Hello everyone, welcome to another Q&A about history of science and technology.
And I see a whole bunch of questions saved up here.
Let's see, there's one from Robot.
How far back does the idea of discrete space go, and who first took it seriously as a scientific possibility?
Well, let's see… So, I mean, in antiquity.
There was a lot of debate of, is the world discrete or continuous?
So, you know, the atomists… Democritus being
I think sort of an early one, Epicurus later, Lucretius later than that. These were all in the kind of… the world is discrete, and they had the very good idea that everything in the world, with all the diversity we see, might be the result of different combinations of some small number of atoms.
Just combined in different ways, and a few different kinds of atoms.
I think Lucretius, 1st century AD, made the analogy, perhaps the world is put together out of atoms in the same kind of way that sentences are put together out of words, according to the fixed laws of grammar.
And that was, I thought, a quite insightful idea. Anyway, so back in antiquity, there was this notion that the world might be made of discrete things.
put together in different ways. The question of whether that meant that space itself was discrete, I don't think was really addressed. I think it was more the stuff that we have, what, you know, what is it made of?
there was sort of a different tradition from people like Heraclitus that was kind of the everything flows tradition. Everything is really a continuous thing, and there's, things are made out of those continuous objects.
Then there were things like Zeno's Paradox, which was sort of a confusing intermediate case about asking, you know, if you say, well, there's Achilles and the tortoise, and they're each going this amount at this time, and so on, without an understanding of continuous mathematics.
that came in much later, like, by in the 1600s and so on, it wasn't really easy to kind of unravel that kind of paradox, because that kind of paradox is asking, you know, you subdivide, you subdivide.
And if you say, well, you can keep subdividing forever, which is kind of the conceit of continuous mathematics and the continuous view of space, then you can kind of resolve the paradox that way. But if it seems like you're, you know, you're talking about subdivisions, and you can just make a kind of concrete subdivision at a particular level, then it still seems quite paradoxical.
So I think that was the story in antiquity, and it wasn't like people were sort of imagining space as a thing you could talk about in and of itself. I mean, Euclid, for example, in setting up geometry, and writing down, kind of, the way to think about geometry. His very first Postulate, or definition, I guess, is a point is that which has no part.
In other words, he's assuming that there is a notion of an infinitesimal geometrical point.
And then he goes on to say, a line is that which has no breadth.
So it's, again, these ideas which implicitly assume kind of a continuity of space are present in Euclid.
What did Euclid think he was doing?
He thought he was trying to sort of clean up what you could deduce

in sort of practical terms, by just drawing diagrams on pieces of slate, or, you know, having rods representing different sides of a triangle, and so on. He thought he was just trying to make a more perfect system that ultimately represented what is observed in the physical world. He wanted to sort of turn into philosophy, in a sense.
That which before had been a thing that you just did with measuring rods and so on.
And that, I think, is, and so, for example, for him, the idea that two parallel lines can never intersect.
was, I think, quite obvious. That was a postulate he had, his so-called fifth postulate. That was just a thing where, from everyday experience, you know parallel lines just don't intersect. Now, it took until the 1800s for people to say, wait a minute, you could imagine a version of space where parallel lines can intersect.
as they would do on curved spaces and so on. And then it took from the early 1800s, 1830s, and so on, up until Einstein in 1915 to start talking about, well, maybe physical space is actually curved in that way.
But, so the idea for Euclid was he's kind of reproducing, sort of in an idealized form, what his common experience says about ordinary physical space. And for him, it's sort of obvious that parallel lines can't cross. For him, it's obvious that there can be an infinitesimally small point That lines can have no breadth, and so on.
So… but for Euclid, he's kind of implicitly assuming there's a continuity of space.
For, the… the only sort of chink in that… in that armor is the story of the Epicureans from Democritus on, who thought of at least the stuff in the world as being made of discrete atoms. I think they still imagined
that it was kind of… the version of it that was used was atoms and the void. So, the void is that which is not part of the atoms, so to speak.
And I think they kind of imagined that you could sort of put the atoms anywhere you wanted, and sort of the void was everything, which included when there wasn't stuff there. They didn't really understand gases and things like that. They certainly didn't understand vacuums. That came much later.
But so for them, it was just like, there's places where there's stuff, and there's places where there doesn't seem to be stuff.
And so, all the stuff is represented as different combinations of these discrete atoms, and the places where there isn't stuff is the void.
Okay, so we then go much later, I guess Descartes?
In the,
Mid-1600s, is that right? Maybe a little earlier than that, I think? Early to mid-1600s.
And Descartes kind of wanted to have sort of a model for everything in the world, and thought about this idea of vortices, that everything was kind of made up of these different vortices. That was kind of his version of the atoms.
And I think he had some notion that was a little bit like
not quite discrete space, because people still imagine that Euclid was the kind of gold standard, that Euclid was the idealist representation of everything about geometry and space and so on. So when Newton, 1687, got to write his Principia Mathematica, Mathematical Principles of Natural Philosophy, he was modeling that on
Euclid, and for him, the idea that he had the sort of base of the geometrical structure of space, and then he was discussing how things in space would be attracted by the law of gravity, or whatever else.

So, at that point, kind of, the notion of discrete… of space, space was just this Euclidean thing that was a background to the things you were doing. I think, as I say, Descartes had a slightly different and perhaps a bit wacky view about, sort of, everything is made of vortices and so on.
I think, let's think, after that…
kind of the next, sort of, thinking about the nature of space came with relativity, 1905,
And the idea that That could be, sort of.
different… that space wasn't just this Euclidean thing that just was what it was, that there was more, kind of, freedom and dynamics in space.
And for Einstein, that was the idea that lengths and times and so on, that lengths in particular, were things that depended on the observer. There's the Lorentz contraction. If you're going faster, things seem foreshortened, and so on. And that the idea that space was sort of a fungible thing, not kind of this fixed Euclidean background.
So then in 1915, with general relativity, came the idea that you can think of space as being curved.
That it… and that, in fact, in physical space, you know, you have those two laser beams going off in parallel, making lines.
If there's gravity in the middle, those laser beams can be attracted together, and you can represent that attraction by saying that the space in which the lasers are… the laser beams are carving out, kind of, shortest paths, that space is curved, and that's kind of an account of what the force of gravity corresponds to.
So the idea that, sort of, space then was this dynamic thing whose structure depended on the presence of matter was a thing that sort of came in in 1915.
So…
around the same time, I mean, it was in the 1800s, that people were still asking the question, is matter discrete or continuous?
So, 1600s, you know, Newton had talked about the possibility of corpuscles, and had various, even, models for what gases might be like. The Bernoullis had models for gases in which they were made of discrete, sort of atom-like corpuscles.
And, I mean, Newton famously had his
universal law of gravity, the inverse square law. He also had a hypothesis for the sort of law of interaction between things in a gas that he imagined might be atoms. He had a fifth power law that doesn't turn out to be right. But, that was, you know, at that time, that was being discussed.
But it was still something where people weren't at all sure that the atomic theory of matter made any sense.
And famously, Ludwig Boltzmann spent a lot of his life thinking about the atomic theory of matter, and by the end of the 1800s, sort of given up. Nobody seemed to believe in it. They didn't even believe in it, they didn't believe in the kinetic theory of gases, they just didn't believe in the discreteness of matter.
And he sort of famously said, you know, he's writing down a book on the kinetic theory of gases based on discrete atoms and molecules. He says, you know, I'm writing this down even though nobody believes it right now, and one man cannot stand against the tide of history, he said, but I'm writing it down, he said, so that, you know, in the future, when this is rediscovered.
It will be brought out again, and people will find what we've done now useful.
Actually, it was not very long at all that… and it was being rediscovered. And that was in… in large part
due to Einstein pushing, kind of.

