

[Complexity](#)

The Economy Isn't A Machine. It's Organic and Constantly Evolving.

The origins of complexity economics



By W. Brian Arthur

Economics is a stately subject, one that has altered little since its modern foundations were laid in Victorian times. Now it is changing radically. Standard economics is suddenly being challenged by a number of new approaches: behavioral economics, neuroeconomics, new institutional economics. One of the new approaches came to life at the Santa Fe Institute: complexity economics.

economist Kenneth Arrow met to discuss the economy as an evolving complex system. That conference gave birth a year later to the Institute's first research program – the Economy as an Evolving Complex System – and I was asked to lead this. That program in turn has gone on to lay down a new and different way to look at the economy.

To see how complexity economics works, think of the agents in the economy – consumers, firms, banks, investors – as buying and selling, producing, strategizing, and forecasting. From all this behavior markets form, prices form, trading patterns form: aggregate patterns form. Complexity economics asks how individual behaviors in a situation might react to the pattern they together create, and how that pattern would alter itself as a result, causing the agents to react anew.

This is a difficult question, so, traditionally, economics has taken up a simpler one. Conventional economics asks how agents' behaviors (actions, strategies, forecasts) would be upheld by – would be consistent with – the aggregate patterns these cause. It asks, in other words, what patterns would call for no changes in micro-behavior, and would therefore be in stasis or equilibrium.

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The standard, equilibrium approach has been highly successful. It sees the economy as perfect, rational, and machine-like, and many economists – I'm certainly one – admire its power and elegance. But these qualities come at a price. By its very definition, equilibrium filters out exploration, creation, transitory phenomena: anything in the economy that takes adjustment – adaptation, innovation, structural change, history itself. These must be bypassed or dropped from the theory.

By the mid 1980s, many economists were ready for a change.

Just what that change would consist of we were not quite sure when our program began. We knew we wanted to create an economics where agents could react to the outcomes they created, where the economy was always

In fact, in 1988 the Institute was still very much a startup. The program consisted in its first two years of 20 or so people, several of whom proved central: John Holland, Stuart Kauffman, David Lane, and Richard Palmer. We would meet, in an early version of what became Santa Fe style, in the kitchen of the old convent on Canyon Road in the late mornings and loosely discuss ways forward.

These “emerged” slowly – sometimes painfully – mainly by talking over why economics did things the way it did and how alternatives might work. Our group was motley, even eccentric. Halfway through the first year the journalist James Gleick asked me how I would describe my group. I was hard put to reply. He pressed the question. Finally I said, “You remember the bar in Star Wars, at the end of the galaxy with all the weird creatures, Chewbacca and the others? That’s our group.”

We did have some tools. We had new stochastic dynamic methods, and nonlinear dynamics, and novel ideas from cognitive science. And of course we had computers. But it took us a couple of years before we realized we were developing an economics based not just on different methods, but on different assumptions.

Instead of seeing agents in the economy as facing perfect, well-defined problems, we allowed that they might not know what situation they were in and would have to make sense of it. Instead of assuming agents were perfectly rational, we allowed there were limits to how smart they were. Instead of assuming the economy displayed diminishing returns (negative feedbacks), we allowed that it might also contain increasing returns (positive feedbacks). Instead of assuming the economy was a mechanistic system operating at equilibrium, we saw it as an ecology – of actions, strategies, and beliefs competing for survival – perpetually changing as new behaviors were discovered.

Other economists – in fact some of the greats like Joseph Schumpeter – had looked at some of these different assumptions before, but usually at one assumption at a time. We wanted to use all these assumptions together in a consistent way. And other complexity groups in Brussels, France, Ann Arbor, and MIT were certainly experimenting with problems in economics. But we had the advantage of an interdisciplinary critical mass for a program that ran

Sometimes we could reduce the problems we were studying to a simple set of equations. But just as often our more challenging assumptions forced us to study them by computation. We found ourselves creating “artificial worlds” – miniature economies within the computer – where the many players would be represented by little computer programs that could explore, respond to the situation they together created, and get smarter over time.

Our artificial-worlds-in-the-computer approach, along with the work of others both inside and outside economics, in the early 1990s became agent-based modeling, now a much-used method in all the social sciences.

