Demetri Kofinas: What's up everybody? Welcome to another episode of Hidden Forces with me, Demetri Kofinas.

Today, we speak with one of the pioneers in the science of complexity, Brian Arthur. Dr. Arthur has long been associated with the Santa Fe Institute, having served on its Board of Trustees and its Board of Science. He has been described by Fortune [00:00:30] Magazine as one of the country's leading economic thinkers, and he is best known for his pioneering work on the operation of high technology markets. He is the author of numerous papers and books including The Nature of Technology: What It Is and How It Evolves, and Complexity and the Economy: A Collection of Papers on Economics and Financial Markets Examined from the Perspective of Complexity Theory.

In this episode, we examine the emerging field of complexity. [00:01:00] We look at its interdisciplinary history. A history born from the work of mathematicians, physicists, philosophers, ecologists, biologists. A field bound together not by its adherence to perfection, but by the imperfections of the natural world.

This is going to be a discussion far from equilibrium. It's going to be messy. It's going to zig. It's going to zag. We're going to cover the booms and the busts of Joseph Schumpeter. The information laden price signals of Frederick Hayek. [00:01:30] The chaotic orbits of Joseph Ford. The infinite fractals of Benoit Mandelbrot. We touch on information theory, cryptography, quantum potentiality, and dive deep into the waves that make markets and life so volatile: a volatility that is born of a universe whose countless mysteries we seek to understand.

As always, you can gain access to reading lists put together by me, ahead of every episode, by visiting the show's website at hiddenforcespod.com.

[00:02:00] Lastly, if you are listening to this show on iTunes or Android, make sure to subscribe. If you like the show, write us a review. If you want a sneak peek into how the sausage is made, or for special story lines, go through pictures and questions, then like us on Facebook, follow us on Twitter and Instagram, at @HiddenForcesPod.

Now, time for this week's conversation.

Professor, thank you so much for being on the program. I really [00:02:30] appreciate you waking up so early over there in Singapore.

Brian Arthur: Glad to be here.

Demetri Kofinas: I was saying to you, before we started, that I do have some background in the field; informal. I mean I've studied it out of sheer curiosity. I'm familiar with the work of people like Edward Lorenz and Stephen Smale and James York and Joseph Ford. Then, of course, there are people within information theory, [00:03:00] which I think dovetails in this in some way. People like Gregory Chaitin and Ray Solomonoff and people like that. Of course, there's Benoit Mandelbrot as well. In fact, that kind of gets to something that I wanted to say off the top, which is one of the things that really fascinates me and interests me about complexity theory and complexity science is the interdisciplinary aspect of the field. It's also very rich, I find it as well.

[00:03:30] I think it would serve me, certainly, and our audience as well, best if we started with an overview. And really, if you could give us a historical context for complexity as a science, as a theoretical framework for understanding the natural world, for understanding the world as we know it, how that sort of evolved over time? Again, given the fact this was really a field of people coming in from different [00:04:00] areas who are looking at their models and saying "Something's not right here and we want to get to the bottom of this, or the top," I guess.

Brian Arthur: Well, for three or 400 years, since the time of Galileo and Newton after that, there's been a real take off of science. The way it was conducted for several hundred years, very, very successfully, was to look at nature from the top [00:04:30] down. You look at something like an animal, or a bunch of animals of the same species, and then you can look at a single animal, and you can look at organisms within the animal, and cells within the organs, and so on. Like taking a Swiss watch apart. What science has done over many, many years is to take nature apart and look at its pieces and analyze how each piece works and [00:05:00] trying to figure out, also, how some of those pieces at a certain level work together.

There's many, many definitions of complexity, but complexity tends to go in the other direction. It's asking if you have a bunch of pieces, may be affecting each other, or influencing each other, how does the whole operate? [00:05:30] Imagine that the pieces or the entities we're looking at, say, are cars. Cars spaced out on some sort of freeway in Montana don't have much effect on each other, but if it's New Jersey, where they're bunched up and very, very densely packed, then each individual car is reacting to its neighbor cars, and you get patterns emerging. Traffic might be flowing pretty well, some [00:06:00] animal runs out, or somebody spills their coffee while they're driving, and slows down as an automatic reaction, and maybe cars behind that slow down and further cars behind that, and suddenly a jam emerges and a pattern forms.

We're looking always, in complexity, at patterns forming and nearly always from the bottom up. If you have cells in the immune [00:06:30] system, how do they form something we call immunity as a larger level pattern?

Demetri Kofinas: With respect to the history of science, and you mentioned Galileo, you mentioned this sort of Newtonian world that seems, I think you were going to this world of component parts, adding up in a linear way, and this sort of classical interpretation of the world and methodology and model. Can you expand a little [00:07:00] bit on what that really means and how that works scientifically, so that people really are able to understand where you're going with complexity and how it differentiates?

Brian Arthur: Sure. Yeah. From the time of Newton on, people have been looking in finer and finer detail at nature and trying to figure out how these individual parts add up linearly and create something. [00:07:30] They made some simplifications along the way, because really all we had to work with mostly was pencil and paper if we're doing theory. We were just trying to figure out what simple mechanisms are. A lot of the assumptions we made were that the world is somehow an equilibrium, that all the forces we're looking at, in a given area, whether they're in geology or biology for that matter, in [00:08:00] the economy; all those forces are really well balanced, so nothing really new is happening.

Bit like a spider's web, a spider's web has many, many parts. They're all neutrally holding each other in balance. If everything stayed the same, we could do the analysis and we could write down equations for the system. We could treat as if it was static, it wasn't going anywhere, and we could hold [00:08:30] it still while we took a snap shot of the whole thing and analyzed it, and how the equilibrium balanced out, and you'd learn quite a lot from that.

There are a lot of people in history, people like Henri Poincare, in France, about a hundred years ago or more, people were not that satisfied with this. Then if you said hang on a moment, it's not a spider's web, it's little [00:09:00] parts that are moving and affecting other parts that are moving. Everything's affecting everything else and it may never settle down and maybe always showing quite new things. But there's no way to analyze that, to hold it still, with pencil and paper. You couldn't easily write equations for a 100,000 things interacting and affecting each other.

Then, around the 1980s, early 1980s, [00:09:30] we all got computers. We got what we called then, desktop work stations. I haven't heard the term in a while. We got laptops after that. We had super computers and so on. People were able to take each element, a bit like cars and traffic, and assign each element its own little computer program, how was it going to react given what the others were doing? [00:10:00] And then hit the return button and see how the whole system, all the little elements, reacted to all the other elements in the system, and what patterns might form, and what those patterns might tell us.

Sometimes, lo and behold, that settled down to the static equilibrium that traditionally sciences were interested in, and sometimes it didn't. Sometimes we saw new phenomena, sometimes [00:10:30] new things would emerge that we hadn't thought of. But really, it's a shift from looking at the world, we say in reductionist terms, from the top down, and imagine everything holding everything else in an equilibrium where not much is changing at all, to looking at the world as alive. Everything's affecting everything. In standard phrase, it's sort of 'one damn thing after another', [00:11:00] and with elements reacting to other elements. Some elements, if they're human beings, might be exploring, seeing if they can do better and changing. That changes the system and so other elements need to change as well.

Demetri Kofinas: To stamp that point home, you mentioned equilibrium, which is such an important point, because these models ... and including in economics, which we're going to get into, relied on this notion of equilibrium. They also relied ... [00:11:30] or rather, they sought simplicity-

Brian Arthur: Yes.