discrete things all over the place. So, in studying Brownian motion in 1905, it had been studied a bit earlier by Smolchowski and others, this idea that Brownian motion, when you look under a microscope, you see little pollen grains being kicked around, that that was

Due to actual impacts of molecules on those… on those little pollen grains.

And, so, by… By 1900, there was a sort of serious view that matter would… might be discrete.

I mean, there'd been evidence of that from all kinds of things Boltzmann had done, and accounting for properties of gases. There'd been evidence from chemistry, from the fact from people like Dalton, noticing that there were these sort of integer relationships, you know, it's water is two hydrogens and one oxygen. It's not, you know, oh, 2.7 amounts of hydrogen and 0.82 amounts of oxygen.

It's these discrete numbers suggesting that there are discrete atom-like things that make up these chemical compounds.

So, and then… In 1905, the idea of photons as discrete particles of light

sort of really got pushed. I mean, Planck in 1900 had kind of leveraged ideas from Boltzmann to kind of account for blackbody radiation using implicitly the idea of discrete corpuscles, particles of light. But Planck didn't really believe in that. He just thought it was sort of a mathematical trick.

It took him a decade or more to really believe in that. Einstein was the young activist, so to speak, who first believed in, sort of, the true discreteness of light as photons and so on.

So… 19… by 1905, a lot of discrete models of things, matter, light, and so on.

And then as quantum mechanics started to develop.

by the 1910s, with people like Bohr and Rutherford and so on, and then by the 1920s, with Schrodinger and Heisenberg and so on, that… the idea that, sort of, everything was fundamentally discrete got to be really a thing.

So…

at that time, although the history is really obscure, and I really need to go really track it all down sometime, because a lot of it is really not published.

Because people sort of tried to say, well, you know, we know matter is discrete, we know light is discrete.

So what about space? Maybe space is like an egg crate, a big, kind of discrete collection of cells.

I think Heisenberg had that idea, I think. I don't know, he didn't publish that idea, but I've heard from people that he had that idea.

Now, there were other things that were, sort of, questions about discreteness of space, like, for example, one of the big questions was, it was known that accelerated electric charges radiate energy.

That's what allows you, as you move the sort of electric electrons back and forth in an antenna, you're, you know, accelerating, decelerating, and so on, that produces an electromagnetic wave.

And so one question was, when you have an electron and an atom, it's really true, as became clear with Rutherford and so on around 1910, that the atom has a nucleus, the electrons are sort of going around the nucleus.

people like Bohr had sort of had to wonder, why is it the case that the electron, as it's, kind of orbiting around the nucleus, doesn't

do the thing that electrons, which are accelerated, because anything that's kept in an orbit is being accelerated, otherwise it would just go in a straight line, the… why is that electron not radiating energy and spiraling into the nucleus? Because it loses energy.

Why does that happen? And one of the ideas of that would be, oh, because there's sort of discreteness to space, and it can't just sort of spiral in, it's got to be in one place.

That was, sort of, one version of this.

So…

Kind of the… the notion of discrete space was something that was definitely in the air, and people kind of imagined everything's going to turn out to be discrete.

I think Heisenberg was one of the people who,

push this further the most, I think it was around the early 1930s, where he just sort of gave up. He said, I can't make this consistent relativity. If you have a bunch of sort of egg crates in space, and you say, well, what do those look like to an observer who's traveling at 0.9 of the speed of light?

Well, it doesn't seem to work. It doesn't seem like there can be a thing that is a discrete kind of array of things in space. That just doesn't seem to be a thing that's consistent with the ideas of relativity.

So, Heisenberg at that point said, well, you know, forget about doing this. Let's just think about, kind of, interactions between particles as being things where there's an incoming state.

and there's an outgoing state, and something happens in the middle, and we're just going to describe that by this thing we call the S matrix, that is just this mathematical object

that represents the transformation from incoming configurations of particles to outgoing configurations of particles. And that's what led to S-matrix theory, which was one of the sort of drivers of modern particle physics and string theory and so on.

But that came out of, sort of, Heisenberg's frustration, apparently, with the idea that he couldn't figure out what was really going on inside there, and… and because he couldn't figure out, sort of, what the structure of space might be.

So, well then…

Kind of the notion of, should you think of space as being discrete or not?

didn't really come up for a very long time. And in physics, people just assumed space is continuous.

general relativity had been invented in 1915, it didn't really get seriously worked on until the 1950s and 1960s. There was a long period of time when it was just kind of like, oh yeah, it's a thing, but it wasn't really studied, you know, the nature of black holes was not understood, it wasn't really understood whether they… whether they were a real thing, whether they were a pathology in the theory, and so on.

And so… but when general relativity kind of came back to being studied, it was like, of course it's a continuous background of space. And when it came to particle physics, it's of course space satisfies relativistic invariance, and that means that… and it has Lorentz transformations which can be at any velocity. So similarly.

you can say, well, we can also take space and we can make rotations. And the idea is, it's not just you can make a rotation through this discrete set of angles, but you can make any rotation in space. And the generalization of that is Lorentz transformations, well, you're making rotations in space-time. And sort of the implicit assumption throughout particle physics was space is continuous, you can, just like you can describe possible

rotations in space by the rotation group. You can describe possible, sort of, transformations in space-time by the Planck array group.

It's a continuous thing, don't even think about anything else.

So… what… what happened beyond that? Well…

Starting in the 1940s, people started thinking, how will we take things which are usually described as continuous, like fluids, and kind of simulate them, solve the equations for them on computers?

And that led to the idea of, well, let's make a mesh, where instead of saying what the velocity of the fluid is at every point that you would mathematically define, V of XYZ or something, for all X, Y, and Z, you would just take a discrete mesh of points, and say, we know the velocity is this at this point, and that at the neighboring point, and so on.

And even, for example, von Neumann, around 1950s, started thinking about weather forecasting by computer. I mean, von Neumann was often a good ideas, but not completely thought through. This was one of those cases, I think. It was like, it's going to be easy to do weather forecasting. He and a person called Charney, were, kind of off and doing that, and it was like, it's going to be easy.

