T. Bollinger, *A Deep-Physics Look at Quantum Computing*.
Apabistia Notes **2026**, 05212000 [May 21] (2026).

Slides: https://sarxiv.org/apa.2026-05-21.2000.01.pdf
Video: https://youtu.be/v4Pu2vEG3hk
Transcript: https://sarxiv.org/apa.2026-05-21.2000.02.pdf
Cite: https://sarxiv.org/apa.2026-05-21.2000.03.pdf

AUTO-GENERATED YOUTUBE TRANSCRIPT, UNEDITED:

0:00 All right. The reason I'm addressing quantum
0:05 computing from a physics angle is that one of my — I guess you would call it
0:11 hobbies in physics — is that I love to look back at the original papers and really dive in, and say, "Where did this come
0:18 from? What was going on? What was the actual physics involved with this?" That
0:23 can be fascinating because a lot of times what you the story that you hear about some concept that has a profound
0:30 impact on technology is often surprisingly at odds with what you actually see when you look carefully at
0:37 the original papers, and this is true for a number of different areas and quantum computing is one of those it
0:45 is also an area in which I've been was strongly involved because of my involvement in the government on quantum
0:52 cryptography. There was a lot of concerns when the quantum computing concept first came up.
0:58 David Deutsch talked gave a talk nice talk at the MITRE Corporation
1:03 and I remember both the enthusiasm and the concerns that went on at the
1:09 same time and there were a lot of interesting interactions. So, a look at quantum computing really from the
1:16 physics viewpoint. I'm not so much trying to say use this method, use
1:21 I will we'll get some suggestions at the end, but to look at it and say like how solid are these foundations? What
1:28 might we need to do in the future and where could you go? Now, I should emphasize because you're going to hear
1:34 some very sort of qualified
1:39 qualified concerns about quantum computing. But I want to emphasize that I am a strong believer in quantum
1:45 computing. I just simply think that we're following paths that are making a lot harder for us than it really
1:52 should be. So, if anything, I think the potential of quantum computing may be significantly higher than what we
1:59 what we tend to think. Here's quick overview of the seven sections. As I mentioned, uh
2:06 badly broken promises. I do want to get into that. going going to be getting into Schrodinger's cat and some of the

2:12 implications because wow, you can't get away from this stuff when you're talking about why quantum computing is supposed
2:20 to do what it's supposed to do. So, you get down into some of the deep history of physics very quickly when you
2:27 want to assess what's coming on with that. I'll also end up I'll talk more about quantum computing
2:34 from some very different perspectives ones that in particular are different from the Everett mini worlds model.
2:41 That's going to be a major focus of this talk because that's one of the things when you look at the details and
2:47 you say what actually happened there. In many ways it's not at all what you would expect. Badly broken
2:53 promises. When I first started, as I just mentioned, I can remember I
2:59 couldn't find a quote for this, but I remember the conversation vividly. we
3:04 were very concerned quantum computing was going to break all cryptography. That was the claim. That was the assertion. a lot of sincere belief
3:11 that that was exactly what was going to happen. I absolutely was one of those people. I was very enthused. I thought
3:17 this is really cool. I understood the basics well enough to say like, "Yeah, I see what you're saying. That has
3:23 potential. that has possibilities." So this was a this was a thing that that was very interesting. But what's really
3:30 remarkable is if you look at what quantum cryptography or what quantum computing is now versus what some of
3:36 those claims were in the very early days, the orders of magnitude of difference that people propose for when
3:44 you get a useful result are just incredible. You're going from 15 cubits
3:49 if they worked perfectly the way that David Deutsch thought they would and many of us thought, it wasn't just David
3:55 Deutsch, many of us thought this, okay, if we if we create these gates and can do a good implementation,
4:01 then that should work. But then the number kept growing. So there's there's an interesting thing going on with that.
4:09 And the interesting thing I'm going to propose is that we have a disconnect
4:14 with the actual model that goes back to two people who worked under John Wheeler who was a very famous and remarkable
4:21 physicist with a very a very creative mind. I don't know how else to say that. Richard Feman kind of helped hold him
4:28 in check and as a result got a Nobel Prize for it. Hugh Everett had different views on some issues but they
4:34 both worked under John Wheeler and there's some common threads. Do you see that the suggestion I would make to
4:41 put it in a nutshell is that had quantum computing followed more of a Feynman
4:46 type path that many of the problems that have been encountered since then of
4:51 just you know enormous physical costs and trying to build these systems surprisingly minimal competitive uh

4:59 advantages. You know, we talk about this proof and that proof and the other proof of quantum computing, but as most of you
5:06 out there, if you followed it at all, you know, when it comes down to brass taxes saying, “Well, what does it
5:11 do for me that I couldn’t do before?” You tend to wind up with a
5:16 surprisingly weak argument considering how many decades this has been going on. another thing I want to bring out and
5:22 this has come up recently some other I give I give regular monthly talks on another meetup group on physics
5:28 topics and Wheeler and Feynman had some work that just has some
5:34 intriguingly different ways of looking at this and in some ways their ideas are more radical not less than
5:41 this idea of mini worlds. So it’s this is not a thing of saying like you know there’s nothing interesting going on. No, there’s something
5:47 interesting going on, but it’s possible we’ve been going at it just not quite the right way.
5:54 Schrödinger’s cat. Every everybody knows Schrödinger’s cat, you know, and I’m not going to try to explain it. You
6:00 have this little thing. You have a radioactive event. The point is the mathematical formalism say you don’t
6:06 really know when the quantum part stops. And that’s the basis of this.
6:12 And that’s what Schrödinger was going after. He said, “Well, you know, an emission of a neutron or of a beta
6:18 particle, whatever it might be, is very much a quantum event. So therefore, it is quantum wave function. Does that mean
6:24 that all of the consequences that found follow thereafter are also quantum?” And
6:30 Schrödinger and people I love the fact that Schrödinger made
6:37 this cat for the explicit purpose of saying this is a ludicrous idea. He was
6:44 he was not trying to propose a cat as a way of understanding quantum mechanics. He was trying to propose it as a way of
6:50 saying folks we don’t understand what we’re talking about. We’re missing something. Einstein was very much in
6:58 agreement with him on that. They was also saying like this this is not right. So they kind of got into collusion with
7:04 each other to this point to the annoyance of many of the other physicists. But Schrödinger was not
7:10 trying to to say this. He was trying he was trying to say the opposite. He was saying that we have an experimental
7:15 understanding what a dead cat is and a live cat is. This doesn’t sound right to say that their superposition is the
7:22 same thing. And yet if you want to do quantum computing boy is this an
7:27 important issue because if they can’t be superposed that changes the nature
7:33 of quantum computing substantially. If they can be superposed, then you have much closer to what David Deutsch has
7:40 been advocating for many years now. So,
7:46 and the irony is you come out with you come out with an example that you’re trying to say this doesn’t work and then

7:54 not only do people quote you as having solved an interesting problem or proposed an interesting problem, but
8:01 you're actually remembered for that. And people to this day when they hear Schrödinger's cat, they think Schrödinger was
8:07 was trying to make this into an explanation of how quantum mechanics worked. how could that happen? And
8:15 and I want to point out that there's a simple principle that makes it possible for very different interpretations of
8:21 the same situation. It's this. The only time quantum mechanics works is when
8:27 nobody knows what's going on. So think about that. If your key requirement
8:32 for making things go work is that you don't know what's going on inside,
8:38 then you can put all sorts of interpretations into what you're trying to do. And that's exactly what has
8:43 happened in quantum theory over the years. Quantum physicists know very well
8:48 that you cannot get quantum mechanics if you know all the details. That's just
8:54 absolutely fundamental concept of quantum mechanics. in order to get effects like two-slit interference, to
9:01 get reflection, to get all sorts of properties that we don't even think about and often don't realize are very
9:07 quantum. you have to have an ignorance of what happened. You have to have a lack of history. As soon as you
9:13 have a specific history, all that disappears and Feynman writes beautifully about
9:19 this in some of his some of his books, both his lecture series and his book QED. So but it really creates a
9:27 quandary and then to that quandary you have these different proposals. So
9:34 both of them worked under John Wheeler. Feynman however had a pragmatic focus that was always
9:41 characteristic. He wanted to be highly predictive. He wanted to come up with something that would actually say
9:46 something. But that doesn't mean he wasn't a radical thinker. He had a very different very different interpretation
9:52 of it. He and Wheeler both play games with time in ways that nobody had really
9:57 done before. And they used it though to in the end create a very precise
10:04 mathematical framework that was able to do predictions to I think it was like 16 digits. I'm not sure what it is now.
10:11 They were able to predict certain properties from theory that no one had ever had that level of accuracy in the
10:16 quantum world. So that that was pretty impressive. you know, it was a it was kind of initial area, but it showed that
10:23 whatever Feynman was doing with this idea, it was it was working. Now,
10:29 Everett focused on the interpretation. This is surprising if you've heard of
10:34 Everett through quantum computing is Everett did not predict anything new.
10:40 And it's easy to think that he predicted the mo the Marvel universe and
10:45 all these different things. Actually, he did not. at the laboratory level he was quite specific and said you know no it