Demetri Kofinas: ... of course. They were highly deterministic. I suppose, also, complexity is not suggestive of a non-deterministic system, but rather one that's unpredictably deterministic. So, there was, essentially, just to frame this, there was essentially a problem in the sense that these models were elegant, they worked very well. For many people, I should mention, they still seem ... [00:12:00] I mean policy makers and central bankers, this is an area where many of the economists and the practitioners and the policymakers rely on these models that look at the world in equilibrium and seek out a place of stasis. They look to achieve stability. Their goal in policy is to somehow arrive at that point of equilibrium. From what I understand, having some [00:12:30] sense of the history of the field of complexity science, it emerged out of this recognition that as much as we may wish to achieve a level of simplicity in our models and we like this idea of equilibrium, that it didn't match with reality.

I also should say it's great that you bring up Henri Poincare. I always mispronounce his name, but one of my favorite quotes of his ends with "chance is only the measure of our ignorance." [00:13:00] That quote was embedded in a lot of my understanding around noise and randomness and the message in information theory.

Brian Arthur: For many, many situations, this equilibrium point of view, where all the forces are balanced, if you want; that is quite appropriate. That's what we teach. We teach students this from high school on and we teach that in the universities. I'd say 99% [00:13:30] of science sees the world that way. For example, you might be looking at the Rocky Mountains, or the Himalayas, or some sort of geological formation, and under gravity these mountains are pushing down on the earth, and the earth's pushing back on the mountains, and all of this is floating on some sort of magma on top of the earth, and all those forces are in balance.

But, occasionally, [00:14:00] systems like that get out of balance, possibly in California or in Japan or somewhere like that, and some of these forces trigger other forces: it may trigger an earthquake. Then faults move and forces propagate and other earthquakes may happen along the same fault, or not too far from that fault. So, you get these events, triggering events, triggering [00:14:30] other events, and propagating across the system. That's the kind of thing, the propagation of changes that aren't in equilibrium, that's the kind of thing that interests complexity.

Demetri Kofinas: That of course happens: the more interconnected a network, the more propagation across that network.

Brian Arthur: For sure. Complexity role is looking at interconnected things. Quite often we're looking at networks, we're looking at things that are reacting to things. [00:15:00] So, in a way, the way I would define a complex system, is a system that has a lot of elements; that could be cars and traffic, it could be cells in the immune system, it could be consumers or producers in an economy, and those systems are reacting to the overall pattern that the individual elements create. So, there's a lovely feedback loop there, [00:15:30] the elements, say cars, are creating something we can call traffic, and in turn they're reacting to traffic, but they're reacting to the pattern that the cars create, and I find that fascinating.

It's not that complicated. It's not hard to grasp. Complexity, I don't think, is that well named. We should have called it 'interactive systems' or something. But it's [00:16:00] fascinating in that you're always looking at elements that create some outcome, those elements are in turn reacting to. Sometimes, that's all in unison. Sometimes, the reactions give you harmony and stasis, and everything is very highly ordered, and goes on, pretty much, forever. Other times, you get disruptions rattling across or propagating across the system. Sometimes you get new patterns forming.

[00:16:30] Let me give you a quick example here. I arrived in Silicon Valley in 1982. Earlier than that I'd been in Berkeley, in the early 70s, late 60s. But I arrived back, and I was in Stanford from '82, and you could say Stanford, or Silicon Valley, that area in California now called Silicon Valley, has a high tech economy. If [00:17:00] you believe standard economics, you think, well, you know, that economy holds itself in balance. That there are so many companies competing, that prices for transistors would emerge, or computers, or whatever they're making.

But Silicon Valley consists of elements, little companies, startups, big companies like Apple and Facebook, and these are always changing, [00:17:30] and those change the landscape, and they form a sort of ecology among themselves. Facebook becomes an ecology for other startup companies. So does Google. Google, may be the hope that a startup company has, I startup some new app or some clever computerized or digital idea, I'm hoping maybe that Google will buy me out.

Demetri Kofinas: That's all of our hopes.

Brian Arthur: Okay. Yeah. I [00:18:00] wouldn't mind Google buying myself out!

But Silicon Valley isn't in equilibrium: it's seething with activity. One of the examples I'm fond of using for complexity and the difference it makes from equilibrium, strange to say, I got fascinated by, the sun. Galileo points his telescope to the sun in 1610, and he sees [00:18:30] this spherical ball of fire. From that distance, he discovers sun spots and a few imperfections, which were a bit shocking in 1610, for something that's supposed to be perfect.

If you think about the sun, historically, if we stare at it, even with telescopes from afar, before we get a bit sophisticated and have really good telescopes, what you see [00:19:00] is a big round mass, or ball of fire that is holding itself in equilibrium. Gravitational forces holding all those elements of whatever they are, particles, in the sun; atoms, particles of hydrogen, helium, et cetera: they're all held together in a big, spherical equilibrium. But actually, if you look at it up close with a modern telescope [00:19:30] and particularly with x-ray types of telescopes, you don't see up close, you don't see a spherical sphere in equilibrium: the whole sun is seething and boiling with all kinds of things; mass plasma eruptions; x-ray bright spots; x-ray dark spots; magnetic loops. So, it's like the surface of that's water boiling. All [00:20:00] that energy, of course, is coming from fusion, coming from deep inside the sun, but it comes to the surface and the whole thing is boiling away.

From one point of view, to a first approximation, the sun is a big animal, a big creature, whatever, a big body that's in equilibrium. Close up, there's no equilibrium at all: all of this is seething and boiling and sending off mass plasma eruptions, et cetera, [00:20:30] all the time. The economy's a bit like that. From maybe afar, an economy looks as if it's in equilibrium and maybe many parts of it haven't changed and aren't doing much for decades or centuries. Maybe the shoe industry in Italy in the 1800s didn't change that much in decades. Other parts of the economy are changing. All the creatures in that, all [00:21:00] the different firms, are jockeying for position and each is affecting each other. So that's the complexity point of view: everything's changing.

Demetri Kofinas: A few things. I want to continue along that thread. What you're really getting to there is also Joseph Schumpeter created destruction. I really want to touch on some of the great work that was done by a lot of those thinkers, before the neoclassical models became doctrine in economics.

Also, I think it's really fascinating. I love [00:21:30] how fascinated you are and how passionate you are about this. I've seen that in your talks and I find it really refreshing and wonderful. I think telling, also, of not just your own passion, but also how much there remains to be discovered in this field.

A few things, before we circle back and just close off a loop on some of the things you were saying with respect to feedback, percolation, and some of those things, [00:22:00] what you're, again, touching on here is this concept of Newtonian mechanics. This idea that existed, or this hope that, again, the sun was in equilibrium. You're also getting to entropy, which I think is a fascinating thing. If we do have an opportunity, I do want to ask you how, perhaps, quantum theory fits into this whole notion of complexity?

Before, when you were speaking about percolation, propagation, you're [00:22:30] talking about positive feedback. I mean some of these qualities, clustered volatility, phase transition, which I think you touched on, which is something I think is really fascinating and I'd like to get to, when we get to financial markets, because I think that's a very relevant point. I think it deals a lot with volatility and some of the things that we see in financial markets and particularly relevant today, where we have such low levels of financial volatility. I do want to ask you about that.

You also, of course, were touching on the notion [00:23:00] of fractals and fractal geometry. I think it's also interesting, you talk about computers and how we had pencils and papers, and we developed computers. Of course, that was so essential to folks like Mandelbrot, to be able to do their work, because of the fact that they had to do these computational geometry.