Well, you know, 70 years later, we can more or less do few-day weather forecasting by solving those equations, by discretizing, kind of, the space for a computer.

But so that idea that you might discretize things for the sake of putting them on a computer was a thing that had come in by the 1950s, 1960s, and so on, but it was viewed as a, well, that's what you have to do to take real space that's continuous and stick it on a computer.

there were, sort of a long stream of what one might say, I guess, amateur scientists. I view myself as an amateur scientist in some ways as well, but… but scientists, I would say, who were probably,

much further from the mainstream than I am, in the sense that, I mean, I, you know, I have the feature that I kind of

learned and did traditional science before I started doing things which were beyond traditional science.

The, the folks who were kind of… the discrete space crowd mostly were people who did not know the kind of traditional canon of general relativity and things like this, and were just saying, hey, wait a minute, let's do something different, without kind of knowing what there already was.

So, a couple of people along those lines, one, a chap called Conrad Zuse, who was a German computer technology pioneer, who I never met, I exchanged letters with him. It's somewhat confused in the historical record, because he had started talking about calculating space.

And I think he was just thinking about

Finite difference, kind of, the idea that you could have

Kind of, you could make space discrete for the purposes of computation.

Some of that is kind of shrouded in confusion, because during World War II, Zeuser had made, apparently, a mechanical computer, and with help, it seems, from the German military, and it was particularly German Air Force.

what it was exactly used for on the wall, I don't know. It's not… not publicly known, to my knowledge. And, you know, that's a…

So, you know, to what extent

The idea of, you know, we're going to solve the equations of fluid mechanics, and we're going to do that by discretizing them, putting them on a computer, and then that turns into what he called calculating space.

And then it's like, well, maybe that's how the whole universe works, because, well, it's at that point he was running a small computer company, and it's like, let's sell computers, and so on. I don't know to what extent all those pieces were mixed together.

It is true that in England, it was a chap called Richard Southwell, I think, who, was responsible for the design of the wings of the Spitfire fighter.

And, he had used, kind of finite element methods, discretizing, kind of, the, the fluid, the velocity of the fluid in discrete elements.

And he had human computers, actual humans doing computations, but the idea of, kind of, discretizing space for the purpose of calculation was apparently important in the design of the Spitfire Fighter, which has kind of notable, different-shaped wings than previous things had had.

So, I don't know to what extent… I mean, I do know that, or I've heard that it's been hard to get the information, but I've heard that Conrad Zuza was connected to the Luftwaffe in Germany, and so it would stand to reason that there were some similar kinds of thinking going on there about calculating,

Sort of fluid motions there.

So that was sort of one branch, and as I say, the historical record is a bit confused, because by the 1980s, my own work on cellular automata existed

And, Conrad Zuza had sort of corresponded with me and started talking about cellular automata, but that was presumably very different from what he was talking about in the 1950s with his calculating space, but not completely clear.

That's one branch. Another chap, who I knew well, was a person called Ed Fredkin, and I wrote a very long and elaborate obituary for him a couple of years ago.

he kind of got the idea, he was really into computers, he knew computers, he didn't know physics. He was interested in physics, but he didn't really know the traditional canon of physics. And so, for him, it's like.

I build things with computers. I engineer the software world with computers. Let me engineer the physical world of the universe. And so, practically to his dying day, he would routinely tell me, you know, I've discovered the electron, so to speak, and things like that, in thinking about discrete cellular automata with particular phenomena, and sort of identifying analogies between those.

And what happens in the physical world.

But his notion that sort of discrete space can be made, as I think Heisenberg had imagined also, as sort of this discrete lattice of points where there's sort of a thing moves from one lattice point to another. It's, first of all, a challenge to deal with rotational invariance, but

And you can get things which are approximately rotationally invariant. I mean, Ed Fredkin had a thing that he, I think, called his SALT model that he said was rotationally invariant, in the sense it was on a discrete square grid, but he says, well, if you make a big enough version of it, it will be… it will be circularly symmetric. I actually worked that out in this obituary, and it isn't true. It's… it's approximately circularly symmetric, but not exactly.

Now, of course, we don't know that the physical world is exactly circularly symmetric, but it's certainly to a better approximation than this would lead to, because even in the large-scale limit, where the lattice is very, very big, you know, Ed's version of this still isn't circularly symmetric.

So, but in any case, there's some, that was sort of a strand, which I must say that I had found very frustrating, because I was studying cellular automata, discrete, kind of.

versions of space, but I viewed them as being not the way the physical world is, but an approximation to the way the physical world is, in the same way that endless other models of the world are. I mean, one doesn't imagine

that, you know, in the equations of fluid mechanics, that the fluid is solving that equation. It's merely the equation represents what happens in the fluid, and then we get to separately go off and solve the equation.
So, in the early 80s, you know, I was interacting with folks like Ed Fredkin and others who were, you know, really, like, we can make everything out of cellular automata, and I was like, no one can't.
It's… it's obviously not consistent with relativity. Same issue that Heisenberg had encountered. It just, you know, space… I…
I reasoned was not as kind of rigid as just an array of cells.
So, I… I just kind of was… was very,
put off this idea, and I was sort of fighting off this idea, because people were like, oh, our cellular automas are really supposed to be a model of the universe? Well, no, they're not. They are like differential equations, like other kinds of things. They're one of the… of the kind of collection of tools that you can use to model things. You know, if you're modeling the pigmentation pattern on a mollusk shell, you're not modeling the physical… the underlying structure
of space. You're making an approximation to maybe the cellular structure of the mollusk or something, but you're not… so it doesn't matter that you say that it's a discrete grid of cells, but you're not modeling the underlying structure of space.
So, for me, the, that was about 1990.
that I started thinking about, kind of, networks as kind of a potential model for what's underneath space and time, a thing that is not like a rigid grid where space has already been defined, but something where it's kind of flexible enough that you could have
a, That, that you could,
That you can kind of make something that emerges to be like space from something that's discrete underneath.
And it wasn't until 2019… well, actually, in the… by the mid-1990s, I understood how one would get relativity and general relativity from these discrete
Network systems, and why the sort of… the issues about, sort of, having to pre-build the structure of space are not issues anymore.
But, there was some… and so then, by 2019, really got serious with our physics project, and we were able to figure out a lot more about, sort of, the derivation of the Einstein equations for the structure of spacetime, and how that can all emerge from underlying discrete space.
Okay, there are other strands.
There are, well, Let's see, a couple of other strands.
One associated with John Wheeler, one associated with Roger Penrose, and I suppose one associated with quantum gravity in general.
So let me see if I can untangle these strands.
So,
I think?
John Wheeler, I'm trying to remember what the origin
Of his interest in discrete space.
was.
But, he…
was eventually interested in… he had this whole sort of program of it from bit, which was kind of the idea that information is the fundamental thing in the universe. I agree with that.

