The Chaitin Interview III: The Changing Landscape for Mathematics

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Robert J. Marks:

Is math invented or discovered? That's the topic today on Mind Matters News.

Announcer:

Welcome to Mind Matters News, where artificial and natural intelligence meet head on. Here's your host, Robert J. Marks.

Robert J. Marks:

Greetings. We are fortunate today to talk to Gregory Chaitin, a co-founder of the field of algorithmic information theory that explores properties of computer programs and how long they should be. Professor Chaitin, welcome.

Gregory Chaitin:

Hi, Bob. Glad to be here with you folks today.

Robert J. Marks:

Great. Thank you. So let me just start out with the question. Is math discovered or is it invented? What's your take?

Gregory Chaitin:

Well I think that's a fascinating question, and deep philosophical questions have many answers, sometimes contradictory answers even that different people believe in. Some mathematics I think is definitely invented, not discovered. That tends to be trivial mathematics papers that fill in much needed gaps because somebody has to publish. So you take some problem, you change the wording of the mathematical problem a little bit, and then you write a paper, you solve it and then you write a paper.

Gregory Chaitin:

But other mathematics does seem to be discovered. That's when you find some really deep, fundamental mathematical idea, and there it really looks inevitable. If you hadn't discovered it somebody else would have discovered it because it really seems to be a fundamental idea.

Gregory Chaitin:

One idea is that mathematics is in the mind of God or in the platonic world of ideas. It's all there, and all we do is discover it. But I think there's a distinction. Poincaré, a famous mathematician, Henri Poincaré, he said, it sounds better in French than in English, he said, "There are problems that we pose and problems that pose themselves."

Robert J. Marks:

Yeah.

Gregory Chaitin:

So those are the two different kinds, invented and discovered. So when you find some really fundamental new mathematical idea, you have this feeling that you've seen into the mind of God and it's really fantastic. That would be Cantor, Georg Cantor. Or if you hadn't discovered it, someone else would have, because it's so basic, it's so beautiful that it's got to be there in the mind of God or in the platonic world of ideas. But everything is in the platonic world of ideas, the platonic world of mathematics.

Gregory Chaitin:

But if you're a mathematician at a university and you're struggling to publish, I don't know how many papers per year, you can't work on such fundamental questions all the time because then you won't publish enough papers, right?

Robert J. Marks:

Yes.

Gregory Chaitin:

So there is this pressure to invent stuff, minor variations on previous work. That is a shame I think, and I think it should be regarded as being invented, although one attitude is to say that it's all in the platonic world of mathematics.

Robert J. Marks:

In engineering, we call these 3DB papers, three decibel papers, because three decibels is the minimal amount that you can increase the volume of something and detect it. So there are landmark papers and then there's lots of 3DB incremental papers-

Gregory Chaitin:

I see.

Robert J. Marks:

That you talked about.

Gregory Chaitin:

You guys have the same pressure to publish as everyone else, right?

Robert J. Marks:

Exactly. Exactly.

Gregory Chaitin:

Yeah.

Robert J. Marks:

Yes, it's unfortunate because you don't hear the word scholarship very much anymore in academia.

Gregory Chaitin:

And people don't write books. In the past, some wonderful mathematicians like G.H. Hardy would write wonderful books, A Mathematician's Apology or his book on number theory.

Robert J. Marks:

And they're just beautiful papers. Claude Shannon's paper is just a wonderful paper in the founding of Shannon Information Theory, and Lotfi Zadeh in 1965 wrote a wonderful paper on the founding of fuzzy or soft logic, and I don't see those sorts of papers anymore. Everybody's interested in number more than quality.

Gregory Chaitin:

Well nobody can work on a difficult project, which may be years until you come up with something or maybe you'll never come up with something. So if you want to try that kind of stuff you have to do it in parallel with more normal stuff. I think that Andrew Wiles, when he was working in secret for years in his attic on Fermat's Last Theorem, he couldn't have stopped publishing altogether so he probably had more routine mathematical questions he published on and he probably cursed them because it was taking time away from his great project. But the great project, it could have failed.

Robert J. Marks:

He would need something to fall back on. There's an old academic joke that the Dean can't read, but the Dean can count. They don't look at the contents of the paper, but they just count the paper numbers.

Gregory Chaitin:

Right.

