CENTRE for LiveableCities SINGAPORE

CLC LECTURE

Scale: The Complex Science of Cities

12 March 2018

Living organisms exhibit a natural life cycle and a limit to growth, governed by the networks of circulatory systems. Do cities and businesses behave the same way? Why do corporations always die, but cities keep on growing? Prof Geoffrey West investigates these questions in his new book "Scale" as he provides insights into the overarching behavioural science of these complex systems. Hear from Prof West as he shares how amazing Laws of Physics govern growth in cities and in business.

Lecture Segment

Yuting 00:00:13	Good afternoon, my name's Yuting, from the Centre for Liveable Cities, and I will be your emcee for today's lecture. Before the lecture commences, we are pleased to announce that the Centre for Liveable Cities and Santa Fe Institute signed a Memorandum of Understanding [MOU] to apply complex city science in urban studies to better understand our city as a complex system. As Professor West will share in a lecture later, complex city science calls for a more integrated and interdisciplinary approach to study the complex urban systems and scientifically derived principles governing the interconnected urban components. Research in this area will add value

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to our understanding of our cities, enabling better decision-making. The MOU will enable CLC to act as a focal point in joint research between the world's leading experts in SFI, local government agencies and research institutes, [thus] leveraging on the collective expertise to discover principles and identify potential solutions to guide the planning and development of our city.

In today's session, we are honoured to have with us Professor Geoffrey West, Distinguished Professor [of the Science Board, Science Steering Committee at the Santa Fe Institute]. In this lecture, Professor West will share with us insights from his latest book Scale: The Universal Laws of Growth, Innovation, Sustainability and the Pace of Life in Organisms, Cities, Economies and Companies, on the fundamental rule that governs the growth of complex systems such as organisms [video drop out] start the session by inviting professor West on stage. Prof West, please.

Geoffrey West
00:01:42

This was the title of the talk that we had decided upon, but in fact it's a little broader than that and it is based—as was said in the introduction—on a book that I've just written that is at a popular level, but discusses many of the things that I'm going to touch upon today.

Scale: Our Future

00:01:59

One of the things we're not so conscious of, even though we know it, and that is that everything around us is expanding at an exponential rate, in terms of our socio-economic life. So, as I've written down here, just to give you a sense of that, 200 years ago the United States, for example, was just a few percent urbanised and today it's well over 80%. The world crossed the half-way mark just a few years ago, it's heading for this sort of 80% level somewhere towards the end of the century.

And, you know, just again to give you a sense of the scale of this, that's equivalent to urbanising, if you just do a very simple average, this is equivalent to averaging well over a million people every week. So it's actually more, if you do the calculation it's more like one and a half

00:02:52 million and that’s equivalent to adding a New York metropolitan area of about 50 million people every couple of months, or adding on the planet a Singapore every month. So every month that’s what’s happening, so to speak, in the next… In the foreseeable future until the… until mid-century.

So another example is China which was very slow to urbanise, relatively speaking, and it too crossed the halfway mark just recently. And the red is the urbanised… the urbanised population, the yellow is the rural population and it’s also heading towards this 80% level later in the century. And of course that is, as you well know, that is an enormous pressure on the questions of resources, the questions of social stability and so forth, some of which I will discuss shortly.

Urbanisation & Growth

00:03:49 So, you probably can’t see anything there, but had there been satellites in the year I was born, which is 1940, this is what a picture of the earth would have roughly looked like. If we had lights we’d see a few points of light there. So that’s, in my life-time, if you would take a picture of the earth from a satellite, it would have changed from this to this. Just glowing fantastically, and of course this is all due to **urbanisation**. Almost entirely due to urbanisation, those are the night lights of cities. And that’s the night lights of you. That’s your night lights, that’s what you look like at night, just burning away like everybody else. And of course this is… This is of course the origin of climate change and potentially global warming and so on. And this is another issue, maybe I’ll have time to chat about at the end.