10:51 doesn’t it produce anything different from standard quantum theory so but the imagination of many folks
11:00 just ran wild when he came out with this idea now Schrödinger did not mean to have that happen Everett very much did
11:09 he was he was one of this this is this is what he was trying to do because he really did feel this was an important
11:14 important issue and later influenced a fellow named David Deutsch who came up
11:19 with some specific ideas some like I say intriguing I just remember that time was a fascinating time absolutely
11:25 fascinating period where Deutsch David Deutsch came up with a way to do
11:30 to try this and to try and make some access with some qualifiers and the qualifiers turn out to be important
11:38 what Everett said was that quantum mechanics has two parts and you don’t
11:43 really need the equations the concepts here are what counts equations are your programs. Those are, in this case,
11:48 the mathematical formalism by which you get precise start plugging in numbers and get that they give you some insights
11:54 but in this case the concepts are straightforward. Every part of
11:59 quantum mechanics has two parts. It has this discontinuous change. You’ve heard the phrase wave collapse.
12:06 You’ve heard the idea of suddenly the particle is there. There’s a probability wave function. The particle was
12:12 everywhere and all of a sudden it’s just right here. And that has caused so much
12:17 consternation over the decades. Einstein literally was booted out of the quantum computing community because he
12:25 kept pulling up these pointed questions about how does that work? Explain to me
12:30 how do you wind up how do you not wind up getting two different electrons in two different parts of the wave function
12:35 was a question that he asked at one meeting that that definitely got people riled because they couldn’t answer it. I
12:41 said like I don’t know how it does that without violating the speed of light and all these other issues. So on it went
12:48 process two is much more conventional if you’re coming from a
12:54 classical physics viewpoint and that is the wave equation. The wave equation which ironically was what Schrödinger
13:00 came up with. It’s ironic because Schrödinger was the one who complained then about saying this this can’t be right on some of the interpretations.
13:07 But the point was a smooth continuous wave equation deterministic if you say with
13:14 sufficient detail here’s what the wave looks like here’s what it’s going to look like in the future and that process
13:20 makes almost everybody a lot happier for a simple reason that
13:25 people understand wave equations whereas process one this thing about observation
13:32 people have to this day enormous debates

13:37 about what that even means, let alone having a precise mathematical model for it. So you get quite a contrast in these
13:44 two. Everett did in some ways a remarkably simple thing. He discarded process one entirely.
13:53 And the intuition if you if you've looked at some of this stuff is said you can't do that. you if you do that
14:01 essentially you destroy quantum mechanics because quantum mechanics was all about why continuous wave functions
14:08 did not seem to allow that. So then if you suddenly go back to this thing and say well but yes they're all
14:15 continuous anyway just like we said classical times then you you're left with this this question said well what
14:21 does that mean in terms of the structure of the universe and what it means are some extremely
14:28 unusual and massive changes to the view of the universe. David Deutsch uh
14:34 attached on to those changes.
14:40 One of the ideas, a couple of the ideas from Everett his
14:47 excuse me just for a second my computer is trying to shut down. Okay,
14:57 observer and observed become a single wave. This is part of how Everett dealt
15:02 with this issue. What he said and he makes a good argument for this. if you read back into his original thesis
15:08 paper, he points out that the idea that that you can just be an isolated observer and you have an isolated system
15:15 that you're observing it. He makes a good argument. He says that well that no, it doesn't really work that way
15:20 because there's an interaction in both directions. You see it more in small systems, but even for a full-size human
15:26 being, there's still an interaction. You know that you've got the you change the particle, but the particle gets you
15:32 information back. And that information then becomes part of your history. So from an information history perspective,
15:39 the two were bound together. So he really emphasized that and used a wave
15:44 model to say like, well, okay, if you take that seriously, you have to come up
15:50 with a new wave. And this new wave has its own set of properties.
15:55 And where you go with this if you take it all the way to the end is remarkable.
16:01 But it's also much applauded in literature and fantasy and there's a company you know company called Marvel
16:08 who made an entire set of universes around this idea. You start getting multiple simultaneous branches of the
16:14 universe and not just a few of them. You get a lot of them. yeah, and I think
16:21 people don't understand sometimes when they hear this idea. They think that oh like maybe there's a you know a Star
16:26 Trek branch of a universe here and a universe there. No, this is a number
16:31 that would be hard to calculate because every quantum event that has a couple of different states winds up creating one
16:37 of these branches. And if you consider that all of quantum mechanics is doing all of that all the time for an enormous

16:44 amount of matter and energy, you get into some issues very quickly with this. So, but this was he was following
16:51 through. He said, "Here's my premises. Here's what it goes, and I am going to play it out to the end." So, he was
16:57 consistent. He said like, "Okay, this is where it takes me." And wow. Okay. So, he got all these branches existing
17:03 simultaneously. And a lot of them. David Deutsch 1985. This is a couple
17:11 years after Everett passed away, died quite young in his 50s.
17:18 he wrote a paper in which he was saying that if you create a certain kind of gate
17:24 there was a premise now by the way this is if you look at the language he said this is a quote from him the
17:31 intuitive explanation of these properties he didn't really make a proof as far
17:38 as I know I've not been able to find an actual proof of saying this is what's gone it was more like a hypothesis and
17:44 hypothesis was this we have this wave that's out there and if we could
17:50 access the entire wave we have enormous computational power. So the way he
17:56 thought to do this was to create these non-entropic these reversible gates by getting rid of entropy. Entropy is what
18:02 locks you into a particular universe according to how Everett went on
18:07 with this. So if you get these non-entropic gates that just sort of settle down and without actually
18:13 expending a lot of energy they come to a conclusion. His premise was that you can
18:18 access these universes these states. Now he bet everything on that. So and
18:26 also it I again I remember this time this was something I was paying careful attention to at the time. It was
18:32 proposed at that time as a hypothesis. it was not proposed as a given just as ever said when he says that it's an
18:38 intuitive explanation without really saying like yeah it has to work the
18:44 attitude was like maybe it'll work maybe it won't work I remember people talking
18:49 about just that said well but if it does work man it's going to make a difference
18:55 so everybody including yours truly was going like well we people need to check this out they need to find out is this
19:01 true or is this not true so it produced a interesting kind of dynamic at that time and this was the premise
19:08 that Deutsch bet everything on is not only was the Everett interpretation
19:13 correct but also that you get access the actual full wave and I'll get into that
19:20 more later. There's some there's some interesting issues when you when you make a statement like that.
19:28 So individual elements of those have are
19:35 supposed to okay this this is what's to me a little surprising
19:41 Deutsch did this paper after Everett died. As far as I can tell from
19:48 a reading of Everett's own work he would not have agreed with Deutsch.
19:55 And that's that seems surprising. think like well why would he not have agreed with it because in every statement that

20:01 ever made about these many branches of universe he was quite adamant that
20:06 the prediction should be the same as what we see in quantum mechanics and quantum mechanics does not give you a
20:14 computational boost and doing this. Instead, it just gives you randomness. So, essentially, ever would have said that yeah this is just going to turn into
20:21 another analog to quantum computing he definitely did not think that you
20:27 could just plop down and grab the entire wave that he was talking about that that
20:32 was he went to quite a bit of discussion quite a bit of analysis saying that no these things split
20:37 off into their own little branches. So there's a very specific terminology and about how the branches could not see
20:43 each other. They would do it like says like complete indifference to the other branches to the other universes.
20:50 So interesting little contrast and I had not realized that before. or I
20:56 thought that that maybe Everett would be a little more agreeable, but as far as I can tell that would have been
21:02 some some difficulties. So, you see a little illustration in here. You got this this wave function. What happens
21:08 in Everett's universe? And he knew this. I mean, he was completely aware of this. He just took it to the max. He said,
21:15 "Well, I'm going to assume this the way the universe works." That was his hypothesis. He said you start out with a
21:22 wave function at whatever time and then it starts to get more complicated. So
21:27 this is just it's very much like at a string. You start tying knots into it. You start doing all sorts of incredible
21:33 convolutions to it only at a scale and at a rate that is just almost
21:40 impossible to comprehend because every quantum event is going around doing this. Now you get some ambiguity say
21:46 like well only an intelligent observer can collapse it. that that might moderate it some. I think people
21:52 unconsciously that's exactly what they do. But Everett really was more focused on like you know if you have a
21:57 recording device he didn't care whether it was a conscious person at that point. He was concerned about these different
22:02 branches. So in his in his viewpoint you have this enormous complexity but you
22:09 never see anything except one universe of it in your viewpoint. So he kind of
22:14 breaks it down and he gives a more limited version of that. So you
22:21 get this contrast. So what happened when they actually tried this because
22:27 Deutsche made a hypothesis. He said that a very small because if this works you don't need many cubits.
22:33 This is this is a misconception. This is a misconception that comes from the current interpretation of cubits which
22:38 has drifted a lot from the original. In the original version, you have this this
22:43 idea that if you can do this at all, you don't need much because effectively
22:48 every cubit is accessing some incredible number of universes and the power just
22:54 just keeps increasing over time. So you have this thing of will it work or