And that somehow everything emerges from that. I have to say, I exchanged some letters with John Wheeler. I met him only once when he was very old. I don't think he ever internalized the kinds of things that I figured out. I think he had a much more, kind of, conceptual view of how it had to be the case

That you could, sort of, make

The make things out of information, and he had kind of a model of,

There's a nice picture in the book by

Misner, Thorne, and Wheeler about gravitation, where, from the 70s, where he has this chainmail sort of picture of what space-time might be made of. He didn't really take that further. That had come from work he did on what he called geometrodynamics back in the early 1960s, where he was kind of imagining sort of discreteness of space

But that was all tied up with the discrete particles of gravity.

in, for example, electromagnetism, one says, well, there's an electromagnetic field, but we can also decompose that into discrete photons, and that's what quantum field theory talks about. So there's a question of, could you do the same thing for gravity? Could you decompose the gravitational field into discrete lumps of gravity that you might call gravitons? And we looked at that, and as did Dick Feynman and other people.

In the early 60s, looked at the possibility of, just like you can have photons being exchanged to lead to electromagnetic forces, so you might have gravitons being exchanged to lead to gravitational forces.

So, two things went wrong. First of all, there had been these infinities found in quantum field theory, which in the 1940s have been resolved by this trick of renormalization. I've talked about that another time, let me not go down that particular rabbit hole right now. But in any case, that trick

had been made to work for quantum electrodynamics, the theory of electromagnetism, quantized electromagnetism. When that trick was applied to the obvious way to make quantum gravity, it didn't work.

And so that meant that the infinities were sort of unremovable in the most basic way of doing quantum gravity.

But Wheeler was involved in that sort of early thinking about quantum gravity, and he wrote this nice book, which is completely out of print and hard to get hold of, and part of the reason it's hard to get hold of is because it has a theory about what gravitons are, and the theory is gravitons are neutrinos.

That theory is completely wrong.

But a lot of the mathematics in that book is completely valid and good. It's just that sort of an anchor part of the theory turned out to be completely wrong.

So, in any case, there was a strand that kind of started with the attempt to do for gravity what quantum electrodynamics had done for electromagnetism. That didn't get very far very quickly, because of these technical problems.

Then…

there was kind of a different strand. Roger Penrose, really a mathematician, had been working in the 1950s on kind of the mathematics of quantum mechanics.

And had been studying, particularly quantum spins, and how you combine quantum spins, and sort of classical limits of quantum spins, and spin networks, and so on.

And, meanwhile, he interacted with a chap called David Finkelstein, both of these people I… well, David Finkelstein died a number of years ago. I knew him, know Roger Penrose, in fact,

just went over in considerable detail about, sometime late last year, with him a bunch of this history.
But, according to Roger Penrose, he met David Finkelstein, and they kind of swapped fields.
So, David Finkelstein had been working on general relativity. In fact, it's a famous thing called the Eddington-Finkelstein coordinates, which are used to study black holes. He'd made a whole bunch of contributions to general relativity.
When he met Roger Penrose, Roger Penrose had been working on quantum mechanics, quantum mathematics, and then Finkelstein started working on quantum logic.
And Roger Penrose started working on general relativity, and eventually proved the singularity theorems, and got famous in relativity, and became famous as a physicist, even though he's really, really a mathematician.
And a very good one.
But, in any case, the,
So, sort of another version of this was…
this idea of spin networks that Roger Penrose had kind of developed for thinking about quantum mechanics, sort of a partial importation of those into general relativity, partly with folks like David Finkelstein thinking about that, partly with things that Roger Penrose pushed further
But I would say that was sort of one strand of kind of discrete space. Another strand was the quantum gravity people, and sort of the…
well, I would say… Okay, the increasing realization that space-time
at some point, we'd have quantum fluctuations. At a small enough scale, space couldn't be really continuous, because it would have to be fluctuating all over the place, as every other quantum mechanical thing does. Just like in the early part of the 20th century, people had said everything's going to turn out to be discrete.
By the 19…
well, late 1970s, 1980s, people were saying everything has to have quantum fluctuations, so space-time must have quantum fluctuations. Okay, at what scale does space-time have quantum fluctuations? At a thing called the Planck scale, 10 to the minus 34 meters, where the, where it so happens that just by, sort of, dimensional analysis, you can see that, kind of, the dynamics of quantum things.
associated with Planck's constant kind of are comparable to the dynamics of gravitational things associated with the gravitational constant.
And so, sort of inevitable that space-time has to be a fluctuating thing down at the Planck scale, and so people by the 1980s were starting to think, well, what's it really like?
That didn't lead to the idea of, kind of, discreteness of spacetime, but it led to the idea that spacetime wasn't just what Euclid had said, or even what Einstein had said on a local scale, of just this part of a continuous manifold that has, sort of, just positions, arbitrary positions.
So… but that didn't really develop much, and I mean, it turned into…
oh boy, I mean, there were a few specific strands of that, but I would say most of those post-dated things that I started to do in the 1990s
I think, the, I mean, there are a bunch of other initiatives, kind of causal set theory, et cetera, et cetera, et cetera. Those, I think, mostly were born out of this kind of idea of, at the Planck scale, we need to do something different.
But the something different wasn't very clear. Then, in the probably 1990s or so, some… well, later than that.

I mean, sort of string theory ideas, kind of, there's fluctuations in things, and somehow, to achieve consistency in string theory, those fluctuations must be on some background that is like ordinary space, and then maybe those fluctuations make ordinary space.
In the end, I think these things are converging very much to the kind of thing that I've thought about since the 1990s, of just saying, actually, space is really just made of this discrete network of atoms of space.
And the things that are being done are sort of backing into that by thinking about elaborate things in quantum field theory and quantum gravity, but in the end, the kind of underlying data structure, I think, is very much emerging, as you can think about it as discrete atoms of space related to each other in some kind of network.
But I think that idea of, sort of space as a network like that, it's… I… I mean, I think that's something I basically came up with in the… originally around…
1989, 1990.
I was, again, I had been sort of frustrated by this kind of cellular automata. I've already burnt in too much about space, and I was sort of imagining what is the most flexible thing that one can imagine that… from which space might be built.
And at first, I kind of didn't see how all those things connected. I think 99.3, actually, was, when I really started to understand the kind of connection between the limits of those features of, of discrete structure and kind of continuous geometry. Actually, okay, here's a little bit of a funny story. Shout out to a chap called Misha Gromof, who's a mathematician. I had dinner with him once, 1993.
I was thinking about these kind of questions about discrete space. He had worked on an area called geometric group theory.
So, you know, groups are these kind of, abstract mathematical things that
You can think of, well, the kinds of groups he was thinking about are things where you would have a discrete set of elements, A, B, C, or whatever, and you have certain rules about how AB is the same as BA, ACC is the same as BAA, and so on. These kind of discrete algebraic-type rules, and then there are some overarching rules about associativity and inverses and so on that make that combination of symbols a group.
Okay, so you can make this thing called the Cayley Graph.
which is kind of a representation as a network that sort of shows how the different elements of the group are connected to each other. And so what Michel Gromofe had looked at was the limits of large Cayly graphs. What is the geometry of a large Cayli graph?
So, for example, for some groups, the Cayley graph is just a cycle, a ring. For some other groups, it could be a kind of a grid, etc, etc, etc. But he was interested in the large-scale limit of of those caliographs, so he was going from something discrete to kind of a geometrical interpretation of that.
Okay, so, you know, we were talking about, kind of, how do you do things like measure the effective dimension of the space that you get? And so, from that emerged these ideas that I'd made a lot of use of, and I think Misha Gromov independently made use of, about Kind of growth rates of balls in the space, and so on, and thinking about that in terms of dimension, curvature, all those kinds of things.
It's just a weird footnote to history that another thing that transpired at that dinner was, Misha Gromov had a friend who's a mathematician called Misha Brin, and Misha Brin had a kid named Sergey Brin, who was at that time about to finish college, I think. And, Misha Grommoff was like, hey, there's this really bright kid.