And of course, all this is a reflection of the ridiculously fast growth of the population. As you can see, if you again look at the year I was born, 1940, the world population was somewhere under two and a half billion, it’s now heading towards eight billion. And it’ll no doubt head towards ten

00:05:06 to twelve billion by the end of the century if it keeps going at this kind of rate. And that's again reflection of this extraordinary discovery that we made, a couple of hundred years ago. Two major things—one is of fossil fuels and the second was the discovery of capitalism, entrepreneurship and therefore of abundant wealth creation, and the kind of quality and standard of living that others led to, which we all participate in, and which we'd all like to sustain in some way.

And as I say at the end, I will try to put cities in the context of that, of this question of sustainability. So I think it's fair to say that the fate of the planet lies in the fate of the cities, and so a critical aspect of what I want to talk about is a certain urgency of understanding cities in general, in terms of the big picture, but also of course understanding them on the local scale. And if I have time, again, I will talk a little bit about that.

Beyond Physicality

00:06:08 Well, we all recognise cities, they come in all kinds of shapes and sizes. And we all understand why it is that they are attractive to people. There is a certain sense that there's greater material well-being, there's greater job opportunities, there's greater kind of buzz, buzzy, sexy life that exists in cities relative to a rural life and this is… this has been proven [audio drop out] to be attractive. And you know, cultural events and education and so forth. All of these are aspects of urbanisation and the continuing expansion of cities. But none of this can happen, at the most fundamental level, without energy supply. Energy underlies everything. And so without energy supply none of this can be either hap[pening or] maintained, let alone sustained.

But I'm sure all of you are familiar with the second law of thermodynamics, the second law of thermodynamics basically says that you can't transform energy, in the way we do it, we transform this into this, we can't do that without the production of entropy. So there's a

00:07:19 kind of socio-economic entropy that's produced from this. That is, there is the sense that there's always waste products that come from transforming energy and that manifests itself of course in social phenomena like this, and this, and this, [accompanied by slides of congestion, pollution and crime] and all these things which you are very familiar with in one form or another. Singapore happens to be a city that's done extraordinarily well in mitigating many of these kinds of problems, but world-wide these are major problems, and are the unintended consequences of the extraordinary rate in which we've been urbanising.

And the other aspect of this is you cannot any longer build a wall around oneself, no matter who you are, and avoid any of these because they're happening somewhere and they impact everybody ultimately. So one of the questions is, is this what our cities will look like in 20 or 50 years? Hopefully not. Or this? Is this what's going to happen? Or hopefully we're going to have the kind of beautiful city that Singapore has developed into. But that's… So that's one of the things that's underlying it.

Now when we think of cities, one tends to think of the physicality of cities. When you think of the urbanisation of cities one tends to think of, I don't know, the boulevards of Paris, the skyscrapers of New York, et cetera, et cetera. That's the image of cities. It's the physical aspect of cities, the roads and buildings and so forth. But the city is not only much more than that—that's actually, in many ways, the least interesting part and the least important part, ultimately of what a city is—because a city is a place of the integration of all that physicality, that infrastructure with of course the socio-economic dynamics taking place between people. And cities in fact, can be seen as, and I want to emphasise this, as this marvellous machine that we have invented for encouraging and facilitating social interactions, bringing together situations such as we have here this afternoon. To get people to interact in order to create

00:09:36 new ideas, to create wealth, and to create and maintain the kind of quality and standard of living we have.

So there, that's Singapore, that's Orchard Street [*sic* Road] but that's the essence of a city. And of course it's been going on a long time, and I like this picture because that's what's happening here. This is the… The background, the infrastructure's been there for maybe 2000 years, and people have been doing this, sitting around talking, interacting, creating ideas for 2000 years. Most of those ideas…in fact almost all of those ideas are useless and pointless in general. They're maybe important for the individuals but they have almost no effect. But here's what's amazing, is that by creating a situation where this happens metaphorically, every once in a while the theory of relativity pops out. Or Google emerges. Or General Motors. Or whatever.