Robert J. Marks:

I think that's unfortunate and there's a pressure to reduce the quality of papers.

Gregory Chaitin:

There also used to be professors who were wonderful teachers. The students adored them. They learned a lot from them. But they weren't a research mathematicians, for example, and you can't do that anymore. You don't get credit for being a wonderful teacher as far as I know or for writing wonderful books. You have to have refereed papers if I'm not mistaken.

Gregory Chaitin:

So that's too bad, but what can you do? We have to play it according to the current rules, right?

Gregory Chaitin:

I was able to not play it according to the current rules because I was being paid to do industrial development work for IBM at IBM research. So I worked on hardware, I worked on hardware design. I worked on the software for new hardware. That was a lot of fun, and I was doing my mathematical research as a hobby basically. So that was how I created an ecological niche for myself, because I had a rather unconventional story as a mathematician. I don't have a degree. I only have honorary degrees.

Robert J. Marks:

You hear about people who were discouraged from doing publication. I don't know if it was Popper. It was somebody like him that wrote that his institution didn't want them to publish because it took away time from teaching, and that certainly changed.

Gregory Chaitin:

He was a professor at first in New Zealand, I think, and he had a terrible ... He had to escape from Europe. I think he might've been Jewish and maybe he ... Anyway, he managed to get into New Zealand and he had a terribly heavy teaching load. Then fortunately he managed to go to the London School of Economics, I think it was. There he didn't have that outrageously heavy teaching load.

Robert J. Marks:

We even see this from, I guess he was an employee of the Guinness Brewing Company, Gosset, who came up with this incredible math which is still taught today to undergraduates. He couldn't associate his name with the article, so he published under the name Student T, and we still refer to it as the Student T or the T statistic. He was also under pressure not to take time away from his work.

Robert J. Marks:

Today it's exactly the opposite, by the way. If you're a mediocre teacher and you publish a lot, you get all sorts of accolades as long as your teaching is acceptable. That's unfortunate, but that's the way things have evolved.

Gregory Chaitin:

Well what can you do?

Robert J. Marks:

You got to play the game, I guess, right?

Gregory Chaitin:

Well, you don't have to. Look at Elon Musk. He's my great hero. He's a wonderful engineer and he's a wonderful entrepreneur and he doesn't follow the rules.

Robert J. Marks:

He doesn't, and innovators don't follow the rules. I think that's one of the elements and one of the characteristics of creativity.

Gregory Chaitin:

That's tough. Elon is clearly a genius, amazing engineer, incredibly talented and innovative. But he also has to figure out a way to do this in the real world, and he has managed to do it. So that's a remarkable achievement also and I admire him greatly.

Robert J. Marks:

But then again, we were talking offline about the relationship between genius and creativity. We talked about, for example, the quirkiness of Gödel, and Georg Cantor spending a lot of his life in a sanatorium because of mental anguish.

Robert J. Marks:

Elon Musk has his quirks too. He has opined that we are all computer simulations.

Gregory Chaitin:

He has? Well that's a popular view now. The computer has replaced God in a lot of people's minds, and I think we're all the poorer for it, but it's the fashion now. So we're machines. We're machines. AIs are going to be better than us. Human beings will be obsolete. This is the fashionable view, and of course I don't appreciate it very much.

Robert J. Marks:

Well that's wonderful. Mind Matters and our podcast is part of the Bradley Center, the Walter Bradley Center for Natural and Artificial Intelligence, and that's one of the things that we push back on, is the idea that there are things that machines can't do that humans will always be able to do. We actually use some algorithmic information theory to back the theories.

Robert J. Marks:

I'm glad to hear that. I'm glad you're not a proponent that machines are going to replace people. We still have some attributes that I think will never be duplicated.

Gregory Chaitin:

They might replace people if they're cheaper and better at uninteresting tasks. But I think human beings will always be better at creativity, at doing art. As Turing said, "A computer is likely to write poetry that only another computer would enjoy reading."

Robert J. Marks:

That assumes that another computer can enjoy. I don't think computers have the capability of enjoying.

Gregory Chaitin:

I don't know. Elon Musk is worried that AI will get out of control, and he also has his personal project to not let computers replace humans by coupling computers and humans into a symbiosis where both can contribute what they're best at. I can't remember the name of the company that's working on a higher bandwidth connection.