If we could now continue along the train of thought where you were going. It sounded like, when you were talking about Silicon Valley, you were talking about the economy there, [00:23:30] and this notion of equilibrium versus this creative destructive endogenously driven changing environment. Could you continue along that thread?

Brian Arthur: Modern economics states, of course, from the late 1700s, Adam Smith and others, but what interested those early economists was kind of two sides of the coin; two different problems. [00:24:00] One is, how do patterns come into equilibrium? You know, if England is trading with Portugal, and usually buying Portuguese wine and sherry, and Portugal's buying English wool: England had loads of rainfall and grass and sheep, and Portugal have loads of sunshine and grapes and wine. If countries are trading with each other, how does some sort [00:24:30] of equilibrium arise? How much wool trades for how much wine? These were what I would call 'problems of allocation': that's what they're called in economics. How are static patterns formed? That's kind of the first question you'd ask.

The answers that were given, I think were pretty good answers in the 1700s and 1800s, all the really [00:25:00] good economists, and I would say Adam Smith, Malthus, Ricardo, J.S. Mill, Marks and others: these were superb economics, and they all concerned themselves with how these patterns came into equilibrium, how they formed, and what sort of balances, what sort of allocations of goods and services were made between countries, within countries, even [00:25:30] within small regions, or within firms themselves. They looked at equilibrium economics.

But these guys were also curious and they looked at, how did an economy form in the first place? Where did companies and firms come from, how did they form? How did trading arrangements form? They had wordy explanations for this. In Karl Marx, in the 1850s and 60s, when [00:26:00] he was writing, how did power relationships form, and how did they affect who got what in the economy? You could say that, up until 1870 or so, all the best economists were looking at two different things or two related things. What patterns might be in equilibrium in the economy and how could you describe those? But also, how do things form in the economy? [00:26:30] How do new structures form? How does technology, the coming of the railways, change an economy? There are two different sets of problems: allocation, if you want, and formation. And they were all traded by the same people, sometimes in the same books.

Then 1870 arrives and people start to discover, or bring into economics, [00:27:00] in a serious way, algebra and calculus. They discovered that these trade patterns, market prices, all those, could be reduced to algebra, and reduced to calculus and algebra, if they were willing to make further assumptions that everybody was rational, that things were at equilibrium. So, there was a little bit of a devil's price to pay. You could analyze an economy [00:27:30] with mathematics and equations if you were willing to assume that all problems that everybody faced were well defined, that people could, algebraically or some other way, come up with rational solutions that patterns didn't change, and so we're back to the spider's web. Can we describe how the spider's web works if we know which points are connected to which points? And the answer's "Sure. We just write down all the equations [00:28:00] and solve those."

One part of economics, this part that deals with, who gets what, how trading patterns form? How producers and consumers together arrive at a system of prices. How those prices don't vary much over years and years. How one thing is valued in terms of another: all those equilibrium questions, [00:28:30] those sorts of questions were mathematizable, and could be-

Demetri Kofinas: Allocation theory?

Brian Arthur: Allocation theory. The 20th century really went to town on allocation theory. So that by about 1980, economics itself, if you talked about economic theory, you meant allocation theory, you meant things that could be expressed in equations. And theory ... this is amazing to me, because I'm [00:29:00] pretty highly trained in mathematics, I've graduate degrees in mathematics, so, basically, theory was taken as mathematics, and economics was the result of solving all those equations. By the time I got through Berkeley, I thought economics was a bunch of theorems. I thought economics just consisted of mathematics. In an early job I was sent to Bangladesh, [00:29:30] of all places, and my mind was just blown by the fact that, you know, I couldn't see any mathematics to apply, anywhere.

Demetri Kofinas: That's very interesting. What, in particular, are the bazaars, the sort of commercial atmosphere of the place?

Brian Arthur: No. The commercial atmosphere might have fitted into this sort of mathematics. If you had woven silk or something, in a bazaar, if you had rice being sold in a bazaar, [00:30:00] that might have prices that you could analyze by mathematics. But, in Bangladesh, they were getting constant flooding, they were getting constant change, economic development was coming along slowly, and things were changing, and as things changed, other things changed. So, bicycles might arrive. There weren't really roads in the country because it was extremely low level land, [00:30:30] and sometimes that land would flood. Land holdings were changing. The population was increasing, this was 1975; very very rapidly, that meant the average size of farms was going down to ... from four hectares to two hectares to one hectare, et cetera. People were pushed to the edge. So, the economy was always re-forming itself and people weren't necessarily reacting rationally, [00:31:00] they were doing what any humans would do in a situation like that, they were trying to defend what they owned. They were trying to defend themselves from famine. They were holding off disasters. They were flocking into the cities. So, the situation was always changing.

Let me go back to 1870 or so, if I may. About 1870, economics changed. The part that dealt with allocation, [00:31:30] what these patterns would look like, prices and the quantities produced, and what we'd call solutions to economic markets; that all came to be mathematized. The other part of economics that dealt with, where does an economy come from? How does an economy change structurally, when-

Demetri Kofinas: Formation theory.

Brian Arthur: That was all formation. That couldn't be mathematized because [00:32:00] new stuff, new things, things that you couldn't foresee, like the coming of railways; you couldn't have foreseen that easily in 1820. The whole economy changed by 1850, and England 1860, the railroads or the railways connected London to Bristol, or London to Birmingham, in four and a half hours. Beforehand, it might have taken horses and oxen to transport [00:32:30] stuff from Bristol, maybe coming in across the Atlantic, to London. So, it could have taken a couple of weeks to get your stuff. So, the whole economy changed.

Questions of, how does structural change work? How does an economy reform itself? How does technological change work? How do these disruptions ripple their way through the economy and propagate across the economy? [00:33:00] Those couldn't be mathematized. So, people like Schumpeter, who was fascinated by all these formation questions, you also have Schumpeter, came along, and the best Schumpeter could do, in my opinion, real genius, Schumpeter very very bright and imaginative, but the best he could do, was to describe this in words. The result, by a century or so later, by 1970s, [00:33:30] 1980s, when I was studying economics in grad school, was that Schumpeter was never mentioned. I never heard about Schumpeter in my studies in Berkeley. You'd have to have taken economic history or some arcane version of economics.

Schumpeter, of course, would have been taught in Germany and maybe even in England, but we weren't taught about Schumpeter, we were taught about all the allocation people, [00:34:00] and wonderful economists like Schumpeter, Thorstein Veblen, who concerned themselves with formation, how did things come to be? How did things come into being? How did the economy change? How did structures in the economy change? How did markets arise? Where did central banking come from? These people were called economic historians. They were literary. They looked at specific examples. And the theorists, [00:34:30] by the 1980s, were all solidly based in mathematics, so was I, and we scorned these people as sort of not being able to do science, and without being able to do science, we had this superior feeling, that we were the real scientists, and that the people who looked at questions of formation were people who couldn't do science.

Demetri Kofinas: Where does Friedrich [00:35:00] Hayek fit into this?

Brian Arthur: If you ask, in the 20th, who were the top three economists in the world, I would have said, Schumpeter, John Maynard Keynes of course, and Von Hayek. Notably, these people didn't use that much mathematics. [00:35:30] Some were trained, Keynes was quite highly trained mathematically, but the other two were less prone to writing down mathematics. Hayek, in particular, was interested in problems we would now call 'information problems'.

If you have a gigantic socialist economy, say like the Soviet Union turned out to be, with all kinds of production capacity. [00:36:00] They could produce thimbles. They could produce tanks. They could produce gardening tools. They could send people into orbit, et cetera.