That's what a city is for, is to create that, to create the environment in order to stimulate ideas, innovate and wealth. So here it is and similarly here's a picture of New York, the greatest city in the world that's…where we see it, again, taking place 120 years ago. New York doesn't look like that anymore, those buildings are still there, identically. Those people are all dead and gone, new people have come, they don't gather in the streets to do this, they gather in big buildings and they create more wealth and ideas and impact. That's what a city, in a nutshell, is really about.

And the whole point of a city, and the whole point of making a city is to engender that in order to increase and maintain the quality and standard of living for everybody. So having said that, we recognise that there are two kinds of independent but totally integrated pieces of a city. One is the physicality, the infrastructure which in biology goes under the name metabolism; and the other is the exchange of information because that's what happening in all those interactions, that's the socio-economic diet forces at work. And in a biological system

00:11:53 that would be the genomics and so on but that manifests itself in those social effects that I have mentioned a moment ago.

So on the one hand, we see that cities and urbanisation create problems but they're also the solution because, precisely because they are the, not only the engine but also the great attractor that attracts all the smart people to cities in order to participate in this fantastic process that we discovered maybe beginning 10,000 years ago, when we stopped being hunter gatherers.

Understanding the Dynamics of Cities

00:12:29 So I think because of this crucial role of the cities, I think it's really important to ask the question: Is it even conceivable that we can develop a quantitative, predictive science of cities in the sense that I'm talking as a physicist, quantitative, predictive, analytic and based on data and so on; and involving some of these big ideas that I've written down there—and maybe many more—and apply that not only in the big picture, but down at the nitty-gritty level of dealing with individual problems in individual cities.

Now the typical way in which we do that is we break everything down into these boxes. This is the classic way of doing it: We have all these boxes and I've just… this is some of my arbitrary choice on my part, but you know, within these boxes, each one of those could be a box. Each one of these things. And each one of these is treated almost independently. Just as in a university we divide up the…our way of understanding the world around us into departments, and each department divides itself into sub-departments and so on. And so it is with this. And that has been extremely successful up to now.

And I would argue that now, we are facing some truly major problems and the pace of life has increased so much so that we need now to really

00:13:55 make a significant change and start to integrate these and see each one of these not only as a system of themselves, and in fact as a system that is continuing to adapt and is highly complex—but that each one of these is like that, but the whole thing together is itself a complex adaptive system. So that's what I've said here.

So I want to switch gears slightly because I want to take it out of the context of one's prejudices about cities and social behaviour, and switch to something that we understand a little deeper—and that is biology, our own bodies and the ecosystem around us and so on. So here are some questions about biological life, which I'm going to touch on briefly. I bring them up because it's immediately obvious that if you ask the questions, "Can there be a science of cities in the sense that I've just described?"—which is very much a physicist's view—that's almost certainly impossible in the… if we take that literally.

The idea that there's kind of a Newton's laws of cities is almost ridiculous I would argue. Meaning that we have a bunch of principles from which we can write down some equations or do some marvellous computations and predict with **absolute** certainty what the outcome will be. That's the way physics works and that's the way almost, much of the infrastructure around us works in detail that we're able to do that. It's why your cell phone works, of course, the way we understand the way satellites work, the way we understand how signals are transmitted and so on.

That's not what we can do for understanding the dynamics and organisation of cities. So, but nevertheless it may be that we can suggest questions and think of problems, where we only need what I will call a coarse grained answer. And so to introduce that I want to turn to biology and ask questions like this. So for example, I can say with certainty everybody in this room will be dead in 100 years. No-one is going live beyond about 100. And the question is why is that? Where in the hell does 100 years come from? We ought to be able to predict that. Why is

00:16:12 it that no-one in this room is going live for 200 years or 1,000 years or a million years, and everyone here has lived more than ten years? So where does that come from? Which is already three times longer than a mouse can live and yet you're made of the same stuff as a mouse. So why is that? Where does that come from? That's a coarse grained question with a coarse grained answer.