23:00 not? But it didn’t work the way it was. I remember
23:07 I remember my excuse me I remember my disappointment. first time I saw some
23:13 of the results back everybody said like well you know we’ll find out soon. It’s
23:18 a little bit like cold fusion actually. So people said we’ll find out soon. You know they’re doing some experiments. We
23:25 ought to be able to know pretty soon. And then this strange thing started happening. And I’m going to rag
23:32 this a little bit because I think it was unfair. pe people began saying that it noise was the problem that that
23:39 Deutsch was right that the universal wave function was still there that you could still access it. But the problem
23:46 was that people didn’t know how to build the systems yet to do it. And the reason I don’t like that is because that wasn’t
23:53 the original story. it just wasn’t. The original story was that we’ll try it and see if it fails and then it failed
24:01 and then people started pointing fingers, you know, implicit and some of the fingers may have been welcome
24:06 because it’s oh good, we have an excuse to work more on this, but it’s still amounts to saying like ah we’re going to
24:13 blame the problem and something else here and analytically from a scientific viewpoint from in terms of
24:20 performance you don’t want to do that. you want to look at it closely and say, “Well, why didn’t it work?” And mostly
24:27 that’s not exactly what happened. It was still this this drop off into the noise
24:32 issue. And that’s a problem. And I’ll get to it because the reason that’s a problem is it goes back to what some of
24:38 Everett originally said. And whatever it originally said
24:44 was that because of the limited subset of the of these infinite waves that you
24:51 always occupy, you’re always in just one universe worth. What you see is exactly what quantum mechanics always predicted
24:59 is that if you try to see a photon, you’ll see one little tiny flash. And that one little tiny flash will
25:04 tell you what it is. But one flash does not give you much information. And this
25:09 is the crux of the problem. One flash only gives you a tiny bit of information. Imagine trying to see a
25:15 very complicated broom and you have a flashlight that only gives off one photon at a time. How long is it going
25:21 to take you to see the whole room? It’s not that the photon is not being accurate. The photon’s giving you good
25:26 information and the photon is doing a good job of doing something. it in a sense it knows the shape of that room
25:33 but it can only tell you one tiny, tiny bit of information about that shape that
25:38 it sees because it’s only one photon’s worth of energy. So you have this tight relationship between energy and
25:45 information. So the reason I have some objections about saying it was just noise is you say yeah it’s noise but you
25:54 know it’s the kind of noise that you get in any quantum system because you have

26:00 quantized the energy and you won't get a full result until you get more. And if
26:06 you think about that that makes a lot of what you're doing into building a wave computer. Wave computers are quite
26:12 powerful. They're actually multi-state devices. All they're waves are superpositions of the foyer transform.
26:18 So they are a form of computation. But if you look at it that way, then you're going like why are we using
26:26 individual photons if all we're really doing is sampling enough of them to get
26:32 a wave computer? Why not just turn on the lights and do it that? So and
26:37 again, ironically and a little bit to my surprise, Everett, as far as I can tell, would have agreed with that. said,
26:43 "Yeah, you're only going to get little tiny pieces coming out of that and you're not really going to get
26:49 the computational boost you want because you have to use so many photons you wind up back into the traditional wave or
26:56 digital domain to try to get that that effort. There's an entanglement issue
27:01 there." Yes. So, if you're familiar with the entanglement, but the basics here of how you get the information and why it
27:07 looks noisy or why quote unquote noisy, I would call it sampling error instead of noise. that still remains. You
27:14 have a sampling issue with this. Now, what Everett did, I'm going to back
27:20 up now a little bit. Whatever it the same idea and try to give you a little graphical representation. Uh
27:26 Remember Schrödinger's cat. Schrödinger came out of this idea. So, while a cat splits into living or non-living, so
27:33 you have a superposition of states. What Everett really did was he said, "Yeah, it's worse than that." So, not
27:41 not only do you have a super position of the states. Each one of those cats creates its own universe. So you have
27:46 these two little films that just go off in different directions and they literally create different universes.
27:52 And then you have this enormous number of choices that branch out of that which I've already talked enough about. This
27:58 is again a number I don't know if anyone's ever tried to actually calculate it and you would have
28:04 difficulty coming out with a number. So again, these branches of this universe are not just a couple here and there and
28:12 somebody does something a little differently get. No. It's like every molecule in your body is
28:18 creating a new universe. Every atom, every particle, they're all creating new
28:23 universes because you wind up all of them recording bits of information. And when they record something, when they
28:29 make a change, when they know what everyone would call it a relative change, it doesn't matter. When they change their relative
28:35 position compared to something else, then, at that point, you get this this process
28:40 of universe splitting. So the I think enough not enough is attention is
28:48 paid to just how many of these universes they would be. Deutsch paid attention to that. Deutsch saw that as an opportunity

28:55 because he said, “Yeah, that’s where the power comes from because you got so many versions of these things going on nearby parallel universes that
29:02 give you this computational power.” So,
29:09 one of the problems — how do I say this?
29:15 Mathematical abstractions are so incredibly important to physics to everything we do and so much progress
29:23 has been made with good mathematical abstractions. However, however,
29:29 if you get into a viewpoint that the math itself doesn’t need to be correlated back with
29:36 the actual experimental results that you just assume something because you can
29:41 write a good data structure, which is all some of these are really is data structures. You can write a good data
29:47 structure and if you’re a programmer, you know very well that just because you can write a good data structure does not
29:52 mean that data structure has some deep understanding of reality. Well, when
29:57 Hilbert defined his generalization of three-dimensional spaces back in the 1800s,
30:02 uh, all he really did was say that, you know, we got three-dimensional space. Let’s take that as a model. We see it in
30:08 nature. Let’s assume that that’s just infinite. And you can do all these different things. It goes through an
30:13 elaborate argument to a very careful argument on that. But he does make that assumption. He says, well, let’s just
30:19 assume that you can have these infinite numbers of dimensions. Now
30:25 what happens though is you want to be careful that you didn’t make an assumption in your math that doesn’t
30:32 correspond to the universe. And the assumption in this case is is it easy to create new dimensions or is it hard? And
30:39 in the actual physical world spatial dimensions are fairly precious. You can
30:45 have states. You can have an enormous number of states. But this idea of these orthogonal dimensions that we see in three-dimensional space that’s a pretty
30:52 unique phenomenon and even on generalizing it to four dimensions or five took a lot of mathematical work
30:59 some Hamilton did some fascinating work with hyper complex numbers. So you
31:04 got to you got to look carefully at these things. And neither of these
31:10 two people, Von Newman from a computer science viewpoint, Everett from his background seem to have and this this
31:16 this bothers me about reading through these. I never saw a clear understanding from either of them that when you talk
31:23 about creating a universe that you have issues of light speed. In other words,
31:29 the universe is very, very stubborn about this point. You don’t
31:35 change things until the light signal gets there. Nothing alters, nothing
31:41 modifies. And entanglement doesn’t affect this because that happens later. So until you see something, it ain’t there.
31:47 It does not have an effect. The light cone limit applies. And this is something you don’t see in the raw

31:54 version of the Hilbert space analysis. And that's a problem because if your entire computational model is based on
32:00 Hilbert space, but the Hilbert space does not reflect reality, which I will
32:05 argue strongly that it does not in this case when you're talking about infinite numbers of universes. It does in some
32:11 other cases for small local things that makes a good approximation for local quantum mechanics. But when you try to
32:17 do these other things, it gets really tricky in a hurry. Now, here's the just a statement from Hilbert just to
32:24 show he's talking about it. He has Hilbert spaces I mean from
32:30 his ever statement about the use of Hilbert spaces which he then got from von Newman who had done earlier work and
32:37 of course von Newman had borrowed the work from the great mathematician Hilbert. So you get this
32:46 idea that you have this analogy but can you actually build a physical system and
32:52 be sure that that analogy holds. It's always good to be careful in mathematics that you say yes I can make the
32:58 abstraction just like in programming I can program anything I want to. Does that mean that it corresponds to what
33:04 actually is happening with the system that I'm dealing with? And of course, in many cases, it's very easy to make a
33:10 complete mistake and do something that is not accurate with that. On physics, it can be more subtle because
33:16 some of the equations are giving you deep insights. Other ones may be a little bit of a red herring. And when
33:22 you're talking about Hilbert spaces for universes, you better be careful about the red
33:28 herring effect. Thing I mentioned earlier, when you accelerate, this is just such a simple principle. You
33:34 get these concentric circles, but you can't get outside of them. Whatever happens, this is a light cone. Whatever
33:39 happens there, you accelerate a spaceship, the rest of the universe doesn't care. It just doesn't care. And
33:47 if you're saying that you're going to create an entire universe based on what you did in that one little rocket ship,
33:54 you need to be very careful about what you're saying in a physics level because there is not any evidence that anyone's
34:00 ever come up with from any experiment that you can violate the speed of light in this fashion. And again, entanglement
34:07 is a separate issue because that happens inside this circle. You've sort of plowed the ground and then you have this
34:12 correlations inside of that. But until that circle reaches some distant point in the universe, you can't see it.
34:19 It doesn't do anything. It doesn't mean anything. It doesn't change gravity either, by the way, because the gravity
34:24 is all inside of that circle. This is a very hardnosed principle of how the
34:31 experimental universe works. when you apply that to quantum wave functions and here's where I will will