Who is interested in being an intern at your company, and, so that's how we ended up, meeting Sergey Brin, who became an intern at our company in 1993, and then left to go to graduate school at Stanford, and then…
went on a leave of absence from being in graduate school to start this company called Google. And I don't know if he still counts himself as on leave of absence from Stanford, but anyway. So that dinner led to two… two interesting things. One was
sort of a much better understanding of the emergence of continuous space from discrete constructs, and the other was Sergio Bin getting introduced to the computer industry.
So, I don't… it was a productive dinner in some ways.
Anyway, so that's a few thoughts about discrete space.
people… yeah, I should say that people had sort of made… tried to make measurements of, you know, is there discreteness in space by a bunch of different techniques. Somebody I see is asking… X7 is asking about discreteness of time.
That was also considered. There was even the idea that there might be chronons that were discrete elements of time. And in particular.
when particles were being discovered in particle accelerators, it is very typical that the lifetime of particles is around 10 to the minus 23, 10 to the minus 24 seconds. That's when you have particles that are decaying through the strong nuclear force, or through QCD,
Same, same, same story. Those particles have a characteristic kind of timescale for decaying that's around 10 to the minus 24 seconds.
And the reason they have that timescale is because they're about 10 to the minus 15 meters across, and you kind of just divide by the speed of light, 3 times 10 to the 8 meters per second, and that's what gives you the 10 to the minus 23 to 10 to the minus 24 second kind of time frame for the decay.
And so, people had certainly asked the question, would it be the case
that actually all the decay rates of those particles were quantized, and that there were sort of discrete lumps of decay. You know, everything is an integer multiple of some unit of 10 to the minus 27 seconds or something. No such thing was ever found. There were just a few, kind of, efforts, probes made of that idea.
But, that's, That's a,
Yeah, that's… that was a story of that.
Let's see, I see a few other questions here from,
Sharon, do you see your blog as a way of documenting behind-the-scenes history of your work?
Well, I renamed my blog to my writings, because people told me it was absurd to have, quotes, blog posts that are 100 pages long and get published as books. So, I'm officially calling it my online writings.
But…
But yes, I have taken, particularly in recent years, I've really made a point of having, including the personal history of whatever it is that I'm studying in that piece of writing. Because I've found that, you know, so much of the time that history is just lost.
And, you know, when you write an academic paper, I haven't published one in academic papers since 1986, I kind of abandoned the academic publishing system, although I do. There is a journal that I publish
which, called Complex Systems, so I'm not completely out of that world, but,
the… I haven't, sort of, used that as a publication channel for my own… my own kind of scientific work since 1986.

But in any case, when you write an academic paper, it's the idea of, kind of, this storytelling description of how the work came to be done.

is absolutely absent.

I mean, at best, it might be, you know, Smith & Jones studied this, and I'm following up on Smith & Jones.

But the idea that, oh, this came up because I had been thinking about this, which was relevant to some piece of technology here, and I started working on this, and I then got stuck, and I then stopped for a decade, and so on, none of that stuff is typically captured.

And I've decided it's interesting, and so I should write that history and try and capture it.

There's a question here from Leanna.

What makes someone worth writing about historically?

Well, I don't know, I mean, the, the,

you know, what is history? Let's start very philosophically.

I mean, history is some kind of shared narrative about what happened in the past.

In other words, if there were, you know, the 100 billion people who've lived, everybody did something.

But most of what was done did not make it into the canon of history. That is what we kind of…

The shared narrative we have about how things were in the past and how we came to have things the way they are today.

So I think, you know, that shared narrative could have many different branches, and sometimes the branch it took is the branch many people think it shouldn't have taken, but nevertheless, there is that shared narrative and that sort of a notion of history. And I think

the same as, you know, when it's… when there are sort of pieces of that shared narrative that sort of fill in an understanding of that shared narrative, that's a place where it's interesting to know those sort of human elements. I will say that much more of history

Is made of individual people doing things than is often admitted.

I mean, you know, you read the story, you know, the history books, or at least the story version of the history books, and, well, sometimes there's a sort of glorification of individual people, but sometimes it's just like…

And… and this happened in, actually, maybe not so much in the history books. I would say it's more in the kind of, you know, the…

the general trend of things was that everybody got a personal computer, let's say. But in actuality, there were particular individuals, in that case Steve Jobs was one of the important ones, who were really pioneering conceptualizing what that meant.

And, you know, I have certainly seen in my life

a lot more contribution of individual people than… than is often acknowledged. Now, sometimes when the history is written, it becomes a story, and then it becomes a story about an individual person that is overly individualized. But the fact is, when there's substantial innovation, conceptual innovation.

It is usually… there's a kind of a groundswell of things going on, and ways of thinking about things, and then there's an individual person who kind of gets it, and maybe can convince other people of it, too.

So I think that that's a… and, you know, some of those kinds of, how did the person come to build this new paradigm? That's… that's interesting to study, at least I think it's interesting to study.

For myself, I've written a certain number of biographical pieces about… quite a number of biographical pieces, even published a book a decade ago called Idea Makers. That's a collection of some of those pieces. I have to say that I did them often

for sort of random reasons, in the sense it was the 200th anniversary of so-and-so, and I wanted… I'd been sort of meaning to study that person. It was true for, for example, Ada Lovelace, been meaning to study that person, and I finally… this was like, okay, I'm gonna do it this time. Or Ramanujan, there was a movie

that had been made about Ramanujan. I was interacting with the people who were making it, and it was like, okay, I'm going to actually try and unravel what I think about Ramanujan. Unfortunately, too many other cases, they were sort of obituary pieces. People I knew died, and I decided I should write an obituary, and I… and in some cases, like the obituary I wrote for Steve Jobs, I wrote, you know, the day he died.

And I hadn't prepped it, and I just… it was comparatively short.

the obituary I wrote for Ed Fredkin.