And we can ask other ones like, "What is ageing? Why does this age? What happened here?" For example: Why do we need to sleep eight hours a night? No-one in this room I suspect, could get by with sleeping more than three or four hours a night. If you did…if you do, you die. It doesn't matter how much you eat and how healthy you try to keep yourself. But you don't have to sleep 15 or 16 hours like a mouse. Three or four hours, by the way, is how long an elephant has to sleep and it does fine. Why is that? And so on. So here's… Now we move back to cities in terms of these questions; why is it… First of all, are cities and companies like organisms? We often think of them that way, we think of them in sort of biological terms, the metabolism of a city, the DNA [Deoxyribonucleic acid] of a company, the ecology of the market place, and so on.

But in particular this interesting question. You know it's extraordinary, we all die as I said. All organisms die. All companies die. And if I have time I will show you all the data on that. Google and Microsoft will eventually disappear. Yet, Singapore and New York and London keep going. There's no evidence that they die. Almost no cities die. You drop atom bombs on cities and 25, 30 years later they're fine. A diddly squiggle in the stock market and you lose a TWA [Trans World Airline], a General Motors and so on, Lehman Brothers and so forth. Why is that? There is the picture.

Understanding Cities through Biology

00:18:09 So I want to just say a few words about some of the science of biology. And I'm going to use that as a point of departure to then take it over and talk about cities, and ask to what extent cities are biological and what we can learn from that and to what extent are they different than biology? So we are one of these, we vary by eight orders of magnitude from the shrew to the whale. And yet we have very different evolutionary histories, otherwise we wouldn't look so different.

Here's what amazing, is that each of those animals has evolved with its own unique history. We all believe in natural selection. Each organ, each cell type, each genome, in each of those animals has its own unique evolutionary history. So if you're asked about any of their characteristics, if you measured anything about them, you would expect—given that everything was historically contingent—that there would be very little correlation between them. And so if you plotted any quantity on a graph versus it's size, the points would be all over the graph, reflecting the unique evolutionary histories. Well, that turns out not to be true! And here's an example. This is the most fundamental quantity by the way, not just for an organism—you— but also for every city, and every company. That is, its metabolic rate, how much energy, how many resources it needs to be maintained. And that's something that every organism has and one should be able to answer that for every system.

So here it is, this is the metabolic rate versus size for a bunch of organisms and it's plotted on a logarithmic plot so you can get a mouse and an elephant on the same graph. And what you see is something extraordinary, systematic and regular has emerged, something unbelievably simple reflecting or coming from something that's maybe the most complex, diverse process in the universe—namely metabolism. And so, that's the first astonishing thing. There's this

00:20:22 unbelievable regularity underlying the apparent chaos, randomness and messiness of natural selection.

The other thing is that if you forgot about natural selection, and I asked you just simply if you double the size of an organism how much energy would the new one use? You would have thought well [if] you double the number of cells, you need twice as much energy. No, that's not true. The slope of this line is roughly three quarters, which means every time you double the size instead of needing twice as much metabolic energy, you only need 75% as much. Every time you double, there's a 25% saving. So there's a systematic economy of scale. The slope of this being less than one, is an indication of a systematic economy of scale, and that is called, technically, a sub-linear scaling. Okay?

So that's interesting but what is equally interesting is that if you measure anything, anything that you can measure about an organism, and you plot it this way, the graphs all look like this. They all have this regular behaviour and I will show you a couple. Here's one, this is something mundane—it's heart rate versus size for a bunch of mammals. Going, again, from the mouse goes all the way down. And this is, again, very regular and the slope of this is minus one quarter.

So here's you. This is white to grey matter of your brain. You see how extraordinarily regular it is. The white matter is the cabling, roughly speaking, and the grey matter is the stuff that actually computes, so to speak. And what you see is an extraordinarily regular behaviour with a slope five quarters, roughly. Here's… This has got more variance in it. This is the length of genomes versus size. And what you see, I've written it down there and that's a best fit, is very close to one quarter. And what you see emerging systematically are these very simple so-called power law curves occurring in things that are unbelievably complex, showing that underneath the extreme complexity lies somewhere an extreme simplicity.