34:38 deviate strong I wouldn't call it a deviation I'm just saying this this is what we actually see if you're doing
34:44 quantum cryptography people do this so it's not exactly a fantastical
34:49 origin you can't get quantum encryption correlations until you've
34:56 sent the wave packet to the other party at the speed of light surprise surprise that's an example of what I'm showing in
35:02 this figure here this is where you say you're actually bound by the light cone for your wave function. So is
35:10 that wave function universal? No, it's not. Does it expand? Does it extend across the whole universe? No, it does
35:17 not. Emphatically, it does not. You can create a mathematical abstraction which
35:22 in which, your mind, use that does. But if you try to put that in any kind of experiment, it will not work because when
35:29 you try to get outside that light cone as you know if you're trying to do
35:34 quantum encryption you have to send the data packet between the sources you can't just get an entanglement out of
35:40 magic you have to actually send them a photon and then the photon is entangled after you send it. How do you send the
35:46 photon at the speed of light? So this is this hard-nosed principle and not one
35:52 that you see well reflected when people use the Hilbert approximation and
35:58 then this bleeds over into the whole issue about if quantum computing expects the universe to involve the entire
36:05 universe some large thing that's not going to work that way not experimentally. We have no evidence that
36:11 that can happen. So you can't delay this pre this this uh
36:19 delay issue you and again you have that issue about entanglement yes but that's internal the reason the Hilbert space
36:27 model is so effective locally is that local quantum computing which the speed
36:33 of light speed of light delays are very, very small it does work well works
36:38 beautifully so you can put up a whole series of possible states of a
36:43 photon of an electron represented in Hilbert space. You can model the progress
36:49 of the wave function or the change in the wave function very well with that. So the Hilbert space model is
36:54 fantastically effective for local. But as soon as you go to universe scale
37:00 things, you cannot let the math dictate what happens to the universe because
37:05 universe does not work that way. You cannot delay. You cannot ignore the delay issue.
37:13 Now here's another thing. Most of us when we think of orthogonality you know like three
37:18 dimensions like three axes straightforward it's obviously a given is it? Is it really? Because
37:25 mathematically when you actually construct orthogonality that is right angles
37:31 in any kind of physical system in which you want to have some kind of separation isolation of signals they go in
37:38 different ways. just talk to anybody who does radio frequency engineering. They'll tell you

37:43 there's a lot of work you have to do to achieve orthogonality to keep your signals separate. It's not magic. It's

37:51 it's hard work and you have to follow some very rigid principles and you have some absolute capacities that you must

37:57 respect. You can't get orthogonality for free. And yet when we're talking about

38:04 three spatial dimensions, we tend to assume that yeah, there's just gibbons. Yeah, you know the uni that's just the

38:10 way the universe is just the way it is really because when you start looking at

38:15 things like speed of light delay you need to start being careful that that that universe example is one where I

38:21 would point out that is an example. You can't make your universes orthogonal if it takes several billion years before

38:28 you realize that you're supposed to be different. So that's not captured by the by the Hilbert space model.

38:36 So the way that this it's interesting the way this works and I' I've heard it

38:42 expressed more bluntly on some YouTube presentations but if you go through if

38:47 you go through Everett's work and the way these functions the you get these

38:52 tensor products that go together effectively you wind up creating kind of unique frequencies it's not frequency is

38:59 a bad word in this case but the but the analogy in terms of the isolation is still good which is you create a set

39:05 of unique relationships that then kind of bind that that that group of matter

39:10 of this group of particle representations to each other and that separates you from the rest of the

39:16 universe. So that means that you have to construct your orthogonality

39:22 and when you try to construct your orthogonality well and here's the example okay I saying that the radio

39:28 frequency engineering you know this is this is basic radio frequency 101 so you

39:34 get one radio frequency got another one as long as they are ideally not even

39:39 multiples of each other you can get some separation so you get an isolation which

39:44 is in mathematical structures is really the same thing as right angle. You know

39:50 you talk about separation right angles very much the same thing. So this is how people actually construct orthogonality.

39:58 And the nice thing about orthogonal the reason it works one way to think of it is just think of it as a lock and key

40:03 mechanism because when you have exact matches between your radio receiver and

40:08 RA and Ed Red's radio broadcast where they'll just match up peak for peak then

40:14 all of a sudden it reinforces and you get this powerful signal coming through. So, and you can go all by the way this

40:20 there's a deeper quantum mechanical QED Feynman type representation of this is just lovely. But the point is that

40:28 you can get this enhanced signal just essentially by a key match. Say I'm I'm only going to let this kind of thing go

40:34 on at the same time. Well, then the other guy, he doesn't see it. He sees only little tiny samples of it. So,
40:42 the guy in the green frequency, he doesn't he, as far as he can tell, nobody's there. It's it sounds like it's
40:47 empty. and you don't wind up getting that much. A little aside on this, this is how large language models
40:56 work. Did you know that? that's interesting because if you go back to the literature back in the
41:02 2010s, you go back to that period where
41:08 they really putting these papers out, they talk about these pseudo dimensions that are created these orthogonal
41:14 dimensions and then these axes interact very much like a Hilbert space. So uh
41:20 the stuff I'm saying here applies to a surprising degree to the internal structure of these large
41:28 language models. So I think that's just fascinating. I did not know that when I first started diving into the
41:33 language models and I was intrigued by how that works and also by some of
41:38 the possibilities because you can you can leverage that concept. So the universe idea is the same thing. You've
41:45 got to create a frequency. You've got to create a unique identifier for each of these universes and it has to be it has
41:52 to be built because you don't know what's going to happen. You can't assume that an infinite number of universes
41:58 already exist or at least if you do it's kind of like at a certain point like what's the point you know you well you
42:03 still have to access them even if you assume they exist you still have to create a set of physical experiments
42:09 that can access that and then you wind up saying the same thing you say like well I still got to build it I've still
42:14 got to access this different universe so quick cheat on foyer
42:20 transforms is if you have a spike it matches everything. So, it's just
42:28 you just like a little hat there. You put the little put the little spindle up there and say, "Well, what frequencies
42:33 match with that?" And you say that all the frequencies match with that. This is a frequency chirp. This is a frequency
42:39 spike. So, when you have a sudden sharp spike of energy, it matches all frequency. That's why lightning is so
42:45 bad for radios because it just it hits all the frequencies at once. And as a
42:53 result, you need to have a similar type of concept for your universes. But the
42:58 one that we're in right now However you might want to define it, but the one we're in experimentally, it's going to
43:05 match up with everything until you get a good frequency separation between those different universes. And this is the
43:12 stuff that is not addressed in in in Deutsch in Everett's model and Deutsch's model. It is sort of
43:18 addressed in in Everett's model. I shouldn't say that, but it's not addressed in enough detail to say like
43:24 how does his work dynamics? He doesn't cover the dynamic side of this. he just uses that static overly simple

43:32 Hilbert assumption and says, “Oh, they’re all there.” Well, no, they’re not all there. That the physics, it’s not that

43:37 simple. You have to pay respect to the way the universe works. And this leaves you in this situation.

43:44 I got a little side note here. If you talk about quantum uncertainty, quantum uncertainty is 100% a direct

43:51 reflection of this same spike relationship because when you have a position in XYZ space that’s a spike,

43:58 the frequencies go crazy. They just go boom, you know, they go off this way. So the momentum representation of the same

44:04 particle becomes extremely broadband. And vice versa. When you have an extremely precise momentum frequency for

44:11 an object, an actual object moving through real space, what you find out is you don’t know where the object is

44:17 anymore. You lose it. It’s gone. It’s, well, it’s not gone. It’s just turned into this big nebulous area of

44:24 wavelike behavior, which if you do it the right way, you can find the particle occasionally, but you can’t

44:30 separate these issues. Fourier transforms the uncertainty relationship are and this is some of the

44:36 stuff was recognized very early in quantum history. So just fascinating little side note on that.

44:44 So you can’t do this because it takes a while to propagate and the time you get

44:51 is just beyond belief. If you’re in a lab and you’re doing Hilbert spaces on a

44:57 little lab experiment, push, you know, few nanoseconds, everything’s fine. If you

45:03 try to do that same split idea to an entire universe, it takes 10 to hundreds

45:09 of billions of years just to touch the other the other parts. Why? Because that

45:16 absolute limit that you only expand the light cone and you can’t touch anything else until that light cone gets there.

45:23 So even worse if you looked at those signal models I said if you only have

45:29 one instance. Let’s assume that you waited a 100 billion years. You got your little

45:36 particle switch there, it’s propagating outwards, it’s touching everybody, it’s all relational, just like

45:41 every described so it goes out there and touches everything else and then you say okay finally I got my two universes and

45:48 you say and it took you how long you find out that it took you hundreds of billions of years. And then you say,

45:55 “But what did I actually get for that?” You said, “I have two universes that still look exactly identical.” Why?

46:00 Because of that same figure I showed before. You still have an inability to reproduce, to find a template, to find a

46:07 lock where that frequency becomes unique. So what do you have to do? You have to replicate your universe, oh, a

46:15 few gazillion times. So, it’s not just one repetition of the universe in a

46:20 mathematical sense. You have to wait long enough for the signal of these different universes to be completely

46:26 unique and for a tiny change in a big universe you know I mean obviously pragmatically it ain't going to happen
46:34 but in terms of conceptually you need all those repetitions you need to design
46:40 a definite lock so that your universes can be orthogonal to each other I don't think ever
46:48 I don't think he got that point I don't and I could be wrong. I mean I would need to I think I need I've need
46:54 to look most of he's got two versions of his thesis. I'd like to think it's
47:00 there somewhere, but I sure haven't seen it when I when I looked at. So I think you just kind of kind of missed that point that you also have to have
47:06 this repetition. So another
47:12 I just can't stop here. Okay, that's not the only problem. In fact, this to me is this is the killer. This one is just it
47:19 just floors me is remember I said that his wave function, the wave
47:25 function that Everett proposed becomes very, very complex very quickly starts having
47:31 all this coding on top of that that wave frequency is still nominally energy just
47:37 like we see in our universe it's also infinite it's also mass because the more
47:44 energy you have the more mass you have that doesn't change. And one of the things that people don't realize about
47:51 these many-worlds ideas is that every one of those universes is going to have a mass. And the mass is going to
47:57 correspond to its complexity. So what happens is if you really take
48:02 this seriously, you have to do one of two things. and I know one physicist who took the choice of saying,
48:09 "Well, mass stays the same." And my response back to him was that if the
48:15 mass stays the same, you have just created magic because finite energy has
48:20 finite resolution. We have never seen any form of energy where that's not true. So if you say that the energy of
48:26 one universe is all you need, then how did that energy suddenly become infinitely information containing?
48:33 Information is expensive. Information is not cheap. Information requires effort.
48:39 just saying it's going to appear magically. It is just that it's just it's a statement of I want it to be that
48:45 way. It's not something we see in any kind of phenomenon in nature.
48:51 Information requires work, requires matter, requires design to make it
48:56 stable. You don't get it just from nothing. So if you actually follow
49:01 through on this whole ever scheme, it either winds up with magic energy or
49:07 instantaneous gravitational collapse. No other options. So you have to
49:12 choose one or the other. And that alone forget all the other things I just said.
49:18 That alone should preclude this because we just don't see that. We don't want
49:24 it. We don't want to convert energy into magic into some kind of strange quantity
49:29 that can just hold infinite information for no reason other than the fact we want it to. Well, we wanted a lot of
49:35 things, but that doesn't mean it's necessarily what the universe does. Or you can wind up with this instantaneous
49:42 gravitational collapse as energy is created. And by and ever did have