One early computer study we did was a model of the stock market. In a stock market, investors create forecasts from the available information, make bids and offers based on these, and the stock’s price adjusts accordingly.

Conventional theory assumes homogeneous investors who all use identical forecasts (so-called “rational expectations” ones) that are consistent with – on average validated by – the prices these forecasts bring about. This gives an elegant theory, but it begs the question of where the identical forecasts come from. And it rules out transitory phenomena seen in real markets, such as bubbles and crashes and periods of quiescence followed by volatility.

We decided to have “artificial investors” in our computer create their own individual forecasts. They would start with random ones, learn which worked, form new ones from these, and drop poorly performing ones. Forecasts would thus “compete” in a mutually-created ecology of forecasts. The question was how would such a market work? Would it duplicate the standard theory? Would it show anything different?

When we ran our computerized market, we did see outcomes similar to those produced by the standard theory. But we saw other phenomena, ones that appeared in real markets. Some randomly-created forecasts might predict upward price movement if previous prices were trending up; other types of forecasts might foretell a price fall if the current price became too high. So if a chance upward movement appeared, the first type would cause investors to buy in, causing a price rise and becoming self-affirming. But once the price got too high, the second sort of forecast would kick in and cause a reversal. The result was bubbles and crashes appearing randomly and lasting temporarily.

created small perturbations. But occasionally some would find forecasts that would change their behavior enough to perturb the overall price pattern, causing other investors to change their forecasts to re-adapt. Cascades of mutual adjustment would then ripple through the system. The result was periods of tranquility followed randomly by periods of spontaneously generated perturbation – quiescence and volatility.

The program, as it developed, studied many other questions: the workings of double-auction markets; the dynamics of high-tech markets; endogenously-created networks of interaction; inductive reasoning in the economy. In an SFI program parallel to ours, Josh Epstein and Rob Axtell created an artificial society called “Sugarscape” in which cooperation, norms, and other social phenomena spontaneously emerged. And in 1995 John Miller and Scott Page started an annual workshop in computational social sciences at SFI where postdocs and graduate students could get practical training in the new methods.

The approach finally received a label in 1999, when an editor at *Science* asked me on the phone to give it a name. I suggested “complexity economics,” and that name stuck.

Things have widened a great deal since then. Doyne Farmer has taken up studies of how technologies improve over time. And he, Axtell, and others have been using large datasets, along with agent-based modeling methods, to understand the recent housing-market crisis. Other groups in the U.S. and Europe have been using complexity methods to look at economic development, public policy, international trade, and economic geography.

None of this means the new, nonequilibrium approach has been easily accepted into economics. The field’s mainstream has been interested but wary of it. This changed in 2009 after the financial meltdown when, as the *Economist* magazine observed dryly, the financial system wasn’t the only thing that collapsed; standard economics had collapsed with it. Something different was needed, and the complexity approach suddenly looked much more relevant.

Where does complexity economics find itself now? Certainly, many commentators see it as steadily moving toward the center of economics. And there’s a recognition that it is more than a new set of methods or theories: it is a different way to see the economy. It views the economy not as machine-like,

Some people claim that this economics is a special case of equilibrium economics, but actually the reverse is true. Equilibrium economics is a special case of nonequilibrium and hence of complexity economics.

Complexity economics is economics done in a more general way.

In 1996 an historian of economic thought, David Colander, captured the two different outlooks in economics in an allegory. Economists, he says, a century ago stood at the base of two mountains whose peaks were hidden in the clouds. They wanted to climb the higher peak and had to choose one of the two. They chose the mountain that was well defined and had mathematical order, only to see when they had worked their way up and finally got above the clouds that the other mountain, the one of process and organicism, was far higher. Many other economists besides our Santa Fe group have started to climb that other mountain in the last few years. There is much to discover.