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And the question is what is that simplicity? Typically, the other thing that emerged from this, and I could show you 50 to 75 of such graphs, is that the slopes of all of them are simple multiples of one quarter. Like the three quarters and the minus one quarter and the five quarters and so on.

Here's one, I couldn't help but put this in, and this is because I've already talked about death and mortality. And that's life-span. Life-span scales approximately with the slope of one quarter. That's the lifespan increasing as mass to one quarter. I've already said that heart rate decreases as mass to the one…minus one quarter. So if you multiply these two together the increase of lifespan is exactly balanced by the decrease of heart rate and so there's no change. So heart rate times lifespan is that same for all mammals with beating hearts. But what is heart rate times lifespan? That's the number of heartbeats in a lifetime. So the number of heartbeats in a lifetime is the same whether you're a shrew that lives for less than two years and has a heart rate of well over 1,000 times a minute, it's the same as a whale that lives for 150 years and it's heart beats at maybe 15 to 20 times a minute. And there's the data. That's the beats per… And that's extraordinary.

I mean this is either some diabolical accident or something very deep about why it is you're all gonna die in less than 100 years. It's all buried in this. Okay. So, what's underlying? Where in the hell does all this come from? Why is it that trees and fish and birds and bacteria and you all scale in the same way? Well, the idea is that underlying it all is that we're all sustained by networks, and it is the mathematics and physics of networks that give rise to these scaling laws. And I… that's another whole lecture of itself, you just have to believe it, or read my book, of course. (Laughs) Best to read the original papers, much better.

So it is the network. And you know, here's just a bunch of networks. There are you, in the bottom there, and on the bottom left is you. That's your brain, that's your circulatory system, and actually on the right is

00:25:07 also you. That’s inside cells and so forth. I want to use this before returning to cities to something that is fundamental to cities. And that is growth.

So we've all done this, and you recognise the growth. When you grow, you’re scaling and as you can see here, and I don’t have time to discuss the way in which you scale, but I do want to tell you a little bit about the way you grow. And you know how you do it—how you did do it—that is you ate, you metabolised you sent that metabolic energy effectively through your networks. Networks feed the cells. At the cellular level, what happens is that some of that energy goes to maintaining what’s there, the cells that are there, including replacing ones that have died, and therefore doing repair to damage that has occurred. And then adding new ones.

And as I say that you should think of cities and companies because they don’t… they work in not such a dissimilar way. And I’ll come to that shortly. So there it is, there’s just a little schematic of it and I’ve written it slightly differently here. And this is… You put into an equation that the incoming energy goes towards maintenance and growth. And you put that into a mathematical equation, you can solve it, and what’s beautiful about it is you get a… This is what you get.

So here’s the weight versus age for a rat. And those points are data and that line is a prediction from the theory. And I’m going to jump ahead and say that this has universal parameters because it’s a universal theory. So the same two or three parameters that determine that line determines the growth of everything else on the planet. Believe it or not. Including you. And I will show you a graph of that in a minute but here’s the important point I want to emphasise here. And that is, you know you did this, you grew and then you stopped. And the theory explains why you stopped, and that stopping is intimately related and derivable from the fact that you have this sub-linear scaling, meaning economy of scale given by the network constraints for your metabolic

00:27:33 rate. Okay? That's where it all comes from. All that network stuff then gives…right, now so this is great.

So this explains why you stop growing and… Here's some other ones. The data isn't so good. Which is just a few, there's two… what is it? Two mammals—a fish and a bird. And here the theory tells you if you re-scale according to what the theory tells you, I do not have time to go into it, you rescale the size and the time in such a way, everything grows effectively at the same rate. Even though of course, in the real world, some of… a whale lives 150 years and a mouse for two or three. But if you re-scale appropriately, and you can see there's a few outliers but it's pretty damn good and the theory predicts not only that they all fall on that curve but the exact mathematical form of that curve. So that's… So by the way, you don't have to believe any of the theory, it's just spiritually beautiful to see the great unity of life occurring in such a graph, that we're all interconnected. And this is just some very small sampling of a bunch of animals.