49:47 some funny little statements he said about energy. He seemed to recognize there were some interesting energy issues, but he never really addressed
49:52 it. So with all that and I'm already over time
49:58 so I'm going to go quickly through this nature of quantum observation.
50:03 everybody tells you that nobody knows what quantum observation is. All right.
50:09 I'm going to give you a suggestion that there is a very simple thought experiments in which you can say
50:15 whatever quantum observation must be there has to be some version of it going on at very low levels because if I put
50:22 two helium atoms next to each other in deep space very cold just sitting there next to each other and I look at the
50:28 wave function which you can do you can do things like reflect the wave function so you can there's ways like what they
50:34 call weak measurement where you can see that yeah that's a wave function that the helium the helium pair has formed a
50:39 wave function. But if you look at that wave function, the consequences of it are that the helium atoms can grow
50:46 indefinitely far apart. Essentially, they have separate overlapping wave functions and they don't really care
50:52 much about each other. They just go like, I don't care. I don't care what the other guy's doing. I'm not looking
50:57 at him. He's not looking at me. We neither one of us cares what's going on. But then you look at hydrogen, which is
51:03 very similar to helium, except it has this little thing called electromagnetic bonding. has a little bonding issue
51:09 going on here. Well, not just electromagnetic, but you have this fascinating thing called bonding in
51:15 which effectively the atoms accelerate each other. They, you know, if one of them tries to get away, the other one
51:21 says, "No, no, no, no. You get back here. Get back here. I'm going to pull you back in." And that pulling part is
51:27 important. So, if you look at this wave function, even though you have two very similar scenarios on the startup, you
51:33 can even put the hydrogen atoms separated by a fair distance. So they don't interact immediately but eventually they will eventually the wave
51:40 function will say oh I want to do this and want to get together. So you wind up that they have no distance. The quantum
51:47 wave function never separated the two. They didn't behave as separate quantum items. the way to interpret that and
51:56 this is something I point out that every case in which you talk about quantum
52:01 wave collapse even if you don't like the terminology you will find there is always an aspect of acceleration
52:07 involved there's a thing where something bumps into something else why would that be important because what is observation
52:14 observation is knowing where something else is well what happens if you bump into something you know where it is you
52:21 both said oh okay you're that way and the other you're that way. So this is an
52:26 incredibly simple definition of observation which is to say that it's nothing more than acceleration

52:33 and you can say that no I want a more complex advanced human consciousness

52:41 whatever you can get all sorts of things but you always want to ask questions says yeah but is that ever not true and

52:48 the answer is it’s never not true when electron and proton bind together they’re constantly accelerating each

52:55 And they’re always saying like, “We’re going to stick together. I’m I know where you are. You know where I am.” And

53:01 it stays as a relationship that is not subject to quantum dissipation. They

53:06 can’t just suddenly drift away from each other in a quantum sense because they’re always looking at each other and every

53:12 time they look at each other, “Okay, I can’t leave. Okay, I can’t leave. I can’t leave.” So that leaves you this

53:17 interesting idea though that wave collapse is not what we think it is. For

53:24 one thing, it’s not always just atoms. It’s not always just particles. If you have a solar sail on a on a satellite

53:30 and that solar cell reflects some light back towards the sun, you get momentum. Momentum is measurement. This is no

53:37 longer an abstract function, but it’s still a wave. So what you did is you

53:42 collapsed an enormous solar wave for some photons and made them into a tiny little new wave that goes there. When

53:49 you hear most discussions about detection, you won’t see these med medium scale cases, but they’re there.

53:56 You know, we have little partial when you get up in the morning, you look in the mirror, you’re collapsing wave functions, but you’re not collapsing

54:02 them all the way down to the atomic scale. If you did, you wouldn’t see anything in the mirror. If you look at a

54:07 a painted black wall, then then you’re collapsing wave functions all the way down to the atomic level. But if you

54:13 look at a mirror, that’s a whole different ballgame. You’re collapsing wave functions in a very controlled

54:18 fashion only to a certain degree where they still look very much like waves, but that wave is now part of you. We do

54:24 this in mirrors all the time. We don’t think anything about it. So my point is that we don’t we’re

54:31 making abstract observation to abstract. Why is that important for quantum computing? because it’s part of the argument. One of the things that I think

54:38 Everett astutely pointed out that if you go with this hierarchy concept of observation which was the traditional

54:45 viewpoint at his time and Wheeler loved this. Wheeler I’m sure he got this from Wheeler. Wheeler loved this idea that

54:51 there has to be an ultimate observer. So you get you get very theological if you started doing this. So you know get

54:58 something has to be observing the universe. and Ever just said, “No, no, yeah, that that that seems like

55:04 a a bad way to do this.” So, he wanted to create this relational hierarchy where he didn’t have this ultimate

55:10 observer. And this is one of the cases where I found like okay, I see where you’re going with I appreciated his

55:16 point more than I realized when I do that. so, he made it into a
55:21 relational situation. So, why would bumping be important?
55:27 Because it’s special relativity. when you go into a different
55:32 inertial frame and that happens because you got bumped. It could be a small
55:38 bump, it could be a big bump. So if you want to know where nonlinear behavior pops up in these things, look at the
55:44 frame issue. When you have inertial frames, inertial frames are ma amazing things, but they’re always local in
55:51 terms of what you can measure. You can you extend the massive forever. That’s fine. If you want to, fine. But you
55:56 still have to have clocks. Einstein noted this back in 1911 when he came up with the Twins Paradox. He said
56:03 you still have to have clocks. You still have to have rulers until you get the clocks in sync. You can’t measure
56:08 anything. So don’t you know he’s he was kind of saying like you know it it’s you can’t do it without the matter. So
56:14 he’s making a very solid connection between that and how these things work.
56:19 So inertial frames when you have them have special properties. quantum field
56:26 theory works. certain behaviors work. we should view these almost like like
56:32 special machines that we get into. And this is why there’s an important difference. If you accelerate things,
56:37 you’re changing things in terms of an inertial frame. And I would I would suggest that inertial frames are
56:42 critical for understanding at a deeper level how the quantum world works. Anything that changes a quantum frame in
56:49 the quantum world, changes an inertial frame in the quantum world is part of this mathematics of what’s going on. So here’s three different models.
56:56 You got Wheeler. Wheeler was one more than anybody I know of who advocated
57:02 that everything is a hierarchy. So, you know, he did propose an idea like eventually there’s this he had some
57:08 he may have used the omega point or something like that for in a different way from how it’s used now. But he
57:14 came up with this idea you know eventually the universe observes itself or something like that. So he is very, very wrapped up this idea of
57:20 hierarchical observation. Now Everett did an interesting different thing. He said,
57:26 “No, no. Everything you do is a relationship between these two. Everything is a going this way, going
57:33 that way. You’re looking at each other.” And you know, at a certain level, it comes out to be the same. But there’s a
57:39 little twist to however it did. The twist is this. Every one of those observations in his relational model
57:45 then grows into an entire universe. At least if there were any qualifiers on
57:50 it, he sure doesn’t show them. He just talks about branching. I mean he just goes straight for the Hilbert model. So
57:56 he creates a universe with these relational things. So you have you know you have molecules that are relationally

58:03 interacting with each other and creating a new system and you have people and you have worlds and all this

58:10 stuff but every one of them creates a new universe. So let me make a humble suggestion and write not so humble

58:16 whichever take the Everett model but get rid of the universes because why do you

58:22 need them? you don't I've got a whole set of presentations on special relativity on the finite nature of

58:29 special relativity. If you pay attention to the history, you pay attention to the history. A lot of the paradoxes just go

58:34 poof. They just disappear. If you insist on saying, "I don't care what the history is. I only want to look at the

58:40 the result." Yeah, the results are the same. But if you want to connect it to the rest of the universe it came from,

58:45 you better pay attention to the history. So, same thing here. If you pay attention to these histories, you can

58:51 have these re these observations going on at multiple levels. You know, you have these different things where like

58:56 the entire universe in a sense of like the cosmic

59:02 microwave background sense that there's kind of a defined frame there and you

59:07 have these other shared frames. So you you're winding up creating special relativity frames. So I like the part of

59:14 the relational aspect of whatever it did. I just see no need for the universe

59:20 because if you keep it local then it all becomes dependent on the speed of light. So what's the problem? Now you're

59:25 creating something that's kind of arguably a little different but it it's still local and it obeys the laws