How on earth does an economy like that, balance itself, or signal, if it's a central government telling factories, what they ought to produce, at what prices? Hayek started to look at that [00:36:30] as a big information problem. Does some unit, some big factory system in Siberia, where does it get its signals from? Not from consumers. Not from people buying gardening tools or wanting a tractor, but from some central committee in Moscow, that may not know what problems that factory faces.

So, Hayek began to appreciate ... [00:37:00] the way I put it about Hayek's work is that he really appreciated that a market system where prices were signaled, the price of haircuts might affect some small town, and price of beer, the prices of steel, if it was a factory: all these prices are affecting other prices. I might buy less steel if I'm a car manufacturer. If the price of steel goes up I might [00:37:30] substitute something else, possibly aluminum or something else, some other alloy, and cut back on steel; if the price of steel goes up. What Hayek appreciated was that you didn't have to have a central committee. You didn't have to have a big planning unit like later they had in China, or they had in the Soviet Union, telling people what to produce. That might be necessary in a war, Second World War for [00:38:00] example, but most of the time a market could send these signals of prices. If I were, say, in Detroit, there might be market signals coming out of Pittsburgh about what price they were willing to sell me steel at, and I could react accordingly in Detroit.

The big insight of Hayek was that you didn't have to have planning committees, you didn't have to have all the information [00:38:30] that somebody said. You didn't have to load it into computers, and anywhere the information may be out of date, or correct, you could let the markets signal prices and signal information, and this would get you a far superior system. So, Hayek, interested in just a pure information problem, turns out to be one of the Gods of the market economy and is celebrated by the Right to this day. But I think his [00:39:00] insight was very sound, that the economy's a system, that information signaled across that system, and price information is really an efficient way to do that.

Demetri Kofinas: And, of course, and I couldn't agree with you more, and I think I agree entirely. His dealing with the information ... the information distribution problem, I think, was certainly what I value most about him: his work on prices.

Of course, that's also dealing directly with [00:39:30] the non-linearity component, which is that you could move a price a little bit in one place and have a drastic effect across the economy. I think, classic case, classic example, our central banks' monetary policy, and the law of unintended consequences, in that regard, which I would love to discuss with you, as well. We can continue along that thread, or we can go back to Schumpeter and, I think, the business cycle, which is something that you were touching on. Either one is fine. I'd [00:40:00] like to cover both of them though, through the course of the interview, so I leave it up to you.

Brian Arthur: All these questions of formation got left behind and they were treated by, what Ferris would have called "Wordy economists," you know, people looking at historical cases, people writing histories of the railroads, or even history of turbine systems, histories of how the jet engine came to be, all of that was actually superb economics, but it couldn't [00:40:30] easily be expressed in mathematics. Just figure it out, if you're writing a book about the birth of turbo jets, the gas turbine jet engine, how on earth do you express that in equations? Yet, that has done huge amounts to change economies, so have the railroads, so has the computer: so, all these things are extraordinarily important, but they couldn't be put into equations.

The [00:41:00] whole question of how things formed, how structures changed, how all this upheaval happened, was left to economic historians. This is where Schumpeter comes in, because that's the set of questions that fascinated Schumpeter. Schumpeter's always interested in how things form. How does change form? How does structural change happen? How does, what we would now call 'technology', he called [00:41:30] it the 'means of production' how does that form? How does that change? How does it change over time? Schumpeter was very much ... he thought, dynamically he thought in 'things affecting things'.

When a really new technology comes along, say computation ... well I should go back to more technology of Schumpeter's time, when the railroads hit Austria in the [00:42:00] late 1800s, Schumpeter was fascinated, not just in how they changed the economy and how they opened up the economy from one end of Austria to the other, the Austro-Hungarian empire even; Schumpeter was fascinated about how they flattened many other industries: you know, horse, dredge, maybe some provincial stagecoach operations. He saw this as a blast [00:42:30] of wind, this ... any new technology that was significant, would be like a gale of wind blowing across the economy and flattening all kinds of structures that existed before. Schumpeter was fascinated by this. Schumpeter called this 'gales of destruction'. Not only would new inventions, new technologies bring construction, bring novelties, bring new creations, but it would flatten all kinds [00:43:00] of old things that are displaced.

It was this sort of formation that fascinated Schumpeter. Schumpeter wasn't mathematical: all his life he regretted that he wasn't particularly mathematical. Schumpeter was a sort of 'real world' guy. He was interested in history, he was interested in law, that's what he was trained in, [00:43:30] and Schumpeter was always looking at real world cases. There's a kind of funny juxtaposition here. Schumpeter is describing economies as he sees them. He's a bit like a painter, or more like a film maker, who sees things changing in front of his eyes, and he's ... in his writings he's kind of making a documentary film about how things are changing. How new things are destroying the old, et cetera.

The theorists, [00:44:00] in the meantime, are constructing a beautiful machine. How does this part affect that part? How does everything keep everything humming along in a sort of equilibrium? The machine consists of equations. The two sides, by about the 1960s, 70s, 80s, were really not talking to each other very well. As I say, I got through grad school, and quite a bit of what I studied there was [00:44:30] economics and I never heard of Schumpeter, I didn't hear of Veblen. Of course, I knew those names, but I didn't hear of them in any of the classes I taught. What I did hear of, were names like Samuelson, and a mentor of mine Kenneth Arrow; these were superb theoretical, mathematical economists. Gerard Debreu, who I knew: all Nobel prize winners of course. But the [00:45:00] wordy types were not mentioned. I don't think this was kind of disdain for them, it's just that they were held not to matter as much.

Real economists, the real guys, did equations. We did mathematics. We did theory. Theory was mathematics. We looked at allocation problems and equilibrium. People who couldn't do that, who weren't trained, had to content themselves with how [00:45:30] economies formed and changed and how structures changed, and how new institutions, new laws, new legal systems, new contractual systems grew and changed and fell away. So, all of formation was kind of neglected.

Demetri Kofinas: I should say, I wanted to say also, it's also sort of question I have for you, in this regard, because as I've looked into this myself, as well, I think [00:46:00] by mathematics and theory, what you're also saying is that you can ... equations, very specifically that you could also find solutions, mathematical solutions to these equations, which is something that complexity does not necessarily allow for. Or rather it recognizes that a solution is beyond your capacity to locate, despite the fact that a solution is potentially possible, or rather that [00:46:30] the system has deterministic elements, but that they are so embedded in what we would think of as noise. Perhaps I'm mis-stating this.

But, yeah, I fumbled that a little bit, but I don't fully understand it and it's something that fascinates me, this idea. I also said in my studies of information theory, in cryptography, and this idea of the message and the noise, and [00:47:00] a normal number versus something that has an algorithm that can be written for it. Maybe you could explain that a little bit more, also, that difference between having equations that can be solved, versus those that cannot be?

Brian Arthur: So far, I've been saying that the allocation people, those theorists, nailed down all the problems of allocation, expressed that mathematically. They set all that up as mathematical [00:47:30] problems. It had mathematical solutions. You couldn't write the solutions down in economics, but you could write down necessary conditions. So, you could write down a little cage that the animal had to be in. Say "Well, you know, solution has to have this properties." Et cetera. So, think of the whole mathematical system, set of systems and economics, or problems with pretty well-defined solutions, [00:48:00] complexity comes along, and more than anything complexity concerns itself with problems of formation. Now we had computers, and we had ... if you don't like computers, we had non-linear dynamics, which I'd been trained in, and we had probabilistic non-linear dynamics, which also was a specialty of mine, [00:48:30] or is; stochastic process theory: All these quite advance techniques for looking at systems that are changing over time.