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9 years ago edited

Wow, I didn't even recall these exchanges (or how blabbermouth I'd been) until I got an email this am about Guy's new contribution. But now that I've refreshed my memory, I'm still impressed at how civil and contributive everyone was at just exploring the fringes of this thing we call 'economy'. So many new things that I was able to absorb from what all of you said. I've not much to add just now and, like I mentioned, I'm not an economist. However, I do wonder if any of you have been following Nextgen or Zeitgeist, and can summarize in brief fashion where those efforts are heading. I tried to figure it out from their papers and websites, but they splash in so many directions it was really hard for me to grasp the overall picture. I think they are heading in some interesting and novel directions, but they also seem to assert that they have "The Answer" but I can't really make out what that is (and am always wary of such claims). Anybody care to enlighten me about what they (or others) are doing?

The only other thing I have to contribute is my own little, imperfect, thought experiment on 'Binomial Economies', which I edited a little bit. I'm not at all sure it offers anything real to the discussion. I am sure that the next thing it would need would be an economic workup which is outside my scope of practice. If anyone wishes to engage that, do get in touch. I'd like to know if the proposal can even shake out in economic terms. its at: <https://www.facebook.com/no...>

o o Reply

**Party_Fants**

10 years ago

The standard, equilibrium approach has been highly successful. It sees the economy as perfect, rational, and machine-like, and many economists – I'm certainly one – admire its power and elegance.-----The moment I read that bullshit, I gave up reading this twaddle.

o o Reply

**Long distance flyer**

→ Party_Fants

10 years ago edited

Interesting comment. Most really serious analysts regularly explore the bases of assumptions used and their interactions with data. This interaction tends to upset those who have forgotten that this sort of dismissive comment simply raises questions about the capacity of the writer to re-examine underlying simplifications and group accepted framing so this essential testing as contexts change inhibits adaptation. It reminds me of the Victorian scientific and broadly held assumption that all that was left after stellar successes in classical physics and their demonstrable precision effectiveness was the next decimal point.

We got it

And quantum theory, QCD, relativity etc etc, simply because of that next decimal point

my previous comment in this exchange was drawn from this classic misreading of the success of one level of analysis being regularly disrupted by the next decimal point or the next new..this time bigdata stream.

Brian Arthur has regularly reexamined underlying assumptions and simplifications, like Sen, and I have paid attention to the things both have written over thirty years as a result.

Of course on a less constructive note one has to observe that the majority of applied economics is about market failure ...

[o](#) [o](#) Reply 



Party_Fants

→ Long distance flyer

9 years ago

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▶

A house is an economy expert, how twee.

[o](#) [o](#) Reply 



Guy Taylor

10 years ago

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▶

I accord the highest priority to "Constantly Evolving" and think of it as a great deal like herding cats or perhaps a more accurate visual analogy would be herding CLOUDS. If you spend much time staring at clouds you can watch them evaporate and reemerge from out of the blue in a sort of turbulence that I suspect somewhat represents many of the more significant patterns in the universe. If you want to herd clouds study meteorology and thermodynamics. In economic terms value is more frequently assigned to elements that represent stored energy. Plot the movement of such energy through whatever system it resides in and it always looks turbulent to me... not entirely chaotic. It would however seem to be convenient to have Maxwell's Demon or one of its close cousins as a prominent member of your social circle.

[1](#) [o](#) Reply 



red_slider

→ Guy Taylor

10 years ago edited

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As I noted earlier, that 'constant evolution' can be seductively misleading in that it is often coupled with the idea of 'progress' or 'advance', which is not necessarily the consequence of either physical or conceptual evolution. The anthropologist Leslie White and his students (back in the 50's) related social advance with the ability of a culture to capture and utilize energy. This suggests, at least, that chaos and random turbulence in such systems can thwart such "progress", even when abilities to capture energy increase. Nor is there any guarantee that the applications of captured and stored energy will be distributed in ways that promote the betterment or even survival of a culture. Nuclear science certainly represents a higher order of energy capturing ability, but does that also reflect greater guarantors of improvement or even survival of our species? We can also see that distributions of surplus energy do not necessarily include those who most need it or investments that offer the best returns to the society as a whole. Leisure time to create new applications for energy and to find improved ways of capturing it are often sacrificed by harnessing people to the products created by that available energy with a net result of less leisure time. We can see that in the cutting of budgets for things like education over 'jobs training' or reducing basic science exploration over resource exploitation. Even corollary time-wasting functions such as tax-accounting, redundant title insurance and similar demands made by the goods and services we distribute weigh in heavily on reduced energy capture advantage. It has been noted by paleoanthropology that the hunter-gathers before the agriculture revolution (appx. 7,000 bce) had considerably more leisure time than at any time since then. So too, Australian Aborigines (within their native cultures) have had their energy quotients quantified (biologically as well culturally) as the most