Turned out to be unbelievably long, and that one was made very difficult by the fact that Ed Fredkin was a wonderful storyteller. He told many stories, including he would tell me stories about me.

And the stories he told me about me were almost all completely false.

So, that meant that when I tried to write his obituary, and there were many, many stories that he told me, which I remembered, and it's like, I have no idea which of these stories are true, because the ones he told me about me had usually been false.

Actually, the ones that he had told about other things

They all had germs of truth in them. Some of them, the story as he told it was slightly, sort of, tilted relative to what had actually happened, and in some cases, there were major stories he could have told, but didn't tell, and had never told, that I was able to find by sort of doing the after-the-fact work.

But, that's been my… I mean, I don't think I have a systematic,

strategy for this at all. I think, you know, our company has been around long enough, for example, and has, you know, it's about 800 people now, it's had different numbers of people over time, but the demographics of humanity are such that, you know, people who have been at our company and so on, you know, are dying at some rate, and I typically write small obituaries for those folk.

Not… not for public consumption.

But at least not now. And but so that's a… that's a,

another sort of type of thing that I'm… that I'm writing.

But, I think,

Yeah, I mean, there's certainly people where I would love to have the time to write an obituary, I just haven't had a chance to do it.

I mean, I could start, reeling off all kinds of people, where if I had the time, I would love to do it. I just have not had the time. I would say that an area that I've been sort of poking out is the history of neural networks. I got a lot of information about people like Warren McCullough.

And Walter Pitts and so on, who were originators of the whole neural net idea, but I think there will more be a history of the idea than a history of the individual people, though it will contain a lot about those individual people. I would say that,

Yeah, I mean, I've kind of worked through a bunch of the early pioneers of computation, but, There's so much more to do. I mean, there are many, many other people I've never really written about. I mean, there's some… there's sort of a trade-off sometimes. I mean, somebody like Newton or Darwin, I know a lot about them. I think there are some things that I have to say about their history that are a little bit not…

the obvious, obvious things, but nevertheless, for example, with Newton, you know, in my own library, I have half a shelf of books about Newton. There's a huge amount that's been written about him.

And, in, and so that's a different kind of, sort of, historical biography than of somebody like Moses Schoenfinkinkel, where nobody had written any kind of history. And, that, that's a, but that's the inventor of combinators,

And, yeah.

Let's see… The question here, are there conversations you've had

that you now wish had been recorded? Oh, absolutely. I mean, you know, I…

I've known lots of interesting scientists and other technologists and so on, you know, many who have now died, and absolutely had all kinds of interesting conversations. It would be lovely to know something beyond my memory.

for… for what happened there. And sometimes, you know, I have a very complete email archive for myself going back 30…

35 years now. No, 37 years now.

And,

you know, I often sort of remember the big picture, the big sort of arc of history about how something worked, but when I go back and I look at the original documents, there's a lot more detail there, that sometimes is confusing.

But sometimes, with what I know now, I can see the significance of things which were there then, that I didn't see at that time.

And I'm sure, you know, in,

I know lots of conversations I had with Dick Feynman, about, kind of, computation, physics, etc. It would be at least fun to go back to those conversations, which I just have a memory of.

And, perhaps there were ideas there that still are to be mined, so to speak. I think, sometimes I will say a little bit to,

that, you know, occasionally, I have to say, in the course of business and so on, there have been situations where, you know, people sort of

choose to rewrite the history of things to their own advantage, and it's like, hmm, if that conversation had been recorded, in some cases they actually were pretty good records, and it's like, no, no, no, this isn't the way it happened.

It's like, sorry, but it is the way it happened, and, you know, whatever you're claiming is just nonsense. It is always an interesting dynamic for somebody like me who does record, you know, everything at this point, or almost everything. I mean, I don't record, sort of.

you know, random conversations. I only record, sort of, structured ones like this, or like working meetings that I have, and so on.

But it's always, it, it has an interesting dynamic in terms of, of, look, I know what happened. You know, somebody's trying to convince you, no, no, no, something different happened. It's like, I'm sorry, but here's the records. I know what happened, type thing.

There's a question from Henry. Have you seen a field rewrite its own history while I was part of it?

I don't know.

I'm not sure, because I think most fields don't write their history. It's usually… I mean, the… the, Well… I mean, sometimes, a little bit.
You know, in computer history.
there are companies that succeeded, there are companies that didn't succeed, there are people who became famous, there are people, who…
You know, who…
who didn't, who built things, but they didn't build companies, they didn't build… they didn't… weren't… didn't become publicly known, and so on. I mean, there's a certain sort of,
you know, I don't know, there were people at one point, you know, did Bill Gates invent the internet? Well, obviously no. But that was a kind of, you know, he was the big name in sort of the computer industry, and so he must have invented everything.
But that's, you know, I think that's a… and there was a, to some extent, you know, some
In some places in… The… in the computer industry.
where people spend huge amounts of money on marketing the wonderfulness of their company, whatever it is. Yes, there are cases… I mean, I'm sure there are cases of things I've invented where, sort of, the history of not
You know, in detail rewritten, has been effectively rewritten by somebody saying, oh, there's this thing, and it was, you know, and it's now big.
And it was made big by this entity out here, and it's not the same as the entity or person who actually invented it in the first place.
But I'm not, not immediately coming up with kind of a… you know, those things are usually kind of messy in the way that they play out. And so it's… it's hard to come up with a clear, you know, this is the rewrite type thing. I mean, there are certainly…
fields whose…
you know, where there was a certain amount of ugliness in their history that's been sort of written out. A good example is genetics and eugenics.
eugenics in the early part of the 20th century, there were sort of institutions that were created to kind of, you know, make the better-bred humans.
people realized it was a bad idea to breed humans in that kind of way, and to have… kind of breed humans like cattle and so on. But, you know, that was an idea, and it was…
you know, the science of genetics that has to do with studying, you know, what happens when you have… well, you're breeding mice, you're breeding, you know, you're seeing what happens with humans. Those things were a bit intermingled.
And later on, kind of, after, you know, the idea that, I don't know, there are institutions which were started as institutions for eugenics.
That later on became kind of really about genetics, and kind of, you know, elided away their past history.
And so there are things like that that happen when there's some kind of embarrassment of past history. I mean, I have to say, I'm not a believer in a tear-down-the-monuments theory of history. I tend to think, you know, the monument is part of the history, and the fact that the monument was put up is part of the history.
And it's kind of not right.
to say, oh, because we don't really believe in the cause that put the monument up today, we'll tear it down. Because in a sense, you know, if you believe in history at all, there's kind of the, you know, the monument and the putting up of the monument is part of the history. And even if now you say there's something terribly shocking about the thing that the monument was to.

Well, that's part of the history, and maybe it's worth remembering that there was something terribly shocking, because maybe they won't make that same shocking mistake again, but tearing the monument down means you don't remember it at all.