It might be a complicated system forming. How do all the little units in the economy change when the steam engine comes along? Previous to that, and I'm thinking of England in the 1800s, [00:49:00] factories and mills had to be halfway up some mountain where there was drop in water, maybe a waterfall, that could turn the water, mills that could the machinery, et cetera. Once the steam engine comes along, they could be pretty well anywhere, and they were put down by the side of canals or rivers, or next to the railroads, because a steam engine can give you energy to run a mill, just about anywhere.

[00:49:30] So, all of those problems of the economy forming and reforming itself, were problems that standard equations couldn't look at, but complexity could. Because complexity says "Okay, I'm going to look at all these little factories and mills, and I'll have them as their own little computer programs, within some larger program in the computer. Or I can write dynamic equations for [00:50:00] them, if you still like equations, and we can allow these equations to unfold." This computer approach, or complexity approach, by saying, we're going to look at the whole system changing. We're not just going to look at say, foxes and sheep, or wolves and sheep and grass being in equilibrium, we're looking at what happens when there's a major change. [00:50:30] Say, when the grass dies and the sheep can't graze and suddenly there's big changes to the wolf population. So, everything's affecting everything and everything's changing, and maybe always changing.

We could look at that on the computer. We could look at that with much more sophisticated mathematics, non-linear dynamics, and we could describe that. So, this has been a [00:51:00] huge change in economics, and it doesn't really make sense from a standard theory mathematical point of view. I want to dwell for a moment on the kind of horrors that gives mathematical theorists. If you think that economists consist of a bunch of mathematically described problems with precise algebraic solutions, then what we're looking at, [00:51:30] from 1980s onward, saying "Oh wow, I possess computers. I've got a really pretty good computer here. I'm going to look at all these little elements, model them in my computer machine, and allow them to fight it out, and to come to outcomes or patterns that may never settle down."

I would certainly see this as a 'paradigm shift' [00:52:00] and one of the things that changes in a paradigm shift, as pointed out by Thomas Kuhn, years ago, in the 60s, is that the whole idea of what is a legitimate problem and what is a legitimate solution: those ideas very often shift. So, you're saying now, in economics, "What's a legitimate problem?" Well, problems of formation are just as legitimate [00:52:30] now, with computation or non-linear dynamics, as problems of equilibrium were. So, we can say the economy's not in equilibrium, there's nothing in equilibrium in the Silicon Valley, for example. Everything's changing. It's like an ecology where little companies are changing, becoming big companies. That sets the scene for yet further companies and everything's affecting everything. Everything's changing all the time. [00:53:00] It's a scene of very rapid change, boiling with energy, in Silicon Valley.

So, it's not an equilibrium. We began to realize that if you're looking at problems of economic formation, you're looking at, not so much at well-defined mathematical problems, because the players, in formation, do not know the system that they're in, they don't know the precise details. [00:53:30] They don't know what the government's going to do. They don't know what regulations are going to do. They don't know what their competitors are going to do. If I'm in Silicon Valley, and I'm introducing some new artificial intelligence app, or some autonomous system, I don't know who's doing what across the road. I don't know what their secret source is going to be. I don't know what they're going to launch. I have no idea how that will be received. [00:54:00] We don't know the legalities or the regulations. I might be planning a system, say, for fleets of trucks that are autonomous, thundering their way across Arizona autonomously. I don't know how the government's going to react.

It turns out that, in these big questions of formation, the problems are not well defined to the players in the economy. [00:54:30] What do they do? Well, their big problem is not so much to accord to some solution, their problem is to try to make sense of the situation they're in. They're exploring. They're trying new things. They're coming to realize their competitors have a different system. They're coming to realize that the technology they're developing isn't as good, or is far better than they expected. [00:55:00] They're adapting and changing all the time. That sort of adapting and changing means that they're not facing a well-defined mathematical problem. They're not saying "If we could only figure out mathematically, how this or that works, and come up with a solution, we'll be perfectly fine." They're saying "We don't know what the hell system, wherein we're working in the dark. [00:55:30] We're trying to do what we think is going to work out. Our competitors are, as well, and everything's changing." Two years later the game has changed.

It's more like, trying this, trying that. Knowing that your competitors are doing the same. That means that problems in the economy are not well-defined, and "solutions", in quotation marks, are patterns. Solutions are no longer mathematical solutions. [00:56:00] They're not telling you exactly how the spider's web of equilibrium will settle out. They're saying that this is one thing happening after another. So, problems cease to be well defined, and outcomes are patterns. From the previous point of view, problems in the economy can be well defined by the players. They can be well-defined by economists and solutions are mathematical [00:56:30] and well described. In the complexity version of the economy, problems are not well defined, but we can define how people, how the players in the economy change, how they explore, how they adapt, and in adapting, how they change the system, and we can look at the resulting patterns. So, we're no longer looking for equilibrium solutions with a capital 'S', we're looking [00:57:00] for changing patterns and how patterns change, and how we describe those patterns. What sort of phenomena come up with those patterns?

So, this is, I think, quite a challenging change in economics. It's not mathematical problem: mathematical solution. It's a system where players are trying to make sense of what they're in. [00:57:30] They're adapting and that changes the system. Further adaptations are required and maybe the system never settles down. The new idea of the solution is to say "It's a pattern that's always forming and reforming."

Demetri Kofinas: You're also essentially there, if I understand correctly, is there's an inexactness, but that inexactness is not synonymous with ignorance, or not having any ... you can get your arms around the system, but [00:58:00] you can't understand it exactly. You don't know exactly that A, if I do A, it will create B or C, or whatever, and that's part of the non-linearity.

You're also, of course, describing, if I can say that, you're describing what is essentially the business cycle in economics, as well; what produces the business cycle. You're also describing ... I think you're touching on something really wonderful that I want to follow-up on, which is the boom and the bust [00:58:30] and these cyclical patterns that we see in markets, in financial markets. The predictability that so often happens, the correlation that so often happens, during a period right before a face transition in complex systems. So, you tend to see everyone moving in a market in the same direction, right before a major shift occurs, and there's a period of great volatility.

[00:59:00] Let me ask you a bit more about this. My great fascination has always been, or has for a long time been financial markets, because it provides such a rich dataset. It is very much ... in what you're describing, it's very inductive. People are constantly coming to create a particular model, which you were touching on again, before. Everyone's developing models that work, they work for a while, [00:59:30] but as they seem not to work, they change, and when you have enough people using the same model you get high correlations, you get a lot of structure. Then invariably, the endogenous volatility of such systems creates ... and I think 1987, the crash in 1987, could stand out as one of those moments, where regardless it doesn't have to be exogenous. These systems are endogenously ... go through periods of chaos, where everyone [01:00:00] sort of has to vie for a new model, a new way of interpreting reality, before the system can reset to a temporary place of agreement.

Talk to us a little bit about the way you view financial markets. It would be really wonderful to ... what I'd really like to take it, is how you view them also in the context of current affairs, in terms of what you've seen in your lifetime, different crashes, certainly [01:00:30] the panic of 2008? I'd also like to get into your views and thoughts around building ... because I love this, this is the other thing that really fascinates me personally so much about complexity, is this ... again, you've got waves in the ocean. These waves can create tremendous amounts of chaos if you don't learn to ride them, and some people either drown in the waves or they try to build dams, and those dams aren't resilient. I think complexity for me, [01:01:00] one of the ways I think about it is, it's so much about learning how to co-exist within those waves and within those forces. And so, when I think about regulation and when I think about monetary policy and fiscal policy, I like to think it in those regards.