o o reply

**Guy Taylor**

red_slider

9 years ago

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If "progresses" was a viable concept rather than a "legacy" one, along with all the other assumptions and anticipatory expressions of faith in "the ideal" you would be on target. As assumptions go and in this case, it falls wide of the mark as I find no connection between evolution (adaptation) and progress (towards the myth of perfection). A thermodynamic logistic model for economics has long made sense. I was born before the 50's so my education was informed by older sentiments although likely not as well as those born before the 20's or 30's which seems the best model if didactic education is preferred. One cannot thwart a myth (such as "progress") in any realistic sense.

All in all as far as I can tell the last really successful "system" predates urbanity, currency and compound interest. It can still be found in small scale societies in distant parts of the world. Ironically the cutting edge of adaptive practice along those lines ended with the arrival in the Americas of the dubiously named Western "Civilization" which had taken rather a turn as I observe it towards the glitter and novelty of the renaissance with the ability to command such plentiful population (until, of course the arguable correction of the plague years)

o o Reply

**Long distance flyer**

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10 years ago edited

Elegantly expressed as it is it still misses key agents..the regulators, who always work on lagged and imperfect..if not contaminated..information. The acceleration of data access, albeit not quite the traditional types, means that regulatory mechanisms now become part of the evolutionary system. I was looking at the effects of imperfect confirmation at different management levels and the lags quite a few years ago, and it indicated that the utility of earlier and more diverse response cues would be substantial..

We now at last have such fast response data flows, big data of all kinds, requiring control theory to also take a central role in 'economics' .this could be considered an Arrow legacy perhaps.

Change is certainly overdue on CGE domination and of economics

2 o Reply

**red_slider**

Long distance flyer

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10 years ago edited

I agree, information and signal processing is extremely important, especially with large scale systems. Governors and regulators are of particular importance, as they are with ordinary complex machinery. They are the things that are meant to prevent serious feedback loops that can degrade or destroy a system faster than anyone can keep up with what is happening. The use of ungoverned nano-second advantages achieved by routing stock reports and Wall Street activity has been used to take unfair advantage of markets that can't keep up with these split second differences. In some ways, regulators on our systems that intentionally and substantially slow things down might be very desirable. For instance, suppose we went back to snail mail only orders for the buying, selling or transfer of stocks. Would that really be such a bad thing? After all, it is the speed at which these orders take place that turns Wall Street into a crapshoot casino, with those who game it the fastest having a de facto insider advantage. Taking a few days to complete such transactions really compels investors to think more about their investments, and the long term outlooks of what they are investing in, rather than

systems rather than planning and regulating them.

o o Reply ↗



ckmurray

10 years ago

Thank you for this. One thing that has constantly bugged me about the standard economic approach is that how rational (or irrational) individuals aggregate to economy-wide outcomes. This is a huge deal, yet is basically ignored in teaching and in practice. "Oh, if everyone is the same we can pretend there is a representative agent". Of course, this makes no sense almost all of this time.

One problem with gaining acceptance of agent-based methods and other similar approaches is that they don't give nice neat, simple, analytical solutions that can be transpose into policy recommendations. People don't like to hear subtle and complex answers. They like simple answers. They like that defect is the rational decision in the prisoner's dilemma. They don't what to hear that various strategies can be more successful in repeated games, but it depends on the suite of strategies used by others you will interact with.

1 o Reply ↗



Proof of work

→ ckmurray

10 years ago

red_slider,

You are articulating something that is near and dear to my sense of social justice. Perhaps you should give yourself more credit. Even if you are "not an economist whatsoever" your stream of thought on this matter is descriptive of a potential economic system dealing "apriori" with core human needs and survival. You have included seven "mandate" needs and I think they are sufficient to satisfy human longing at its most basic level. I notice you allow room for debate and interpretation but the list feels reasonable, food, energy et al. I actually had a smaller list in my mind but after looking at yours I think it's more reasonable and practical. I had teetered on the idea of including "entertainment" or "art" due to the way indigenous cultures always used ceremony and celebration as a part of their social system.

