high. Emotions definitely ran high, but, uh, I respect him a lot. So, you know, it's, it's a fun, uh, thought problem and I like to think about it. But knowing his, his standpoint, I thought, well, maybe I. That must be the answer. He, he's a smart guy, but it, it is an interesting thing, right? I, I, I talked about, you know, quantum physics, even existing, and, and thinking about that we have these physical constants that are constant across the entire universe.

Sometimes that makes me think, like, that certainly seems like something I'd program into a video game or, uh, you know, a computer simulation where, oh yeah, you, you can never go faster than the speed of light. Good. That'll send that one. And then they, it's convenient, isn't it? Things like that are convenient.

If you own a simulation, you go, these constants can't be broken. Yeah. These are the, the unfelt, you know, unchangeable things. So. Uh, it is certainly a fun problem to think about. Uh, and, and in the main, in the main, um, conversation there, Catherine was talking about digital twin of the brain and needing Yeah.

A quantum computer to be able to [01:00:00] simulate the brain. So, you know, so simulation as an, as an idea is something we're developing, right? Catherine, we are thinking about that. Uh, I don't think I back myself to predict 5,000 years into the future. No, go on, give it a go. Nobody's gonna be around here, so you'll be fine.

Just wake it up. It's good. But my general rule being, um. I would say realist, optimist. Mm-hmm. Is that as long as I can see some sort of plausible ish technical path towards doing something, I can believe it. Right. Um, and simulating the brain, I feel like is something that, um, I can, I can see how I would, how I would do that.

I feel like I draw a diagram, uh, that, you know, would sort of represent an approach to doing that, whereas simulating the universe. Uh, that I'm not sure I quite, uh, see sort of a technical critical path to doing. And I feel like actually what we're getting into there is, is questions

[01:01:00] about religion. Mm-hmm.

Uh, which maybe you're not, not quite the, the types of philosophical questions you guys want to discuss. Oh, no, we'll take it. We'll take it. Um, yes. I, I would, I would put my philosophers. Uh, hat on, uh, if I would think about, uh, that topic rather than my, uh, quantum computing, uh, hat. Well, very nicely summarized and let's leave the conversation there for today.

Um, a huge thank you as always to James and Catherine who just bring such fascinating subject matter to the conversation. So guys, great to see you, and thank you very much. Thank you so much for having us. Thank you. Now we end every episode of this podcast by asking our guests what they're excited about doing next, and that could be simulating the human brain or that could be something in your personal life that you're looking forward to do in this weekend.

So, Catherine, why don't you kick us off? What are you excited about doing next? Well, it's extraordinarily sunny here in London, so I feel like that is unusual [01:02:00] enough that it must be mentioned and it'll have to go and seize the day tomorrow. Mm-hmm. But besides that, I'm just so excited about the, the long term product roadmap.

I think we have some really great ideas for how we can make these quantum computers. Useful and available to the wild and what the sort of main, uh, milestones, uh, there should be. So yeah. James, I hope, uh, you're looking forward to the, to building all of those versions of the, of the product too.

Absolutely. So yeah, we're, we're starting to have our very first external users running on our quantum hardware, so that's something I'm very excited about. But, uh, more short term is, you know, Google IO is coming up next week, so I'm heading up to the mothership in, in Mountain View, uh, and excited to see some of the things that are gonna be announced there.

So that's, that's top of mind for me right now. But yes, getting, getting users on hardware, that's what, uh, is keeping me going right now. If you would like to discuss any of the issues on this week's show and how they might impact you and [01:03:00] your business, please get in touch with us at Cloudrealities@capgemini.com.

We're all on LinkedIn. We'd love to hear from you, so feel free to connect in DM if you have any questions for the show to tackle. And of course, please rate and subscribe to our podcast. It really helps us improve the show. A huge thanks to Catherine and James, our sound editing visit, Ben and Louis, our producer, Marcel, and of course to all our listeners.

See you in another reality next [01:04:00] week.

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