Robert J. Marks:

It's called Neuralink, I believe.

Gregory Chaitin:

That's right. That's the one I'm thinking of.

Robert J. Marks:

Where he implants a chip in the brain. I think I'm going to wait awhile before I do that. I don't think I want a chip in my brain.

Gregory Chaitin:

Well to justify doing that they're doing it for people who are quadriplegics, for example, who need help. No one will argue that it's a good thing.

Gregory Chaitin:

But trying to make a symbiosis between humans and computers. Elon thinks you need to do that so the human beings aren't left behind. So if you give a high bandwidth link between computers and people he thinks that'll help people to not feel obsolete, but to participate.

Gregory Chaitin:

Human beings use machinery, and we don't think that just because I can't run as fast as a sports car or lift as much weight as a steam shovel, we don't think that that means that human beings are valueless. We invented those devices.

Gregory Chaitin:

Similarly, some things computers certainly are better at than humans, like remembering precisely large quantities of information unless you have a photographic memory. Elon seems to have a photographic memory for technology while Norman was said to have a more general photographic memory.

Gregory Chaitin:

So a symbiotic relationship between the two of us, each one might contribute what they're better at and people will not feel that they have become obsolete. It'll just be like using a steam shovel or using an airplane instead of trying to fly by flapping your arms.

Robert J. Marks:

The comedian Emo Philips says that computers might be able to beat him at chess, but he can always win a game of spirited kickboxing. So I think that, yeah, there are things which computers can do, they can do well. But there are limitations on them.

Gregory Chaitin:

On the other hand, we invented the computer. So we can take the credit for whatever they do well.

Robert J. Marks:

Well yes, and you'll notice this idea of Elon Musk's fear, and I don't want to detract from Elon Musk because he's clearly a genius. But this assumption that computer software is going to write more creative computer software that's going to write more creative computer software, and you're going to have an AI which reaches just this hyper intelligence has the assumption that computers can write programs that are creatively more able to do things than the original computer programs.

Gregory Chaitin:

I would think a team of brilliant engineers might write an amazing piece of AI software, but the AI software doesn't rewrite itself.

Robert J. Marks:

Exactly. This actually dovetails, this is something I think I read that you wrote, and you have to correct me if I'm wrong. But you were talking about computer programs and software that was able to prove

meaningful theorems, that is insightful theorems of the type that a brilliant mathematician would write. I believe you said that there's no evidence of that happening.

Gregory Chaitin:

Well I made that remark some years back. What they have now are proof checkers. You write the proof in a special language, in a precise mathematical notation, and there's software that can check if the proof is correct or ask you to provide more steps if it doesn't understand how one thing followed from another. That technology is improving, so there are mathematicians who claim that at least that all of math should be written up this way and submitted to checking like this. But these computers are not doing wonderful new mathematics.

Robert J. Marks:

Exactly. There's a difference between checking the proof and originating the proof.

Gregory Chaitin:

There's an enormous difference. Now, there is what I regard as a piece of AI, so it might be interesting to talk about it. My friend, Stephen Wolfram, the system he's created, I don't know what it's called, the Wolfram Language, WolframAlpha-

Robert J. Marks:

Yes.

Gregory Chaitin:

What Euler would have accomplished with that is unbelievable. Euler and Gauss used to calculate, were wonderful at doing calculations, and they would do lots of calculations and then make conjectures based on the patterns they saw.

Gregory Chaitin:

Well, if Euler or Gauss had had WolframAlpha or Mathematica, they would have done a lot more. Especially when you go to WolframAlpha, it begins to start feeling like an AI. Now it's an AI which has a big team of people behind it who take information and curate it about the world, about physics, about chemistry, about economics, about geography. They curate it and they put it into the system.

Gregory Chaitin:

But it's pretty amazing. It would have looked like magic, I think, to people. Well computers, almost any computer would have looked like magic just a few years ago.

Gregory Chaitin:

But I think this is a genuine AI, but it's not a human general intelligence and it's not creative. But it's different. I think it's an enormous achievement what Wolfram has done.

Robert J. Marks:

Wolfram's Mathematica and his other works are just astonishing in what they can do. But as you mentioned, they're all algorithmic. The logical steps, much like the theorem checker, are something

which humans have placed in there which allow you to put in things like indefinite integrals and advanced calculus equations-

Gregory Chaitin:

Right.