I feel that one of the things that we struggle with so much in policy today, to bring it into current affairs, is that so many of the policy makers don't think in that regard. They think very much [01:01:30] and try to exercise a great deal of control over the system and it doesn't provide that level of resiliency and flexibility.

So, I'd love for you to tell us a little bit about how you see financial markets? How you see current affairs? Perhaps, even ideas you may have for better ways of dealing with this stuff?

Brian Arthur: Well, on my side, I can say it's a pleasure to talk to someone who knows an awful lot.

Demetri Kofinas: Thank you.

Brian Arthur: Yeah, so let me plunge in here.

[01:02:00] I want to talk about a piece of work, actually, we did in the very early Santa Fe Institute: this had to do with financial markets. The standard economic theory of financial markets, sees them as being, not surprisingly, in equilibrium. What neo-classical or standard economics asks us, what would a stock market look like [01:02:30] in equilibrium? It's called the problem of asset pricing. Maybe you imagine a firm, and it's got a little stream of dividends or earnings, and it's paying out something to its investors. What economists solved, actually, mathematically, was, in the 1970s, and very beautifully solved this problem of, if you had a certain stream [01:03:00] of dividends, what price for the stock would that imply? They solved it, I wouldn't say by cheating, but they solved it by a major shortcut. They said "Well, we can't exactly imagine that everybody has different ideas. We'll imagine that all the investors have the same ideas, the same forecasts. We'll imagine those forecasts are something that we call 'rational expectations'."

[01:03:30] Basically, the whole idea is that given the stream of dividends, we imagine that all the investors come to the same conclusions and they know that other investors come to the same conclusions. Given the stream of dividends, they all imagine that that implies prices that may go up and down with the dividends or the earnings, but those prices will be [01:04:00] in rational expectations equilibrium, meaning the prices you see in the actual market, over time, will on average mimic or be roughly statistically in harmony with the prices they forecast. So, let me say this a bit more intelligibly. The standard model assumes investors that are all alike and [01:04:30] that they know that other investors are just like them, and those standard investors have little kind of forecasting machines, say if the earnings are such-and-such, here's what that will do to the prices. Earnings are announced. They forecast prices. They buy in, or sell, in the market, and certain prices are realized. If, over time, those prices [01:05:00] realized are pretty much the same statistically as the prices that were forecast, then that's called 'stochastic equilibrium'.

Now, that was well solved in economics and, pretty much, Nobel prize was given to Bob Lucas for solving that, and well deserved if you ask me. But around 1988, we came along ... oh, [01:05:30] and by the way, that solution was wonderful. If you plot the solutions mathematically, they look just like real market data, and everybody stood up and cheered and said "This is wonderful!" But there was something embarrassing about it. In actual markets, as you mentioned, in actual markets there are correlations, volumes correlated with prices. There's auto-correlations, what you get tomorrow [01:06:00] might persist, if the market's going up, it might go up further. There's these little bubbles and crashes. Sometimes very large bubbles and very large crashes that are unexplained. So, there are periods of very high volatility randomly followed by periods of low volatility that persist for a long time. None of that should be present, or was present, in the standard solution.

Around 1988, [01:06:30] John Holland and myself ... John's a great theorist in computer science, died a couple of years ago, and some other ... John Holland, Richard Palmer physicist, Blake Lebaron, and myself, and Paul Taylor in London, who worked in the city, in finance; we got up a different [01:07:00] study. Our idea was to say "Well, hang on. We've got computers now. It's 1988. We're going to imagine that we have little investors. The little investors are going to be little computer programs within our machine. We can have 10,000 of those if we want, and we can allow them ... we're not going to say they've a perfect mathematical model [01:07:30] that they can solve in advance. We're going to say they're just blundering along. They're trying to form hypotheses. Ideas about how the market works. We'll allow them to differ and we'll allow them to start with pretty random hypotheses, and if those hypotheses don't make money, then they'll throw them away and replace them, maybe, with ones that improve over time. They'll keep the good ones that work, but [01:08:00] they don't have to be the same as anybody else."

We cooked up our model. It was identical to the neo-classical one, except that our investors weren't perfectly rational. They weren't perfectly well informed. They weren't identical. They differed and they could blunder their way into the market and get smarter and smarter. What would happen? Well, lo and behold, [01:08:30] we did see the standard solution, we thought maybe that's all there is. Our market, when we finished up in the computer, our market looked like real markets. It looked like the neo-classical solution, but when we looked a bit further we saw little bubbles and crashes. We saw periods of random volatility that was high, followed by periods of volatility that was low. We saw all the same auto-correlations [01:09:00] and cross correlations that you'd see in real markets. So, it was a bit like going back to the sun. The previous theory had said, the sun is in equilibrium, the market is in equilibrium, what would that look like, in the case of the market? But we were showing all the little mass plasma ejections, all the forming magnetic loops, that would form and affect other loops [01:09:30] and fall away; we were showing that, like in real markets.

This piece of work, I think, was a little bit complicated, so the Press didn't pay as much attention to that as I expected. But, basically, in our model, and in our computer model, we were able to show all the phenomena of real markets, whereas the previous theory didn't: And [01:10:00] why? Let me take one of the things; volatility. Suppose some of our little guys, our little agents, artificially intelligent in the computer, suppose it's all going along, our stock market in the computer with our artificially intelligent little agents that are programs in the computer, all trading with each other, and the price forms. Suppose that's [01:10:30] reasonably at equilibrium, nothing much is happening, then somebody discovers a much better way to forecast, a better way to beat the market because our little agents in the computer can explore, they can change, they can see what works and what doesn't work from the patterns that they're paying attention to.

Lo and behold, they change what they're doing. That change is at a micro [01:11:00] level. The market ... maybe these agents that make the change or are quite well off, so maybe that affects the market. Suddenly the market character has changed. The market psychology you could say, has changed, within our little machine, within our computer, and other agents then have to change too, because what they were doing, previously, doesn't work. So, it's a bit like an earthquake system. I make a change. [01:11:30] I affect the market in a fairly small way, but that might make changes that tumble across the system, that propagate across the system; then everybody has to start changing because the old methods don't work any longer. The market's changed a bit and suddenly everybody's changing. Prices then become quite volatile as people are changing their behaviors. Then, after a while, some new quasi- [01:12:00] equilibrium comes about and settles down again, and that kind of volatility disappears.

Demetri Kofinas: But this exists everywhere. I mean, certainly, I was laughing to myself when you were saying it, I was thinking just simply about the guy who has the coffee shop right outside my apartment. He's always complaining to me, how people will come in, and when he's got muffins out, they don't take a muffin. Then he has to put them away. But he's constantly taking muffins out, putting them back in, [01:12:30] playing around with his design. He's constantly changing his models. That's a very volatile environment that he has.

Or I think of, for example, my father, who recently moved ... my parents, who recently moved to a new apartment. The traffic situation was very different there and it took a number of months for my father to become accommodated to the traffic. To decide, for a week, or two, he would wake up at six, then he would wake up at seven, then he would go back to 6.30, and he was constantly discarding models, trying to change [01:13:00] and adapt.

And, of course, some people simply want to change and try something new, on their own, without any particular reason whatsoever, and all these actors are within this very complicated 'soup' of a market. Their actions are affecting other people's actions and so there's this, I think ... that captures the endogenous volatility of complex systems.

Brian Arthur: I think so. I think that's precisely the case.