I don't know exactly when, and I suspect it was very early in my life that I felt something along the lines of your Binomial Economies was missing from our system. I learned a trade in carpentry due to this moral sense of contributing something that is on the "mandate list" instead of pursuing a career in law for instance. I later earned a BS degree which opened up a way for me to learn and more critically analyze the world

[see more](#)

1 o Reply ↗



red_slider

→ Proof of work

10 years ago edited

Wow, Tony (and CK). You have taken some things I've very roughly and imperfectly thought about and sent them in directions I've not even considered. That's a real payoff for me, and encouragement to think more deeply about these matters. I've got chores to do, and can't respond just now. Tony, I will read your remarks more closely and reply later. I do know I'd like to discuss these things further with you both and perhaps others who might be interested. Perhaps a preliminary exploration of off-track, 'crackpot' ideas for building a sane economic system. But the topic here is 'complexity and evolution' so it probably isn't the best place to carry out that discussion

I leave it for you to decide if its worth a focused discussion of its own.

Meantime, I'll leave a couple of links to some facebook notes that might have interest, or at least fill in where I'm heading with all this. One is the very preliminary concept of 'Binomial Economies', itself, which can be found at <https://www.facebook.com/no...>

Another unfinished draft may shed a little more light on changes in the foundational structures of democracy that I think might best support an enlightened implementation of a 'Binomial Economy'. That work in progress can be found at <https://www.facebook.com/no...> (I'm still working on it and don't normally distribute this link. Please understand this is an unrefined and unfinished document -- don't beat me up for that, though anyone's ideas and criticism are certainly welcome. _

[o](#) [o](#) Reply [🔗](#)



Nicholas Mew [→ Proof of work](#)

10 years ago

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I agree with you that red_slider's ideas and observations are most interesting.

[o](#) [o](#) Reply [🔗](#)



red_slider

10 years ago edited

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There is a categorical fallacy hidden in the assertion that complexity and evolutionary process can lead to what an idealized version of a healthy, sane and flourishing economic system might contemplate as its fulfillment. In the fundamental designs that describe the defining characteristics of a system, there are matters which are not subject to change without redefining what one means by a certain category of that system (e.g. an 'economic' system). Such things as 'economic system', or 'political system' or 'social system' have a core region which no amount of tinkering or evolution can reach. The best one can do from within the systemic definition is to imagine an unrealizable ideal which only exists outside the systemic category. From that position, one can contemplate what it wishes to achieve, but never arrive at achieving it. The only way one gets past that is to extirpate the systemic definition itself and conjure up a quite different category which might embody the thing that is sought.

In current theory, for example, we treat the nexus of socialism/capitalism as independent, antithetical systems. In reality, however, they can be viewed as a single bi-polar axis generated by some fundamental ideas about economies which both systems share in common. For instance, both systems manifest in ways that support the notion that people are objects intended to serve their economy (e.g. as labor) rather than subjects meant to be served by their economy. Socialism and capitalism differ greatly in their methods, but when fairly regarded, don't exhibit

[see more](#)

4 [o](#) Reply [🔗](#)



Carl Henning Reschke

[→ red_slider](#)

9 years ago edited

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If I understand you right, the fixed point to change the paradigm - or rather where it needs to (be) change(d) is - in the 'western' world - the Platonic (partly Aristotelean) view of the World with materialistic / idealistic and subject /object dichotomies. It should be replaced by a process oriented 'framework' that can encompass the object / subject worldview as a special case. We need to retrace and unwind the evolutionary history of science, philosophy and religion for that.