So I'm not a believer in the rewrite history by tearing down monuments. I think that, you know, there does tend to be a… there's a slight tendency of things that get invented, and then kind of, people realized the history was wrong, and they start sort of tacking names onto things, like the Friedman universe, which is a model of… kind of homogeneous model of the developments of cosmology in the early universe. It became the Friedman, Robertson, Walker, and then it became the Friedman…

Roberts and Walker Lemaitre universe, and so on. It's, I mean, I do have to say that there are things which

where… I'm like…

the true situation would tack my name onto some combination of names that were sort of the promoters of some particular idea, but where the original idea actually came from me, and I'm not sure people are doing that yet, maybe they will, but that's another tendency. I'm not, you know… in the end, those kinds of things defeat themselves, because by the time you have, you know, the whole alphabet soup of names, you're shortening them to abbreviations, and then they're

Shortening them to nothing.

And you know, it's kind of like, well, it's, and I'm not sure… you know.

the main, I think, reason

First of all, there are things that need a name. So you just attach a random human name to the thing, and it's, like, it might be cool for the… for the person who it's named after, but mostly it's just attach a name for the sake of attaching a name.

And… but some of the time, it's super useful to have that name attached, because it tells you the kind of paradigm of thought that that thing came out of.

It's… it kind of is a… is a… is a kind of a coordinate in concept space that, oh, that's a thing that came out of, you know, George Boole or something, who was thinking about roughly these kinds of things. So it's useful at that level also.

Let's see…

Phil Leona is asking, if you weren't a scientist, do you think you'll be a historian? Oh, I don't know. I'm not sure that,

I have many things that I'm interested in, so it's, it's, that's, I… I definitely enjoy history, but I feel like, the,

The thing that, is,

what can I say? The, the, I am…

I think I can make a bigger contribution building the future than analyzing the past.

But for me, analyzing the past is interesting as kind of a way of sort of buttressing the effort to build the future. So I…

you know, I… I enjoy spending a bit of time on history. It really makes me understand more about how things can progress, going forward. Let me just,

Before I start croaking out here, let me just, get myself some water.

the,

The question here, will you write about your own history as a book, an autobiographical kind of thing, or leave that to someone else? Well, I've written lots of pieces of it.

And Maybe one day I'll write some kind of, sort of overall

sort of story, but the fact is, you know, I've written about lots of pieces which already are pretty long descriptions of things, and I think the, I really feel like it's more interesting to talk about one's history in terms of various kinds of arcs of narrative than just the
you know, I was born this day, and this day, and this day. I mean, I've thought about writing about some of my educational journey, because that's kind of interesting. I think people have found that interesting to hear about. I don't know if… another thing that's true about writing one's own history
Is that it is shocking to me the extent to which one understands more in retrospect.
Decades later, I, you know, it's like, I did this, I did this, I did this. Why? How did I come to do this, this, and this?
I mean, I have to say, in terms of my own history, I was actually thinking about writing something about my history with AI, which is, kind of,
I'm not sure I've told that in these livestreams, but, that's kind of,
It's sort of interesting. It sort of reflects and bounces off the general history of AI. I did a bunch of things very early. I didn't believe in certain things. I didn't… I didn't pursue them. Some of those things worked out in the end, some of them crashed and burned. You know, I started a company that wound up as an early AI company in the early 1980s, but that didn't make any sense at the time.
I just found a speech that I gave when I was 12 years old, that was 1972, about AI. And it was kind of a speech that, I cringe a little bit,
with it. I wonder what I actually said in the speech, because I have the… I have my written notes for it.
Which are a fully written out speech, but I doubt that I read it as it was presented there. I think I was a better public speaker in those days than to have actually read the words that were written there, because they just weren't as flowing as they might have been. But, I also kind of cringe because it was a little bit of a… an AI doom
story.
From 1972,
that, well, two things that are a little bit, to me, you know, it was kind of an AI doom story that… was… Perhaps… Not completely misplaced.
but a little bit, kind of, coarse in terms of its idea about how things would play out with AI. And the second thing that is tremendously cringeworthy from modern times is just all those features of the way that one talked about things in the early 1970s,
You know, from…
from, you know, men will do X, which would now be people will do X, and… and so on, that, and… and various features of, kind of, well, I mean, it's all… I was… I grew up in England, and that was a speech given, you know, in
my elementary school in England in, you know, with many Britishisms that, are strange, to put it mildly, you know, whatever it is, 50 years, 55 years later.
There's a question here.
from Harry, did you ever meet Irving Finkel, the cuneiform
Master. I did not, I don't actually know that name.
My son Christopher happens to be a big enthusiast of things Babylonian. He has had a big project for years that's almost finished, he says, to do with making the old Babylonian astronomical diaries computable, finally, after all these years, you know, after teaching LLMs to read Akkadian and things like this.

the, I have to say, I've not encountered that very much. There was one person that I did know named Otto Neugebauer, who was kind of a key person in decoding Babylonian mathematics, and particularly Babylonian astronomy, and this is one of these stories which is sort of an unfortunate story.

Which was, in the early 1980s, I worked at the Institute for Advanced Study in Princeton, sort of famous as the place where folks like Einstein and von Neumann and Godel had worked in the past, I would say, when I was there, it was perhaps a little less distinguished than that. But in any case.

There was, an old chap.

white-haired chap who would, sort of had an office very near mine, named Rotter Neugebauer, and he would sort of

you know, pad around the place, and I would say hi, and, you know, we'd exchange pleasantries. And I knew that his office was just full of card catalogues. Had a big office, and it was just, you know, lots and lots of card catalogues, and I would sort of see him going in there and pulling out his card catalogues and so on. I had no idea what these were. These were actually records of Babylonian tablets.

that he was using to kind of piece together the structure of Babylonian astronomy. I never talked to him about that. This is one of the sad things about life before the web. You know, if the web had existed, I would have typed his name into the, you know, web search.

And it would have brought up all kinds of information about him. You know, even the institution, Institute for Advanced Study, would surely have, you know, I'm sure on their website, probably, maybe even now, from the fact that he was there in the past, but I don't know, there'll be information about him. But in those days, there was nothing like that.

There wasn't, you know, maybe…

if I had gone… I don't know where I would have gone, to find out what was his story, so to speak. It was really word of mouth, and… or I would have to have happened to go to the library and say… I mean, I could have gone to the library and said, let me look up books by Otto Nagebauer, but I didn't do that. And so, to my…

regret. I never had a chance to talk to him about… about ancient astronomy and so on. And, you know, for me, he was just a pleasant white-haired chap who would,

You know, say hi.

But, I mean, I've actually learned even very recently, he had quite a history in… in Germany, where he came from, in the, in the whole…

sort of Nazi period disaster with mathematicians there. He was involved in that, came to the US, he was, started math reviews.

as sort of a place, among other things, to employ mathematicians who were sort of escaping Nazi Germany and so on.