What we see, in general ... [01:13:30] and, by the way, what I'm saying about stock prices, applies to oil prices, in markets, it applies to commodity prices, et cetera. That people might have models in their mind, little hypotheses or ideas of how oil prices are forming and what the Saudi's are about to do, or the people in Russia and how that's going to affect the market. Maybe that doesn't happen, maybe they have to change [01:14:00] their behavior. So, markets are not static affairs. They're not things that are at equilibrium that much. They're very much people adjusting, but those adjustments and explorations and little experiments, like the guy with the muffins, that changes the market, even at a kind of micro-level, and that might cause further changes. So, the very [01:14:30] changes that agents are making, that investors are making, may change the market so that further changes are necessary. And a system like that, by its nature, is always sort of bubbling and boiling and never quite settling down. Changes are rippling or propagating across the system.

So, to come to 2008, the interesting thing is that, let's say, it's just before [01:15:00] 2008, and just before the Lehman Brothers' episode, and if I get it right, AIG, and-

Demetri Kofinas: Correct yes-

Brian Arthur: ... and the other ... So just before the Lehman Brothers' episode, AIG, et cetera, and Paulson and others, intervening. So, let's say we're in a market situation, things are kind of more-or-less in a relative [01:15:30] equilibrium. Derivatives are being bought and sold, housing loans are being made in a very dubious situation, but things are roughly at ... not in perfect stasis, but in a kind of bubbly equilibrium, up and down. And then something intervenes. Somebody says "Hang on a moment. The emperor doesn't have as [01:16:00] much clothes as we thought here." Or whatever happens, and certain events trigger a situation.

I remember watching Iceland very closely, in October 2008, where suddenly what had happened, actually, in Iceland, was a group of MBA people who'd come back to Iceland with their MBAs from America, decided that [01:16:30] they could buy up the assets of the three banks in Iceland, and they did. They started to take investors' ... consumers, bank customers' deposits, and play in the property market with those deposits. Properties suddenly collapsed and the banks collapsed. People lost their very deposits. The State had to intervene. The [01:17:00] whole thing was a shambles.

What happened in America was that things went wrong, so certain companies started to collapse. Confidence in the derivatives started to collapse. People started to see the real value ... there was a bubble that happened, people started to say "Are these things really worth ... stocks, worth these prices?" And suddenly expectations [01:17:30] collapsed. Certain companies that had investments and banking companies, collapsed. Memorably, the Lehman Brothers collapsed. The Government decided "Well, we're going to make an example. We're not going to come in and save all these large companies." So that led to further collapses. AIG, if I remember, collapsed. Prices collapsed. So, it's, again, like earthquakes: [01:18:00] it's failure and difficulties or stresses, propagated across the whole economy, one thing causing the collapse of the next.

This wasn't a system at equilibrium. This was a system in which one part of the network was bringing down the next part of the network, which brought down the next part of the network. Things more or less evened out, [01:18:30] when the actual values, which may not have been that wonderful, were reflected in market values and an awful lot of assets started to look like junk, because rather stupid loans were given out.

Demetri Kofinas: I'm curious, because you obviously are familiar with the crisis, you've paid attention clearly during that period, what do you think ... how do you see the contribution of monetary policy [01:19:00] and the setting of interest rates, very specifically, to this? How does that fit in with your sort of view of the economy and financial markets as complex systems? In particular, also, we could bring it back to the information problem of Hayek and prices, and the setting of the risk free rate. How do you see that? Do you have any views on that at all?

Brian Arthur: I have some views. You can judge, later, whether they make [01:19:30] any sense or not, because this isn't the area of economics I feel I know best, but let me give you some views anyway.

If you see the market as being in equilibrium, so the old way of looking at the economy, everything's more or less in equilibrium, people are rational, everything's well behaved, then perhaps you can adjust interest rates, you can affect markets, you can affect housing prices, [01:20:00] you can affect loans, via interest rates, and if you're a monetary authority you can adjust things and pretty well forecast how markets will adjust. Maybe that works, quite a bit of the time. However, if you are in a situation, and the real situation, I believe, is where there's a network of investors, and the decisions and beliefs [01:20:30] of some are affecting the market, and other investors then have to change, and people are always adapting and exploring; then maybe you need, in addition, some other policies.

So, let me give you an idea. Go back to 2008, and you can say "Well, maybe there's nothing we can do. Maybe the system is prone to these big collapses. [01:21:00] Is there anything we can do, and what could you say from a complexity theory point of view?" What I would point out is that banking systems, and specifically investment banks, consumers and so on, investors, but particularly the banking system, over a period of time before that, became not so much independent banks, not separate entities, but [01:21:30] they became a network of banks lending to other banks, banks heavily interwoven on the balance sheet of other banks. So, there was a system of "I will give you credit and you give other people credit." And a cascading system of banks that were connected in their debts and [01:22:00] credits to other banks, and the network began to become very, very closely interwoven.

So, in other words, the banking system, rather than being an awful lot of dominoes that stood alone, started to be a set of dominoes that were set up, maybe not in a straight line, but set up close together, so that if one domino failed, it would bring down a whole bunch of dominoes.

Demetri Kofinas: The propagation aspect fits [01:22:30] very well right there, in your point.

Brian Arthur: You bet. So, what you could do as a monetary authority, or at least as a governmental authority, and let's take things out of the US now, and just say, we're looking at Europe, we're looking at China or Iceland or anywhere else, what could you do in general? Well, you could set things up so that you're aware that all the dominoes are now standing a lot closer, or you could say there's [01:23:00] more dominoes, and you could be very aware of what could bring down what else. It's not that hard. You could look at balance sheets. You could do stress testing, and so on. And then you could say "Well hang on. We're going to make sure that this system maybe carries further reserves, or there's some rules where the whole system isn't going to bring down ... two or three major elements of that system bring down something, that they're [01:23:30] not going to collapse the whole system."

Personally, I think, that this is not that much different from an economy or a governmental system saying "Look, you know, this is an earthquake zone, and we're going to make sure that one part of the system doesn't collapse here." San Francisco, parts of San Francisco, are built on sand and silt, and those are dangerous, so we need to have certain building codes [01:24:00] there. We have codes about flooding. If some part of a city, like New Orleans floods, we don't want that to spread to other parts. So, we have rules and regulations that are tested over time. We have an air traffic system. We know if part of that system goes down, it may affect some other part, so we've rules and regulations for that. We've regulations about aircraft maintenance. [01:24:30] What is it, in the name of God, that is so holy about financial systems, that we dare not touch them? I'm not saying they should be laden down with regulations, I'm just saying that we should have some earthquake prevention rules.

Demetri Kofinas: What you're really getting at, is something that was largely in place before 1998, which was Glass-Steagall.

Brian Arthur: Yes.

Demetri Kofinas: Which was this firewall and this notion and this [01:25:00] recognition that financial networks are networks, and that building firewalls, separating them, in some ways the same way that when you have an oil tanker, you don't have one giant open space under the tanker, because if one area is broached, if you have a break in part of the hull, it doesn't result in a flooding of the entire hull.

In the interests of time, I don't want to go over and I know you're busy, [01:25:30] I wanted to see if we could just touch on that notion of quantum theory and information theory, if we had a chance.

I also want to say to our audience, early on in our discussion you mentioned Thomas Kuhn and, of course, you were referring to, either indirectly or directly, The Structure of Scientific Revolutions, an amazing book, and I'm going to put it that in the reading list for our audience, on my website, after this episode. So, everyone should go look for that.