59:32 that you want. So three different ways of looking at the idea of observation. Finally the part I'm going to wrap it up

59:38 here and I'm already late. quantum computing what I want to emphasize is photons. U

59:45 Feynman I'll mention this one. This is straight from what Feynman's QED book. Light is weird. If you look at the

59:52 photon perspective, light doesn't even have to go in straight paths. And they're just some marvelous examples of

59:57 that where very counterintuitive examples of how light can even go at a right-hand angle. it can

1:00:05 go over the edge of a lens and then come down the other side. The light doesn't care. it does not work the way we

1:00:11 tend to think intuitively as a little ball flying through space. actual photons are much more interesting than

1:00:17 that. You also have things called lensing and lensing produces these fascinating effects nicely described in

1:00:24 the book QED. I recommend the book highly. I've also done two talks that I'll be giving a third talk on this idea

1:00:29 of QED and how all these little arrows of amplitude of little probability angles how you can get them

1:00:35 to add up and how you can get them to give a particular result. If you’re thinking about quantum computing, you

1:00:41 should think about that because these are computations and they can be quite powerful computations. They can say I

1:00:48 can look at a whole number of things and I can come up with an arrow that tells me this is the result and it can say it

1:00:53 with extreme firmness. This is not the fuzzy kind of stuff that you get when you’re looking only one photon that

1:01:00 bounced off of some distant object. So there’s a hint here that the simple idea

1:01:05 of lensing which is a remarkable phenomenon that does not destroy the currency of the quantum wave has

1:01:14 an ability to do it. But this is foyer transform turf. This is this is not this is not this not a tensor analysis

1:01:21 stuff. This is much more photons. I’ll give some examples. There’s fascinating things where just the fact that we see

1:01:28 anti-reflection codings in our glasses require that light have a certain ambiguity in time. Now, isn’t that isn’t

1:01:34 that interesting? you can’t do it unless the photon can see itself two n Well, this is for a large this would be

1:01:40 a very thick glass. but you can’t do it unless the light can’t see itself until it can see itself a nanosecond a

1:01:47 couple nanoseconds later. Try that with a baseball. You know, you can’t do that.

1:01:52 And yet this is fundamental to just such everyday phenomena. Every time you see a colored soap bubble, you’re

1:01:59 seeing this effect. You’re seeing photons reflecting back in themselves and kind of change their mind about

1:02:05 where they want to go based on what they see themselves doing in the future in the past.

1:02:11 So lenses make a good possibility. exon lensing by the way is used in

1:02:16 photosynthesis. they call it a quantum effect. To me, I would just say no, this is just

1:02:21 fiber-based. I always like the simplest term. If it’s lensing, call it lensing. It’s a lens. Yes, you can call a lens

1:02:28 quantum because they extremely quantum. But don’t, you know, don’t over you don’t want to overblow it. But what you

1:02:35 can do with that lensing is just remarkable sometimes and I think we don’t explore it. For example, single

1:02:41 photon going onto a digitally controlled 2D mirror array. You bounce it off,

1:02:47 you get signals. And each photon, this is what’s weird. Remember I said the thing earlier, a photon can have a lot

1:02:54 of information in it, but it can only give you a tiny tiny piece of it at one time. This is an example. If you if you

1:03:00 reflect a photon off of a complex structure, that photon, if you sample enough examples of that photon, each

1:03:07 photon somehow knows quote unquote that entire structure that it saw, but it can

1:03:12 only tell you one little pinpoint at a time. That’s why we don’t see the whole structure. But think about in terms of

1:03:18 the information content of the photon, the relationships, we are missing some aspects of what's going on with us and
1:03:24 and something that we need to understand better. And that brings up to an
1:03:30 interesting paper from 1949 by Wheeler and Fine before he went off on QED,
1:03:35 and Wheeler was more dominant in this. He talked about, okay, I'll just skip over that one. He talked about how
1:03:42 Maxwell's equations for electromagnetic waves go both ways in time. So, you
1:03:47 think like, well, no, no, they don't. They just go forward. We all know they just go forward. Well, that that has
1:03:53 puzzled people for going on a couple centuries now because Maxwell equations
1:03:58 from the 1800s did say that the waves could go just as easily backwards in
1:04:03 time as forwards in time. And yet the universe we see does not do this and uh
1:04:11 that is a stumbling block for many interpretations. You have just there are
1:04:16 hundreds if not thousands of papers written about this single silly little thing that Maxwell's equations puts
1:04:22 electromagnetic radiation photons going both directions in time and Feynman
1:04:29 with Wheeler actually mostly Wheeler in this one. Wheeler pointed out that you could have and I think I may have a
1:04:36 slight out of order that you could have an interesting
1:04:41 topology problem that the photon You can have a photon going backwards in time, reflect off a mirror, and hit
1:04:48 yourself at an earlier point in time. And I like I said, I think that slide was out of order. Um,
1:04:56 so this gives you some strange issues about how photons work.
1:05:06 And the strangest issue is that the photon has a pairing reaction where this future impact of something where a
1:05:13 photon goes in the hits something in the future. It also comes back to now and
1:05:18 gives an actual physical effect called a retro a recoil and then that recoil is measurable at this end. So like if you
1:05:25 shine a laser at the darkest part of the sky, you will get a measurable kind
1:05:31 of a rocket effect from that photon. And yet the actual construction of Maxwell's
1:05:37 equations only allowed that if you have a photon coming backwards in time. This was the topic of their paper. And they
1:05:44 went they had a whole series like for several years they went on about how you measure the recoil. And recoil by the
1:05:50 way was and actually still is a bit of a mystery because you go like yeah that
1:05:56 shouldn't happen that way. It looks like something's coming back from the future and banging into it. Here's the actual
1:06:02 diagram from the Wheeler Feynman paper. And I cleaned it up a little bit. The diagram was just almost illegible. And I
1:06:10 think that's unfortunate because I think this is a very cool pair of diagrams. Wheeler was saying like, well,
1:06:16 it's one thing to talk about light going backwards in time, but could I actually measure it? Could I actually create a
1:06:22 paradox? And he came up with a clever little device that you see on the left and which yeah, it says like it looks

1:06:27 like I could create a paradox. And then he did some further analysis in the second figure and it goes on to say
1:06:34 yes but what really happens what really happens is a continuous kind of
1:06:40 negotiation between the two. In other words, you will either get the event or you won't get the event but the event
1:06:47 depends on what's happening in the future which is really wild. We don't
1:06:52 think of light as coming back from the future and influencing what we have now. But every time we talk about this recoil
1:06:59 effect in effect that's what we're saying and Feynman and we now Feynman
1:07:04 went on did his QED theory which took some additional assumptions and created a very mathematical version of this but
1:07:11 the bad side is I think we lost something there because this version of
1:07:16 it which is more dynamic than the QED thing which is a very static model says here's a point here's a point calculate
1:07:22 the probability from here to there that's a very static view on this Wheelers 's version was not that static.
1:07:28 Wheeler's version really was trying to say like, you know, can we create a paradox? And what happens? Is there
1:07:33 a negotiation? And his conclusion was that yeah, there's a negotiation. Now, here's what that other diagram was a bit
1:07:40 out of sequence after showing that one. If you run through this, here's the
1:07:45 figure that you come up with. This this is what fine what Wheeler and Feynman were talking about is this idea of waves
1:07:51 coming back in future. you see this thing where you you've got a you got
1:07:57 this I think my mouse shows up but you've got this this wave going
1:08:02 backwards bounces off a mirror comes here and then changes and courses the
1:08:07 path to do path to do a certain thing that didn't do before and that's
1:08:13 that's an interesting way of thinking of time in fact it's so interesting that I
1:08:18 would argue that we need a more complex model of time this is a figure I did just a couple weeks ago and uh
1:08:26 continuing of interest, but this captures better in what I've done so far about this is we have two kinds of time
1:08:32 going on here. When you have material objects like ourselves where we have this continual collapse interaction
1:08:38 between the different parts, we go one way in time, you know, we just we're stuck because anything that's
1:08:44 complicated and gets stuck, we go that way. Photons don't do that. And this
1:08:50 is why it's important to see it. When you talk about photons going backwards at the speed of light, well, you have to
1:08:56 have a metric, a dimension by which you can make such a statement. You cannot make the statement. You actually
1:09:02 see this in some physics textbooks. They'll make clumsy statements about, you know, the seconds per second. And
1:09:10 and that's really addressing exactly this issue. The seconds that you're using are
1:09:16 actually the ones of the causal time, the clock time, the ticking time that we have here. as part of material objects.
1:09:22 Electromagnetics don't respect that. And that sounds like a wild statement, but at some level they