Which points also to the necessity learning from e.g. Chinese and Indian traditions of

**red_slider** → Carl Henning Reschke

9 years ago edited

My remarks were really less complicated than that, and I'm not certain what framework would actually be sufficient. I do observe that 'complexity' or 'equilibrium' economics is making a whole lot of assumptions that might not only be seriously flawed, but very dangerous to the people that have to live with them. The idea that evolution is continuous, for one. The inference that evolution is an every "correcting and improving" dynamical system (which is borrowed from the old "invisible hand" edict from classical economics; the one which proved so horrifically false for millions of people only a few years ago). There is also the idea that evolving economic systems do so to correct and adjust for earlier flaws. But there is no reason to believe this is so either. Early flaws in a system may just as well work to control successive attempts at evolutionary adaptation and prevent corrective measures which it was presumed evolution would express. We can see, for example, that the ability of governance to maintain a measure of stability and equitably distributions of wealth and power has been entirely overwhelmed by the evolution of capitalist economics which adapted to first influence government, and then buy it and take over its principle functions. Our current spate of proposed trade agreements are but the end-game of a long process of that early flaw in capitalist economics.

i could continue, but I think the writing is on the wall. This new view could not only introduce old false assumptions into the dynamical models it proposes, but could make things a good deal worse, as it's predecessors have.

o o Reply

**Carl Henning Reschke**

→ red_slider

9 years ago

I agree with your 'non-optimal' process character of economics and evolutionary processes.

Both are pathdependent and 'making' not necessarily optimal or even best choices. Rather the opposite.

The role of assumptions in economics is to delimit the 'field' of validity of a model and also to say a lot about what will and can not work. Evolutionary processes by all practical means follow paths of haphazard tinkering. Thus the Panglossian "only optimal results are observed in the world"-assumption in both domains seems to be an artifact of Victorian concepts. These have been tradited until today - often enough unfortunately and ironically by social scientists and critics delving not too deep in their subject of attack.

Read: these critics did not do their homework.

o o Reply

**Guy Taylor**

→ red_slider

10 years ago

Isn't "ideal" a problematic assumption to insert here? Ideals are imaginary targets impossible to aim at because there is no "there" there..

o o Reply

ideal in the sense I use it is really little more than a generic for 'ultimate intentions' or goals - nothing special about that. To say that one wishes to have an economic system in which no one goes hungry is a type of idealization. Though it may be unreachable using current economic systems which all seem to leave a residue of those who do not have enough to eat (and some with far too much) the ideal, though imagined, is not at all 'imaginary'. Just the contemplation of a condition which might be very real if we set about designing a system that would embody it. A very real "There", even if we don't yet know how to find our way to it.

o o Reply 



Proof of work  red_slider

10 years ago

Very thoughtful comment. "Who owns the means of survival?"

Excuse my naivete but is this meant to juxtapose the means of production, as in capital and labor surplus value ideas? That's what it somehow conjured in me.

1 o Reply 



red_slider  Proof of work

10 years ago edited

Thanks for the question, Tony (I don't often get many questions about my ideas). It's not naive of you, at all. More the naivete of my imperfect rendering of a complex idea (I have no expertise in economics, whatsoever).

Perhaps I can explain what I mean by "the means of survival" by telling how I came to substituting that for Marx's 'means of production'. As I thought about the matter, it seemed to me that the core issue was not the broad sweep of 'production' that was of greatest concern, but that part of production that concerned providing everyone with the things they require to survive--the essentials of life and participation in their society (food, shelter, healthcare, education, information, energy, transportation....).

The amount and kind, modest or generous, are arguable. But the basic requirement for every individual to have enough of those things to survive is not. That led me to wonder what might happen if we took just that much out of the purview of the dominant economy, whatever its type, and put it in a special preserve, insulated from all other productions (call those "luxuries" if you like) and put them beyond reach as well as beyond the reach of the

[see more](#)

3 o Reply 



Nicholas Mew  red_slider

10 years ago

red_slider

Your thoughts and explanations are most interesting, very nuanced and yet very logical and interesting. I like them.

o o Reply 



Anne McCrossan

10 years ago

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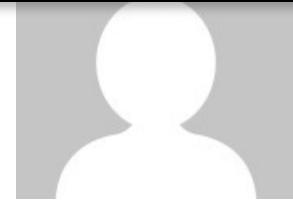
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W. Brian Arthur is an External Economics Professor at the Santa Fe Institute and a Visiting Researcher at PARC in California. Formerly at Stanford, he is the recipient of the inaugural Lagrange Prize in Complexity Science and the Schumpeter Prize in Economics.

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