So there was a lot more story and a lot more, kind of, a lot more, kind of, backbone, I would say, that was absolutely invisible by the time this was an old white-haired chap, you know, puttering around and going to his card catalogues and so on.

Much to my regret, not, not making those connections. I actually knew Otto Neugebauer's son, Jerry Neugebauer, because he was a physics professor at Caltech, and I didn't really even make that connection until years later. But, that's a… that's a yet different story.

Elk asks, did you ever meet Carl Popper? No, I did not.

another person I should have met, but I didn't.

I mean, I have to say, in the Did You Meet category.

I have many regrets along those lines, and I have to say, I always am telling young people, you know, if there's some interesting, sort of old person that you kind of wonder about, try and meet them. I mean, among other people I didn't meet, I never met Paul Dirac.
could easily, easily have met him, I just never did. I mean, I had been sort of put off, because people said that he was kind of monosyllabic and, and very hard to talk to, although I think in his later years, when he retired to University of Florida, he kind of opened up a lot.
Another person who I almost met, but didn't, was Werner Heisenberg, and this is just such a silly story, because it was probably 1975,
And, I was 15 years old, and I was working on physics, and I used to go from time to time to… not actually quite often, I would, go to these seminars, physics seminars in Oxford, which was a train ride away from where I was in school in Eton, which is,
I don't know, an hour's train ride away or something.
Then it was an hour, now it's less than an hour. But in any case, the, somebody said, oh, Werner Heisenberg is going to give this talk in Cambridge, which was, in those days, like a 3-hour train ride away, or a little bit more, perhaps.
And, you know, you should come, he said. He always is interested to meet young people, and so on.
And I was like, I don't care. He's an old guy, I don't think he's done anything interesting since the 1940s or something. You know, I don't, I'm not interested. Stupid me.
I mean, for two reasons. One, because it just would have been interesting to get more of a sense of the personality there.
And two, and I would say that when you meet people, at least in my experience, it's kind of like what you read about their personality.
I mean, it helps when there are videos of people and so on, but when, you know, one's own, sort of, one's own impression of the personality is affected by one's own personality, and the interaction kind of makes a clearer idea. And certainly, if I was to write biographies of people, having met them is very useful.
I mean, you know, it's interesting, because I've talked to people who've written biographies of people, like, for example, Jim Glick, who wrote a biography of Dick Feynman. I talked to him about that, and I asked him, did you ever meet Dick Feynman? He said, no.
And his claim was, which I think is partly true, that it's sometimes easier to write a biography if you haven't met the person.
I think it's a mixed bag. But in any case, I am, you know, my second, you know, my second mistake with Heisenberg was that
I didn't know the things that he did after, you know, in the 1960s and so on. He was working on a unified field theory, which the physicists
Thought was all nonsense.
But actually, it was an interesting theory, and it kind of, I think, leveraged work that Heisenberg had done, which I didn't know about when I was a kid, on turbulence and fluids and so on, and thinking about kind of nonlinear equations and so on, and how they play out. And that would have been a very interesting thing.
to I probably would have… it would have accelerated some of my own thinking about these things, I think, quite a long way to have had that interaction. But I unfortunately did not.
Let's see… Well, I think I have to go to my day job in a minute, but
Okay, X7 is asking, in your personal experience and participation in computer history, is there a thing of the past that you particularly enjoyed using and has no modern equivalent or successor?

You know, it's funny, I was dropped in at the Computer History Museum in Mountain View, California, a few months ago, and it's always… it's a well-done museum, I must say.
And it's sort of funny, because I looked through the sequence of computers that are there, and there was lots of, oh, I didn't… I don't know about that, I know about that as a matter of history.
And then there's a moment in the mid-1970s where it's like, I personally knew every computer from here on out.
And I would say that of things lost.
One fun one was the first computer that I used, the Elliott 903, a British computer that isn't in the Computer History Museum, I will say. It's at the museum in Bletchley Park in England, but it's not at the American Computer History Museum. Although.
other things made by Elliott Brothers, the people who made the Elliott 903. Elliott Brothers, was actually a scientific instrument maker dating back into the 1800s, and I did notice that in the sort of early part of the Computer History Museum, they have some other pieces of equipment for, you know, various kinds of slide rule type things from Elliott Brothers, but they didn't get to their computers.
In any case, the Elliott 903 had the feature that it kind of whistled as it worked. So it had a tone generator, and as it was running, it had kind of a representation of some aspect, it wasn't ever very clear quite what, of the running of the CPU.
And so, when it was in a tight loop, you would hear it go, you know, very high-pitched, whistling, and when it was kind of processing something where there were big blocks of data, you would hear, you know, thunk, as it processed different chunks, parts of those chunks of data.
I've sort of missed that.
And in the, I kind of almost feel like, well, at one time, actually, at the beginning of the 90s, we sort of thought about building some of those features into… into Mathematica and our language.
One of the less glorious parts of that was we decided to have a startup sound. You know, it's like games often have this. We decided it was a cool sort of luxury thing for a piece of software to have a, you know, startup-type sound.
which we put in, it lasted for a few versions, and I have to say, people who had, kind of, labs where they had many computers that were using our tech were like, oh my god, I'm so fed up with hearing that sound.
Now, obviously, some computers, like Macs, have a startup sound that's pretty useful, because it's a thing that they can emit even long before the screen drivers are up, and so on. That's a useful thing, it's a useful kind of, oh, people sometimes call them not icons, but earcons.
That, you're hearing there. But I sort of miss the L8903, and its, and its tone generator. That's a one piece of software. I would say that,
You know, most things, they went away for a while, and finally they're back.
of pieces of software that existed in the distant past. I remember screen sharing was a thing that sort of existed from the… from the beginning of the 1990s, and then it sort of disappeared for a while, and then finally is back as a sort of an adjunct to video conferencing, but that was… that went very obscure for a while.
Alright, there's a question from Pozzi.
Are there historical artifacts?
In my library, absolutely.
And I keep on meaning to have one of these live streams where I kind of show you all around some of the things that I have. It's just a lot more technically difficult than having a camera sitting on a tripod right in front of me, so to speak. And we just have to…

get the right moment when we have the right kind of camera talent to go and show this stuff. And I also was trying to figure out
And maybe if somebody has an idea, I'd be happy to hear it. I've got a library full of books, and I'd like to be able to show you guys some of those books.
But if you've got a camera, and you're, like, you walk up to a shelf, you pull a book down, it's not so easy with one camera to then show the book.
you know, over one's shoulder, you put it on a table, I'm not quite sure how to do it. And it may require two cameras, which is an even more elaborate piece of production, and, it's just something where I don't have the right, the right folks,
Around to do that, but maybe we will, maybe sometime, in the next couple of months, we'll finally be able to put that together.
Which would be fun.
Alright, well, thanks for,
all kinds of interesting questions. I see many more that I would love to address, but we'll have to leave those for another time.
Thanks for joining me, and bye for now.