1:09:29 just don’t. They just they don’t see the universe the same way we do. So when you’re talking about a single dimension
1:09:35 of time, you need to be careful because you got time going this way, you got time going that way for some types of
1:09:41 radiation. You got other things going this way, which winds up being the dominant one. But then we wonder why
1:09:47 it’s so hard sometimes to what say whether you know are we in a predestined
1:09:52 kind of structure in which the future’s already determined or is it something you know more chance. This
1:09:59 is kind of a mixed model. It’s saying that that it is and it isn’t. Some things depend on things very far in the
1:10:05 future other things don’t. So, where
1:10:10 this shows up at a should bring that into a smaller level. If you look at the papers that Hopfield to in my mind
1:10:17 should have gotten a Nobel Prize for, although they focused on the other one, which I think he should not have gotten a Nobel Prize for because he made
1:10:23 a mistake and he did. He just he just he misunderstood part of what he was doing
1:10:29 based on the earlier interesting work he had done here which was that that biological molecules have some form of
1:10:36 quantumlike computing that they do all the time they don’t care this is
1:10:42 just standard operating procedure there’s a whole literature about this starting with Madden and back in 1980
1:10:49 about how molecules compute what they do and the fact that the fact that we
1:10:54 have so many computers have to be dedicated just to say what one molecule does should be a hint. It’s saying that
1:11:00 that one molecule is doing a lot more computation we’re giving it credit for. So these are a couple papers by
1:11:05 Hawfield. They’re mentioned in his Nobel prize and I’m glad they were mentioned there but I wish they had uh
1:11:10 given him for this. so quantum computing in one universe to wrap it up
1:11:17 with this. Yeah, I’m over time by half an hour. there’s no such thing as
1:11:22 multiverse. I just No, it doesn’t it
1:11:28 there’s I mean you can you can hypothesize it and whichever but it I mean experimentally
1:11:33 even from Ever’s viewpoint there’s no multiverse that you can observe even from Ever’s
1:11:41 view. So and experimentally we spent decades pursuing this wave function from
1:11:49 the multiverse that almost certainly well I’d be more from a multiverse
1:11:54 it’s not there there’s just this is a hypothesis it’s one that collapses into
1:12:00 gravitational instability instantly if you take it seriously it has all sorts of the other problems I talked about the
1:12:07 the ever hypothesis is just a very it was an interesting hypothesis but it is a failed hypothesis in the end because
1:12:14 it violates too many aspects of what we know to be correct about physics
1:12:20 especially like in you know information is not free so the other idea is
1:12:26 collapse is the basis of now that’s a completely contrary recom way of stating I’m saying that we

1:12:33 don't notice quantum collapse because we swim in it like fish it is so prevalent
1:12:38 in everything we do every motion we say everything we push when everything we touch things together this there's an
1:12:45 enormous amount of quantum collapse and observation going on but it's a two-way thing it's a balanced symmetrical thing
1:12:51 so you don't notice that much you don't invoke all sorts of complexity gets interesting when you push it to the
1:12:57 farther limits but we don't see it because it is just there all the time another statement is quantum computing
1:13:03 is more common than we realize and I think we should dig into that more I think those papers you know we're
1:13:12 a good starting point but but they didn't really we need more work in
1:13:17 that another statement I would make is foyer transforms are a lot more
1:13:22 important than tensor math for exploring this area you can do great things with tensor math but you're essentially
1:13:29 following an extremely continuum type viewpoint the foyer transforms are
1:13:34 inherently remember I said quantum uncertainty comes from foyer transforms foyer transforms are inherently more
1:13:41 realistic about the limits of what we can apply the math to and that's one of the reasons I like them. Tensor math can
1:13:47 tempt you down a road of hyper precision that is not reflected in any
1:13:53 actual experiment. So for transforms are way of keeping and they're also powerful computationally lensing is a
1:14:00 good example of you know what can we do with lensing I think the really interesting challenge on future quantum computing is that if we don't
1:14:08 have access to parallel universes we do have apparently and this is work going back you know
1:14:15 over half century now we apparently do have access to the future and the past
1:14:21 we knew we had in the past but we also have access to future somethings that we don't have a good
1:14:28 understanding of and yet that future understanding that future impact seems
1:14:33 to have something to do with how we compute now. So if we can understand more about how does this looking into
1:14:40 the future with electromagnetics and understanding more how that that operates I think that's where we can
1:14:47 find some some really good insights to new approaches to quantum computing. And with that, I'm almost exactly half an
1:14:54 hour past and I will stop now. Yay.
1:15:00 Thanks, Terry. Okay. Sorry. Sorry about the extra length. You were about 12 minutes over. We
1:15:07 handed it over to you late with all the announcements. That's true. So, you're No, you're
1:15:12 within bounds here. But I would also like to turn it over to the audience for
1:15:18 questions. And if nobody has any questions, I have
1:15:24 at least a couple. Dennis, I want to sort of have a comment almost an aside. There was a
1:15:31 NOVA, the PBS program, the science program called Parallel Worlds, Parallel Lives. It talked about Everett's

1:15:40 because he was at Princeton and it talked about his personal and his professional life and it talked and it
1:15:45 goes through the eyes of his son who's a musician who's goes by the name of E. And if you get a chance I would Google
1:15:52 it parallel worlds, parallel lives, Nova PBS. It's an absolute wonderful watch.
1:15:59 And there's the last scene where he's sitting on the bench in front of the Nassin. It's just chilling as if
1:16:07 we're the whole entire show. Okay.
1:16:14 Can you put that in the comments? That sounds fascinating. Yeah. Right. Yeah, I can.
1:16:20 It's kind of I have a question. Yes.
1:16:26 Okay. So these astronauts who recently went out into outer space, they
1:16:32 went out, they went really, really far away and then they came back and then
1:16:38 they slowed down by going around the earth a bunch of times until they finally landed. So the question is based
1:16:46 on some of the things that you've said did they get older when they were out there than us relative on the earth or
1:16:54 did they get younger than us or are they the same ages as as they were? That one that one actually gets
1:17:00 complicated because it's a combination mostly they should be a little bit younger because of the acceleration they
1:17:06 went once you have once you have the acceleration again if you use embedded inertial frames instead of going like oh
1:17:12 each one's unique. Yes, they are. But you have to understand there's a history. And when you understand the history, say
1:17:18 the person who got accelerated always has the slower clock. So when they went out there at high speed, went around the moon,
1:17:23 yes, they had a substantial slowing of the clock. This is exactly what Einstein predicted. And when he predicted it,
1:17:29 people thought he was a little as as with most of his papers, they thought he was a little crazy, but he was very
1:17:36 specific. He said like, you know, this is what's going to happen. And people said, "Oh, come on. This can't be real, K. You can't actually detect this
1:17:43 and Einstein. Yeah, you can. I don't doubt that they have clocks. those
1:17:49 ships I somebody has data on that. I they must. Yeah, they must have. That's that was my guess was that they
1:17:56 experiment with atomic clocks. Yes. Yeah, that was my guess was that they got younger. But yeah, I definitely
1:18:02 Yeah, nobody has said anything about that, but you're I think you're correct. I think that you're you know my
1:18:10 thought was in agreement with if you didn't have an atomic clock of extreme precision on that trip you were
1:18:16 you you know that was stupid that would have been stupid but they're not telling us about
1:18:21 it. How can you miss that opportunity? Right. Right. They couldn't really do that with the earlier flights. They just didn't have
1:18:27 the I mean they didn't have the machinery. They didn't have the clocks. They didn't have the capacity. But now

1:18:33 Oh yeah. Yeah. And, of course, the thing where they missed they were out of the gravity well. So that actually puts
1:18:38 them in the other direction. So that's why I say it's a complicated equation because you have to add it together. But
1:18:44 um okay. if you get accelerated, you know, and this is the simpler answer. You'll see all sorts of complicated answers.
1:18:51 Once you accelerate, no matter how you measure it, if you run across another clock, you will be slower every single
1:18:57 time. And that can go down to the atomic level. So just say it's slower because it you know instead of going
1:19:04 through all these prime mutations inertial frames are embedded in each other. When a train goes
1:19:10 relativistic velocity, it's still on the track! The track is still using the clocks that
1:19:15 was using before. That's right. And there's actually a nice little equation that you can use to figure out exactly what the time will be. And it's
1:19:21 different from the two ends of the of the train. So you know we need to just respect
1:19:26 it. It's a it can we can make it a little simpler than it seems sometimes. Yes, you will see the other side from a
1:19:32 certain viewpoint, but that gets into something you do only after you've already delayed enough time for that to
1:19:38 be possible so you never lose the embedding. Cool. Okay. That's an interesting question. I
1:19:44 got to look at I got to find out what they Yeah. Please I want to I Yeah, I want to know. Please connect with Dennis. Let us know
1:19:50 what the answer is when you get it. Yeah. um David Brenn works for NASA
1:19:56 and I might poke that question by maybe he's heard something about it because I know he tracked that mission
1:20:01 carefully. and I think we're supposed to have lunch or something soon. so yeah, that would be I'm going to try
1:20:08 maybe I can poke somebody and find out a little about that. Okay, get back to us. That's great. I'm so glad I asked that question.
1:20:15 Yeah, cool. Very nice talk. Thank you. Okay, question. go ahead.
1:20:22 Where are we on the stability of cubits? Any what about cubits?
1:20:27 Yeah, the stability of cubits. That seems to be, you know, one of the one of there is a whole separate
1:20:34 presentation I did a few months ago about quantum computing. In fact, I'd forgotten that I done a different one
1:20:40 that was from a different somewhat different angle. Cubits have a whole little history and I cut out about 10
1:20:47 slides about cubits. and the short story about cubits is this uh
1:20:54 they're based on the Mannon concept that you can have a superposition which is a casual comment but it had
1:21:01 it hit home and influenced a lot of history but Yuri Mannon made the comment I think back in 1980 before Feynman that
1:21:09 you should have a flurry of virtual
1:21:14 computers that then you know work and compute a little bit like some of the Deutsch stuff later on. But the point is