The Complex Science of Cities

00:28:42 Okay, what's next? So here's a summary, and I'm going take… of biology, and I'm going take over this paradigm into cities and plot it into companies. So we have these non-linear scaling laws, dominated by this one quarter in the slope of those graphs in the exponent of the power law, they manifest an economy of scale. The bigger you are, the less energy is needed per cell or per capita to stay alive. The pace of life, I didn't stress this, but the other thing that comes along with it and is related to this economy of scale and constrained by the network, is the pace of life systematically slows. The elephant and the whale's heartbeats are much slower than yours or of the mouse's in a systematic, predictable way. Growth is sigmoidal, meaning it grows quickly and then stops—and then you die. And the theory predicts all of

00:29:39 that, and it's all explained by the dynamics and mathematics of networks.

And this is great, but it would be terrible in our present paradigm of our socio-economic system we live in. Because we don't like the idea that we stop growing. It's endemic that we need to be…keep growing. I now want to move into cities and into that whole paradigm, to see how it differs from this and also its relationship to sustainability. Because, the fact that we stop… everything stops growing and lives most of its life in a relatively stable state is one of the reasons why life has been so sustainable. Sustainable for two to three billion years. Socio-economic systems have been around, even if you stretch it for less than 10,000 years and in the way we normally think about it for just a few hundred years. Okay, let's move on.

So, with this paradigm the first question we have to ask is are cities scaled versions of one and other? That is the whale is a scaled up elephant, which is a scaled up giraffe, which is a scaled up human being, which is a scaled up mouse. Despite the fact that the whale lives in the ocean, and the elephant has a trunk, and the giraffe has a long neck, and we walk on two feet, and the mouse scurries around—we're scaled versions of one another. If you actually look at the data and do what I just showed you, up to 80, 90% coarse grained, on the average, roughly, we're scaled version of one and other. And the question then is, are cities within an urban system scaled one… scaled versions of one and other? Is New York just a scaled up Los Angeles, which is a scaled up Chicago, which is a scaled up Santa Fe where I live? Despite the fact that like the animals, they look very different, they have different histories geographies and cultures.

Nevertheless, you could still ask the question, especially given this paradigm, when you realise that the scaling comes from networks and you realise that cities, of course from this viewpoint, are nothing but a bunch of networks. They're lots of transport networks, transporting

00:32:00 people, transporting electricity, water and other resources and so forth. There's underground transport and there's this kind of transport you have here, and they're supplied by network systems and so forth.

But, as I said at the beginning, this is the least interesting part of a city, but the part that we spend almost all of our time thinking about is the infrastructure—maybe because in some ways it's the simplest part of it. Because this is really what a city is about: It's what we're doing here, it's the interaction between people and what happens in their lives, and how they form societies and create the kind of fantastic phenomenon that we have around us. And this is just the social network graph, each node is a person and those lines of course at those… the people they connect to. And one…two things about the network, you've no doubt seen lots of these pictures of networks, and there's now a burgeoning science of networks. A lot of it started and is very prominent among my colleagues at the Santa Fe Institute.

So the first question is: Are cities scaled versions of one another? So this is the infrastructural part. And this is something relatively mundane. This is the number of gas stations, petrol stations versus city size, plotted again, in this logarithmic way for a bunch of European cities. And what you see is, as in biology, very…you know, it's good evidence of scaling. And what you also see is that the slope of these lines are less that one. This would be one. So it's sub-linear. So it's an economy of scale, not surprising, the bigger the city, the less gas stations per capita are needed.

But what you also see is, the slopes of those are not so different. And in fact, if you look across the world, which we have done, at gas stations in countries from China and Japan, from Columbia, Chile… I don't know, everywhere we could get data. They all look like this, they all have pretty much the same slope. And that slope is about 0.85. So the only difference in biology in this sense, is that instead of a 25% saving on each

00:34:25 doubling, you only get a 15%. But otherwise it's pretty much the same, and there's an economy of scale.