Robert J. Marks:

And it gives you the solution. It's really, really remarkable.

Gregory Chaitin:

Wolfram is a genius. I rate him with Elon Musk. He's a genius at different kinds of technology than Elon is. So WolframAlpha is an accomplishment of this man of genius who is just like Elon. Elon has an enormous team of very talented engineers. But he's on top of the whole thing, making it work. Wolfram has wonderful mathematicians, wonderful software people working for him.

Gregory Chaitin:

So this artificial intelligence of an inhuman kind that they've created, but it's very powerful. It's done by human beings, so I think we should be proud of that achievement.

Robert J. Marks:

We should be proud.

Gregory Chaitin:

But it's not creative.

Robert J. Marks:

Yes. I think the creativity is the big thing.

Gregory Chaitin:

It didn't program itself. Wolfram worked very hard with all his people to make it capable of doing more and more and more. It wasn't his software that made this thing involved to what they can do now. It was all of them working very hard on it and Wolfram making sure they had a system that could be extended.

Gregory Chaitin:

Because what often happens to software is that, I know because I worked doing software for IBM, is there comes a point where basically the software dies. Because what happens is it's so complicated that no one can understand it anymore, which means if you get bugs, it's tough to debug it and it's also tough to make any enhancements.

Gregory Chaitin:

So the fact that the mathematical language has gotten us all the way to WolframAlpha is something that Stephen worked very hard on, to have a system that could grow and be extendable that wouldn't end up

dropping him in a corner like most large corporate software does eventually. So far he's achieved this remarkably.

Robert J. Marks:

Oh, it's astonishing.

Gregory Chaitin:

But this is a human being of genius with a very talented team of engineers, mathematicians. This is not software that reprogrammed itself.

Robert J. Marks:

I think that AI in general is going to be a tool which we can use to better ourselves.

Gregory Chaitin:

Absolutely, like a steam shovel, right?

Robert J. Marks:

Like a steam shovel, exactly.

Gregory Chaitin:

It doesn't mean that human beings are obsolete.

Robert J. Marks:

I read the chapter by Stephen Wolfram in your Tribute book, which we're also going to list in the podcast notes. He went, somewhere, I'm not sure, but he went to a library and he took a bunch of pictures of the notes of Leibniz. I tell you, boy, we've come a long way. These old mathematicians, they couldn't compute e to the third power. They just couldn't enter it. They had to go to their margins and work out all the details. It's astonishing all of the work that they had to do that we don't have to do today.

Gregory Chaitin:

Exactly, and Leibniz made mistakes in some of his arithmetical calculations there in the manuscripts. He wasn't good at that. But I don't know, you could say we don't have anybody at the intellectual level of Leibniz. It depends how you rank it, because he was good at so many, he came up with fundamental new ideas in so many fields. Maybe it's because he never married and never had children.

Robert J. Marks:

Yes, exactly.

Gregory Chaitin:

But he was off the scale which shows what human beings can achieve, Euler and Ramanujan and Cantor showed what human beings can achieve.

Robert J. Marks:

This is very interesting. I was sitting down tallying, I think, the intellectual giants that have introduced new mathematical ideas, brand new. I was thinking of people like Claude Shannon, Lotfi Zadeh, yourself. I don't know if we see these introduction of new, great ideas today. At least I don't see them. Do you have any thoughts on that?

Gregory Chaitin:

Well I think the bureaucracy is killing the golden goose. There's too much control. You have to get research funds, you have to publish lots of trivial papers and you spend too much time filling out grant proposals.

Robert J. Marks:

Yes.

Gregory Chaitin:

They're managing to make it impossible for anybody to do any real research. You have to say in advance what you're going to accomplish. You have to have milestones, reports. So what happens, and the European community has made it worse. I was talking to a scientist in Europe and she told me, "I have to spend all the time interfacing with the bureaucracy in Brussels. I put together a research team but they are the only ones really doing the research because my time is all taken with this administrivia." So if you give the bureaucrats a chance, they'll grow and grow and grow and eventually sink the ship. But this seems to be the way this society is working.

Gregory Chaitin:

The Chinese seem to be innovating and engineering in a remarkable way. They have a different system. I don't know what it's like there. I've seen videos of them putting up a building in amazing speed, with amazing speed, for example.