1:21:21 he he based the idea of a cub. This is the kind of the ancestor of the cubit. And the trouble is this. If you
1:21:29 follow through and you accept the idea of saying that that that observation
1:21:35 is much more common than we think and is inherent in in ordinary objects. You
1:21:40 never have a dead or alive cat. You only have a dead cat or a live cat that you don't know the status of yet because
1:21:47 that cat is completely taken care of itself, but it can still interfere at a
1:21:53 spatial dimension. That's what's so confusing. It can still go through a double slit. Spacetime does not follow
1:21:59 those rules. You can superpose complex objects in spacetime, but it doesn't change the internals. Cubits,
1:22:05 unfortunately, went in the direction of mana and saying, "Let's make this as much like a computer as we can." And yet
1:22:12 a computer is one of the most classical objects in existence. It is packed to the gills with information. Every time
1:22:18 you have information that's anti-quantum, you're saying that I'm going to make the most anti-quant object I can
1:22:25 think of into a computer that has a little bit
1:22:30 just a little bit not much because it's too scary. I don't want too much of this, but I'll let have a little
1:22:37 bit of leeway of, you know, like one bit flopping and down. So, my problem with qubits, in a nutshell,
1:22:44 is I think we're short-circuiting what we could do with them. I think we're making the problem harder than it is.
1:22:51 You look at these biological molecules, back in that in that that was announced in the Nobel Prize, one of his
1:22:58 comments was that it's just chaos. He's saying, "Look at all these things. What are these things doing? He's got
1:23:04 molecules that shouldn't be there. They're all bouncing around." And it comes out with a 100% perfect result.
1:23:11 That's what we should be looking at in quantum computing, that kind of chaos, structured chaos, because biomolecules
1:23:17 are really structured, but they know how to use it. They kind of go like, I don't care the chaos. I'm going to put it all
1:23:23 together and do that. So, my research, it's not that you can't do quantum computing with cubits. It's just that we
1:23:28 strangled it before we started by insisting it to be so very computer-like
1:23:34 with again computers are kind of anti-quantum. They're the opposite end. It's trying to like make a child
1:23:41 stroller starting with razor blades. Yeah. You know, well, you know, you can it's not that you can't do it, but do
1:23:47 you really want to make a child stroller out of razor blades? Is that really a good way of starting point? So, kind of
1:23:52 goes with that. So, good question. Yeah. Thank you. And I do have some um that same site where that one where my I put a note
1:23:59 on there's an early presentation I talk more about the cubits. Fascinating area that was a pun by the way. It was a
1:24:05 biblical pun because cubits was an old was a was a you the unit used for the

1:24:11 Noah’s arc and the guy who came up with they were driving along and they just started
1:24:16 twirling said yeah we can call it cubits because it was it was a unit of measure and so there’s a pun there. There’s
1:24:23 there’s an interesting blend with that. Other questions? I have a question if you don’t mind.
1:24:30 Sure. my question is related to the idea of quantum encryption itself
1:24:37 rather than using quantum physics to decrypt things and there’s the idea
1:24:43 that if you have a set of encryption keys that contain cubits if you were
1:24:49 to steal or copy the key you couldn’t know the state that the cubit was in
1:24:56 before you stole or copied the key. and it changes the moment that you
1:25:01 make the copy. And I’m interested in this idea. Maybe my understanding of it
1:25:07 is is not clear enough. But I read an article about this in Wired and it
1:25:12 interests me because IBM has quantum computing that you can play
1:25:19 around with in the cloud and I think that because of the expense of quantum computing that is probably going to uh
1:25:27 come to the cloud before it comes to your living room because of the nature of the way that computing is
1:25:33 going. And I think that this combination of things could lead to a
1:25:41 revolution in encryption as we know it. And it could lead to encryption that
1:25:47 depends purely on physics that you couldn’t crack with a quantum computer.
1:25:53 And I wanted to know what you thought of this idea. quantum encryption, in fact, I was probably more involved with it by my
1:25:59 day job, not just as a hobby. Quantum encryption is a technology that
1:26:04 I would describe to people that quantum computing is very iffy, but quantum encryption absolutely there is
1:26:10 there’s reality to that. It’s always a more difficult reality than what it looks like at first thing because
1:26:16 there are all sorts of tradeoffs that you get into. But the whole entanglement idea, Bell’s systems based
1:26:23 on Bell’s theorem, that is one of the deepest and weirdest pieces of physics
1:26:29 that exists because it just says this ain’t doing what you what you
1:26:35 thought to do thought it was doing. It’s just not. It’s not. I know people like to say it’s a hidden variable and then
1:26:41 they then they then they kind of modify and say it’s a hidden variable, but it’s an entangled hidden variable. Well, come
1:26:47 on. You know after a certain point the whole point is the entanglement doesn’t work the way we would expect it
1:26:53 to. You can’t transfer information by it. You can’t touch the universe a remote part. Nothing changes when you
1:27:00 look at a cubit here until somebody there sees what your result was. Then you see a result and try to sort that
1:27:07 through your head sometime. It doesn’t you know it how do you get a correlation when you didn’t change anything? So quantum encryption is based
1:27:16 on these ideas and it’s one of the analogies I used oh gosh way back in
1:27:21 2000 early 2000s in fact I got picked up by a Russian magazine but it I said
1:27:28 it is as if when you look at the entangle bit it’s as if you went back in
1:27:34 time and change the original system to a classical state and then everything

1:27:40 shows that classical state from there. Turns out that's a very good mental model for understanding how these

1:27:46 encryptions work is just picture yourself tunneling backwards through time resetting it to this the value you

1:27:53 saw but then you just you know go away and I hadn't thought about until you asked it right then but this whole thing

1:27:59 I was just saying about multi-dimensional time may actually have a component of that you may may be

1:28:04 literally going back there changing it but again it's a negotiation you don't change the past but you can negotiate

1:28:11 that past. So, yeah, it's real stuff and just some some fascinating physics

1:28:17 that I think is related to some of the issues that I've just been talking about. This eye that time doesn't work

1:28:22 quite the way we thought. And Belle's inequality, you know, Bel hoped that that wouldn't

1:28:28 work. He was actually he was kind of hoping it wouldn't work. It's my understanding. I different people have different opinions, but I think he

1:28:34 wanted it to be more like a hidden variable thing. And I think he was as surprised as anybody when he said, "No,

1:28:40 you know, it it's this is real. This this is real and can't be explained." So

1:28:46 correlations that don't match any model that we can do purely locally.

1:28:52 Thank you. We have time for a couple more questions.

1:29:00 anybody am I allowed to ask a second question?

1:29:06 Absolutely. Okay. My second question is and this is something that I don't really know a

1:29:12 lot about but I remember reading about chemical computers in Scientific

1:29:18 American in the 1990s and I got interested in this idea because you

1:29:24 know the brain is a chemical computer. It doesn't work with zeros and ones. It's based on electrochemical

1:29:32 messaging. And I thought that this was a great idea for computers because um

1:29:39 you know we did have multi-state computers back in the 50s and it got simplified to zeros and ones. But the

1:29:46 mind works like a multi-state computer because you know you have things like um

1:29:51 serotonin and dopamine that are you know a message that's not a zero or a one but

1:29:59 um you know might be a two or a three. and you don't hear people talking about chemical computers anymore, but

1:30:05 people were very excited about quantum computers and I was wondering if you knew why. I don't I remember seeing some of those

1:30:13 articles. I now you mentioned I hadn't thought about those and oh gosh a very

1:30:18 long time. but yeah, there was some there's some speculation on that and I don't think it ever went anywhere. uh

1:30:25 and of course one of the things I'm advocating is that if you look at the model of those biomolecules that are

1:30:31 able to come up with these remarkable I call it probability bending they bend probabilities so systems molecular

1:30:38 systems that bend probabilities enzymes in general but if you try to build a mechanical
1:30:44 model of an enzyme that has all the same parts and you try to get it to work it won't work that the time scales I mean
1:30:52 it might work by the end of the universe or something like that those molecules are doing things we still don't have a
1:30:57 good understanding of and the mechanics of them we have understand that better but it fools us into
1:31:04 thinking that we have a good understanding of what's going on. So I think getting more into chemical
1:31:09 computing would be would be interesting if you're not familiar with it. Roger Pinrose has advocated for decades,
1:31:16 decades and decades since I was in college that the mind is quantum and
1:31:22 I used to occasionally like every two or three years write him a letter and say you can't do that. the molecules are too
1:31:27 big, you know, just and he actually answered me once or twice. He's a nice guy. He's a nice guy, but but I said,
1:31:33 you can't do that. These you can't they're too large to get quantum. And
1:31:38 within the last, I think two years, I kind of go like, ah, dang it. There were
1:31:46 some results with some of the models, some of the chemicals in the brain which they showed laser-like interactions over
1:31:51 a distance at at room temperature. because lasers work at room temperature and they are actually strong
1:31:58 correlations between different locations and I just kind of go like a shock. So it's never, ever a good idea to underestimate Roger
1:32:05 Penrose. So I even though I after decades I kind of flipped over and said all
1:32:10 right there may be something going on there. And I think that's fascinating because those correlations, those many
1:32:15 variables, increasingly, especially with what's going on with LLMs, I think
1:32:21 there is a quantum component because they're so energy efficient. And you see that same thing with those little
1:32:26 molecules. They're incredibly energy efficient. And if you go pure digital, every bit is a hammer and every hammer
1:32:33 breaks something. It may be a little bit of breakage, but one of the reasons why computers get so hot for that kind of
1:32:39 applications is that when they try to model reality, eventually that that binary model, it's like I say, it's like
1:32:45 everything's being modeled at some level with little tiny sledgehammers and at
1:32:50 least biologically we seem to have some more sophisticated stuff going on. So fascinating question. I'm going to look that up. I want I want to find out
1:32:57 more about computer chemical. I'd forgotten that. Thanks for bringing that up.