But I'd love to [01:26:00] hear your thoughts. Again, I understand it's not your area of expertise, quantum theory and physics perhaps, but I'd love to hear how you feel that all kind of comes together. Because, for me, I didn't ... and I imagine for you, as well, this is how I sort of have come to see this area of complexity, science; it seems that people sort of just found their way into it. That certainly was the case for me. I found my way into it through the study of various [01:26:30] subjects, whether it was physics, theoretical physics, quantum theory. Whether it was information theory, cryptography. And so, I'm just curious, how do you integrate those things into your view, given your study of this field for so long?

Brian Arthur: Sometime around the 1960s, 1970s, at least when I was studying as a student, we certainly had a theory or ... I wouldn't say a theory; we had a point of view on science, where [01:27:00] everything could be mathematized. Where the world was basically very highly ordered. It was an optical illusion, it turned out, where economies were in equilibrium, where the theory should be an equilibrium theory. And then, somewhere in the corner of the space of all economies, there were ones that were a bit out of equilibrium, over in the corner, [01:27:30] there was exceptions. There were things that affected things that weren't in the market and all this sort of thing. So, there were exceptions where life got a bit wild.

We began to realize, and this is what complexity theory has done for us, and chaos theory, I suppose, which I think you know loads about, and non-linear dynamics, and computer science, we've begun [01:28:00] to realize that highly well behaved systems, highly ordered systems are not that prevalent, and we tend to try to build systems that are very highly ordered and we treat them as the norm. They're not the norm. You have to work pretty hard to have a system that's very highly ordered, that can persist for years and years. If you find something that persists [01:28:30] for years and years, say like the Christian church or something, you will discover that it's changed fundamentally at different times to adapt to different situations. So, the norm is not one of high order.

I'm a big fan of an American architect called Robert Venturi, who didn't like highly ordered architecture. He [01:29:00] said he wasn't an admirer of what he called 'prim dreams of pure order'; the work of Le Corbusier, or the Bauhaus; these very geometrical buildings. Venturi rails against 'prim dreams of pure order' which I think we have in the economy, and says he's on for 'messy, vitality'. In other words, go back to the teenagers. [01:29:30] Complexity science as a whole is beginning to realize that the world is fairly well ordered, but shows signs of a lot of vitality, just like the teenage years. Most kids go to school. Most of them can drive cars, and they're not out of control. But occasionally the system needs to readapt, readjust, and it's full of vitality. New things are arising. [01:30:00] Everything's always in formation. Everything's changing. One thing is changing another, and basically, it's a question of constant adaptation and constant change. That's what complexity's showing us. Whether it's in physics, whether it's economics, or whether it's in, God knows what ... geology. And we're learning a lot from that.

Demetri Kofinas: There's something very beautiful and it expresses itself in that manner, the complexity is itself [01:30:30] something very beautiful. I think also, again, much of what I know about this field came from my studying of information theory, and there's something deeply interesting about a system that is sufficiently complex so that it is not perfectly knowable, but not so complex that it is chaotic.

Brian Arthur: Yes.

Demetri Kofinas: Jazz, is very beautiful, and it's very complex, whereas the percussion, [01:31:00] drum beat, of a military parade, is very simple and not interesting, and not particularly beautiful. And so, I think, it's interesting to me that these subjective measurements, like beauty, and the notion of something 'being interesting' coincide with this theory. I think that's also something really fascinating to me. That's what I wanted to say.

Brian Arthur: I think that's extremely well said, [01:31:30] and I would applaud all that, certainly. I think you're absolutely on target.

Let me say the same thing, in my own language, but I'm just echoing what you're saying. That what we're learning is that, there are quite highly ordered systems and there are systems, for example, perhaps certain aspects of classical music are very highly ordered, and [01:32:00] then there are things that are totally and utterly random. There are people who don't like randomness at all. I'm not a big fan of randomness. But I'm not a big fan of highly ordered systems.

I grew up in Northern Ireland. It was very highly ordered society. Parks were closed on the Sabbath day. Swings were chained [01:32:30] shut on a Sunday, in case anybody could get in, over the wall of a park, and take pleasure on a swing. So that sort of order just makes me grit my teeth. It's like living in some Calvinist paradise, God knows, in Switzerland or somewhere. I should be more careful what I say. It's like-

Demetri Kofinas: It's fine. That's fine.

Brian Arthur: I don't like highly ordered [01:33:00] systems. And I think that people who are attracted to complexity and to really studying complexity, are very much people who like this balance between order and chaos. We're discovering in complexity, and this goes to quite a bit of work, in complexity, and in information theory, and I'm thinking of Wolfram, [01:33:30] Stephen Wolfram's work, Greg Chaitin's work, and others, they're showing that there are chaotic systems where one thing is affecting another, so inter-connected and fast; that that system's just always boiling and raging, and there's nothing ever settles down. Nothing you can do with it. You can't propagate information, if that information is adapted to, [01:34:00] destroyed, and further adaptations, and further explorations; nothing, no information can be propagated.

On the other hand, if systems are frozen, if they're too ordered, like, say, a river in the dead of winter in Siberia, and that river's frozen; there's nothing that happens at one bank that could be easily propagated to another, at least within the river. The whole system is [01:34:30] frozen. All of life happens in between order and chaos, and this is where information can be propagated. We find, as human being, we're living in this world between order and chaos. It's exactly as you said, jazz, in particular, improvisation, lives in this world. We sense the order, but a good improvisational [01:35:00] musician, whether it's in jazz or some other, will play upon what we're expecting and what the order is, but they're not chaotic, they're showing you a new pattern, and after that yet another new pattern. They never ... may never repeat themselves from one performance to another.

But this is what it means, in my opinion, to be alive. It's not that you want everything ordered and perfect. [01:35:30] It's what you're looking for, and you don't want it too wild, you know. I lived in Berkeley in the late 60s, no thank you, you don't want everything too wild and out of control. But what you're ideally looking for, is situations that are always changing, and you're always adapting, and you're always alive in that sense. I remember, early in the 70s I kept a surf board in Hawaii and I'd [01:36:00] go there quite often-

Demetri Kofinas: You had a tough life!

Brian Arthur: Oh, it was dreadful!

And I remember ... but I learned a lesson from surfing: no wave is ever the same as the previous wave. So, you're always ... you're trying to stay in the green water, you're trying to stay in clear water, not where the wave has tumbled into white froth, that doesn't work. You're always adapting. The waves always going different places. [01:36:30] Different waves are affected by previous waves. And you're adapting and changing and adjusting, and I think that what it means to be alive. I think that's what makes life worth living and why life is always endlessly fascinating. You think you've mastered something and then something totally unexpected comes up.

Demetri Kofinas: I was going to say, I mean I think that's an excellent point [01:37:00] to end on.

Brian Arthur: Good.

Demetri Kofinas: That's very beautifully said. I couldn't agree with you more.

So, professor, thank you so much. I really appreciate you taking so much time, being so generous with your time, and sharing your time with me, and with our audience. I really do appreciate it.

Brian Arthur: Well, and thank you, because it's, for someone within complexity, it's pretty rare to meet an interviewer that's that well informed. As I say, I looked at your web [01:37:30] page, and it's clear you've talked to quite a few people in this area, and it's clear it's a whole area that fascinates you, so I'm delighted.

Demetri Kofinas: And that was my conversation with Dr. Brian Arthur. I want to thank Dr. Arthur for being on my program.

Today's episode was produced by me, and edited by Connor Lynch.

For more episodes, you can check out our website at [01:38:00] HiddenForces.io. Join the conversation on Facebook, Twitter and Instagram at @HiddenForcesPod, or send me an email.

Thanks for listening. We'll see you next week.