Robert J. Marks:

There's an old saying that only rich countries can afford poets. We used to have these great research centers such as Bell Labs, which dissolved after divestiture, I guess.

Gregory Chaitin:

They got so many Nobel prizes. They got so many Nobel prizes.

Robert J. Marks:

It was incredible. But they dissolved. It was a rich country so they could have these poets where they got together some of the greatest engineers and scientists of all times. Maybe they would only make one big breakthrough in their lifetimes, but they employed them for their lifetimes, for their scholarship.

Robert J. Marks:

We also see this today at Google, where Google is making available to people all of this wonderful artificial intelligence software. That's where I see the innovation coming from and not so much from academia.

Gregory Chaitin:

Right. Well the universities were always very conservative. Elon Musk makes, I think, this remark in an interview he gave, maybe it was just a few days before that remarkable flight of the Starship SN8. I think he makes the remark that if you don't have a lot of research projects that fail, you are not doing enough research. The problem is if failure is unacceptable, then you're in trouble.

Gregory Chaitin:

For example, the Legacy Aerospace companies that make rockets, they take years to design a rocket and it's got to work on its first flight. Whereas Elon does rocket engineering the way you develop software, using it.

Gregory Chaitin:

The software I worked on, we were constantly using our own software. We were doing compiling and we kept compiling the compiler through itself, so we were constantly eating our own cooking. We had many prototypes, and if there was something wrong we would fix it and try again.

Gregory Chaitin:

Elon is doing that. He's doing his rockets very fast and breaking them and learning from each. So if you don't have a lot of research projects ... But failure is now unacceptable. That means the research projects have to be very conservative. You can't try something really crazy.

Robert J. Marks:

If you try to do a project and you fail you can't publish it. That's bad for the bean counters.

Gregory Chaitin:

Well the bean counters should get out of our way.

Robert J. Marks:

Let me ask you this. What is the solution? Do we have any solutions? One of which, this is very controversial to me. I think that some of the government funding is not good. I know in Japan and Germany they require, well this is one solution, they require interface of the professors with industry so that they can work on more interesting problems. But that doesn't clear people up to pursue pure creativity. So what's the answer? How can we fix this?

Gregory Chaitin:

It's tough. I have a pessimistic vision which I hope is completely wrong, which is that the bureaucracies are like a cancer, the ones that control research and funding for research and counting how much you've been publishing. I've noticed at universities, for example, the administrative personnel are gradually taking all the best buildings and expanding. So I think that a society, the bureaucracy and the rules and regulations increases to the point that it sinks the society.

Gregory Chaitin:

At that point, basically, I think I expect like with companies, the country will collapse because it will fail in a competition with a younger, more vigorous, more daring country. So nations and corporations seem to have a life cycle like human beings do, vigorous youth where they think they can do anything and

then they get very conservative. They don't want to come up with a new product which competes with their existing product line because you can't predict how much it's going to earn in advance.

Gregory Chaitin:

At IBM it used to happen. The salespeople would, this is a completely new technology, a new kind of computer, they're going to make a very low estimate of how many are going to sell so we have to charge a lot for each one because we had a lot of development costs and you have to divide it by the ... We weren't allowed to dump products.

Gregory Chaitin:

So the result is that it's a lost cause. If you want to try some daring new product it's going to be so expensive that no one is going to buy it.

Robert J. Marks:

It's frustrating.

Gregory Chaitin:

It's more than frustrating. I think it's the end. When our society reaches that point, their innovation is going to go down.

Gregory Chaitin:

I remember when I was a kid, Scientific American every month was very thick. Why was it thick? Because it had lots of ads from General Dynamics, from other aerospace companies that were trying to hire wonderful engineers. Things were more dynamic.

Gregory Chaitin:

What did an airplane engineers say once in a speech I heard? He said, "In the old days, a bunch of engineers could go to a motel for the weekend, so they wouldn't be distracted by their family, with a bunch of six packs of beer and design a new airplane."

Robert J. Marks:

Uh-huh (affirmative).

Gregory Chaitin:

That doesn't happen anymore. Elon refers to some of these topics in his ... It was an interview by the Wall Street Journal, somebody at the Wall Street Journal. I think it was the 8th of December. I found it on YouTube.