But what is also interesting is that if you look at any other infrastructural quantity which you can measure, like the length of all the roads, the length of electrical lines, the water lines, whatever. Whatever you can get data on that's infrastructural, it looks like this, it's the same 15% savings every time you double. And it's the same everywhere across the globe where you can get data. So there's a kind of… this remarkable universal behaviour that's very interesting, it's very similar to what we see in biology. But as I said, that's the least interesting part of a city. The most interesting part is stuff that didn't exist before we started talking to one and other, and forming communities. And these are things like, on the left here is wages as a function of city size, and on the right are numbers of professional people, super-linear… what do you call them? Super creative people—Richard Florida's term—as a function of size.

And you can see there's more variance but you can see very good evidence of scaling. But what you do see, which is something which is new, is that instead of having an economy of scale less per capita we get a slope bigger than one and those are those numbers there. Beta, the slope. And they're bigger than one, which means the bigger you are the more per capita. Doubling the size, you get roughly 15% more wages per capita the bigger you are. You get 15% more sexy, super creative, professional people. You're more creative 15% more patents are produced. 15%—another creative phenomenon—15% more crime, 15% more police, tax receipts… Everything that is socio-economic that has no simple analogue in biology increases by the same amount! Even though it's completely different in many cases. And, dare I say, it's the same across the globe.

Look in Argentina, look in Columbia, look in the United States, look in China, Japan, it's always the same 15%. There's restaurants in Holland. So here's just a… six quantities from different countries plotted together

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just by eye, you can see they all scale in pretty much the same way showing this slope approximately of about 1.15, which is 15% addition. And I don't know if you can read from there but they're some of the things I've already shown. So here it is in English. The good, bad and the ugly come together. On average, if you double the size of the city you systematically increase all these marvellous things. Some of these good things systematically increase—income, wealth, patents, colleges, creative people, but also police, AIDS [acquired immune deficiency disease], flu, crime and so on.

And at the same time as that increase of 15% in socio-economic activity and socio-economic outcomes, you save 15% on all infrastructure. So cities are good. The bigger the city, the better, from this viewpoint. So... and indeed you could speculate this is the reason why cities keep growing. That on the individual level you gain, and you tend to repress the bad things about a city. But collectively, we gain because you need less infrastructure to support the same amount, and you get a 15% bonus by all that creativity and innovation and wealth that's being created, grown. And that's the thing, and that's why we've done it. It's marvellous. Okay.

Interconnected Cities: Networks

00:38:14

So, where does it all come from? How can it be that Peru and the United States and Japan and Portugal, which have never... it wasn't as if in 1743 there was some major world convention that everybody got together and said okay, the industrial revolution is just beginning, and we're going to build hundreds of these new cities. Let's decide on some of the parameters of the urban systems that we're going to create. No. In the same way there isn't in my... at least I don't believe, there isn't some old geezer up there who's a great engineer saying this is how we're going to design all these animals and plants so they go on doing what they do. No, it all happened by organic evolutionary process. And the question is

00:39:05 what is it? Well, going back to what I said earlier about biology, it's in networks.

And the idea is that here what's driving it is the universality of social networks and these things I talk about earlier. And it is their nature. So here's that universality in data. This is income, GDP [gross domestic product], crime and patents, all plotted on the same plot, adjusted. But you can see that they all have the same slope. Though you can see quite a bit of variance but it's pretty good. And the question is how do you test this? Well, I'm not going to go into any of this. This is not the place to go into any theory. But you could, without knowing any theory you can ask how do you test this?