Gregory Chaitin:

So these are all, since I was working in industry, I could see all these forces at work at IBM, which in the early days was full of adventurers. There was no computer engineering. The guy I worked with, I think his field was English literature originally. But he wanted to make a new industry. He was fascinated by computers and he was one of the great contributors at IBM.

Gregory Chaitin:

So IBM was very vigorous and innovative at first. But then it got more and more bureaucratic and afraid of competing with their existing products. So you get to the point where a new kind of computer can only come from a new company because the existing company will never want to take a chance on something new.

Gregory Chaitin:

Anyway, all this worries me. I hope I'm completely wrong and this doesn't happen. Elon Musk certainly is an example that it's still possible to be tremendously innovative in the field of technology. But he also talks about bureaucracy and how it's a question that worries him a lot, and the fact that failure is not allowed, whereas you have to learn from your failures. If you don't fail, it means you're not innovating enough.

Gregory Chaitin:

That worries me a lot. I hope I'm wrong, but I have this vision of the life cycle of corporations and nation's eyes. I saw what IBM was going through, and a lot of people are worried that China is becoming more capitalist than we are in a funny way.

Gregory Chaitin:

I don't know, but I think it's something that I worry about and here in South America I see US influence disappearing and more and more business with ... China is now the leading trade partner for a lot of countries in South America rather than the United States.

Gregory Chaitin:

I used to have an account here, a bank account in Citibank, which is the bank I use in the US, and they decided to leave. Yeah, they sold all their customers and all their branches to another bank, a Brazilian bank.

Robert J. Marks:

Boy, that's interesting.

Gregory Chaitin:

It's worrisome. But on the other hand, the Elon Musk and Stephen Wolfram makes me think that the United States can still do basic innovation in spite of everything.

Gregory Chaitin:

Maybe the bureaucracy is ... I remember when I lived in France, people told me that to have a startup it's much easier in the United States than in France. The rules and regulations are very tough for a number of reasons that I won't go into and I actually don't remember very well.

Gregory Chaitin:

That's probably why Elon Musk wanted to come to the US. He went from South Africa.

Robert J. Marks:

Now he's moved from California to my backyard in Texas.

Gregory Chaitin:

Probably because California, all of the aerospace companies have left manufacturing. Aerospace manufacturing is all gone from California. Too much bureaucracy. I think Texas is a freer place.

Robert J. Marks:

Yep, so far. I hope we can keep it that way.

Gregory Chaitin:

Let's hope so. So Elon built his spaceport in Southern Texas and he's moved his foundation there.

Gregory Chaitin:

Fortunately there's still Texas. Texas could be a separate country.

Robert J. Marks:

It can, and you know there's rumors that when we joined the union, we were a separate country.

Gregory Chaitin:

You spend a year as a separate nation then, didn't you?

Robert J. Marks:

Yes. The Republic of Texas.

Gregory Chaitin:

Right.

Robert J. Marks:

In fact, I work at a place, Baylor University, that was founded when Texas was a Republic.

Gregory Chaitin:

Well I worry about creativity. I have a chapter on that in my book, Proving Darwin. I make a remark that from the point of view of creativity, I think that the best thing to do would be to split up the European community in separate countries and split up the US in separate States. Because that would give more freedom of action to creative people instead of having a central bureaucracy.

Robert J. Marks:

And it would set the free enterprise system into effect.

Gregory Chaitin:

I once asked a Greek how come ancient Greece was so innovative? He told me, "Well the ancient Greeks asked that question themselves and one answer," I don't know where the answer is, but he didn't tell me that. But he said, "Because Greece was divided into separate city states, and actually it wasn't Athens. The talented people would come from other city states and they would go to Athens. Whereas Egypt was very uncreative. And why was that? That was because it was flat and they weren't split up in separate islands or on land divided by volcanoes as Greece, or mountains."

Gregory Chaitin:

So a central government was able to control all of Egypt and as a result Egypt wasn't very innovative, ancient Egypt. And the crazy Greeks were always fighting each other and always with these separate little nations, the city states.

Robert J. Marks:

Well Greg. We've been talking to each other for quite a while. I think that we've come to the end of this podcast and we're going to continue our conversation on a subsequent podcast.

Robert J. Marks:

We've been talking to Professor Gregory Chaitin. He's one of the co-founders of algorithmic information theory, and until next time on Mind Matters News, be of good cheer.

Announcer:

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