Well, if they all come, if all of these disparate things come from social interactions, one critical test is to ask how many social… how does the number of social interactions between people change with city size? The prediction should be that it'd be just like this. Because they're supposed… It's supposed to have been derived from what we're doing here—social interaction. Well how do you get that? That's been very hard to do until very recently. And now we have, of course, all of us carries one of these things around, of course. A little detector. So that everybody knows… So there's someone [who] knows exactly where I am and where I'm moving. Even when I move across this bloody stage they probably can detect with this thing. And it… there it is. And so this is fantastic data.

And the cell phone companies, the telephone companies have this, and we were fortunate to collaborate with… Some of you know him, Carlo Ratty at MIT [Massachusetts Institute of Technology] with some of these young people. And one of my collaborators here, Marcus…. Marcus! Was a post-doc at… was one of my collaborators then and we… What we did - and Marcus was majorly, majorly involved in this - was you used that data, you analysed the billions and billions of phone calls, this big data set and ask, you know, how many people indeed.. I mean I call you…

00:41:19	I call Will, and Will calls me back within six months, we call that a relationship. So we count those roughly speaking, as a function of city size. And… here's the result. There it is there at the bottom. And you can see just by eye it's pretty much the same slope as predicted, and the green and the red… I'm sorry the green and the blue are data from the United Kingdom and from Portugal. And that was, that was very nice. It's a lovely confirmation of the theory. One of the things we did not suspect, but it wasn't predicted by the theory is the following: You can ask how many of your friends talk to each other? So, sort of getting to the modularity of the people around you. So this is, roughly speaking, how many people are interconnected, of the people that talk to you. And what we discovered in the data was that that doesn't change with city size. So it's sort of interesting. Even though your interactions are increasing rapidly, the bigger the city size, the people that you are sort of staying connected to and staying connected to each other, is the same. And in this case, down at the bottom there, a small town of 10 to 12 thousand people, which is a small town in Portugal, as is in Lisbon near the end there, of over a million people. So this is, I think, extremely important, in terms of understanding and creating the kind of life we want to have in cities, and that is that as we increase the incredible connectivity, there is this need to remain village-like—small, and interactive. So, if we design environments, buildings, blocks of flats, not to somehow understand…to take that into account, we are destined to create more social issues than we're already creating. Okay, so I think I'm probably running late. I think I might miss this out. This is another beautiful piece of work that Marcus and I worked on, and it's predicting…I will just show you this quickly. It's…if you take…where are we? Here, we're in Singapore, that's right. You take this little area around here and you ask, "How many people come into this little area around here, are coming from a kilometre, five kilometres, 10

00:43:57 kilometres, 20 kilometres away, once a week, twice a week, three times a week, once a year?" You ask that question. R is the distance away, F is the frequency. And you can prove a little theorem that says: as it goes as the inverse square which was ideal, which is amazing. Very simple ridiculous result.

And what is even more ridiculous is that that's what the data confirms using these billions of cell phone data and here it is, roughly speaking what I just said. That dotted line is inverse square, it's for Boston, Singapore and Lisbon, and Dhaka and Senegal—all the same. Completely different societies, cultures, histories, but they all line up pretty much the same way. And then we deconstructed it, I think this is the one I want to show. This is…that's Boston, that's Singapore. That's taking all the different areas in Singapore, those blue lines are the inverse square, and there, I can't read them here, somewhere… you know, but you take these little areas around. So this is wonderful tool, in principle, if you're serious about urban planning. And it's not just rules of thumb that you have. Here is something, not only do you have a theory, but you have the data to confirm it. Okay.

Increasing Pace of Life

00:45:19 So I've got two more things that I want to talk about, and then I'll stop. One is, I just mentioned, that in biology, the pace of life slows down the bigger you are. And that is to do with the…that's related to the structure of the networks and the sub-linear scaling. It turns out, in social networks—[aside] oh, I have, that's very good—the pace of life speeds up, and that's associated with this super-linear scaling. And we can understand it, because the nature of our social networks are: I talk to Will, Will talks to Teng Chye, Teng Chye talks to Tom, he talks to me, then I talk back, then you talk, and we talk. And we go around and we build up. We build up ideas, we build up things. And we are very positive feedback. Lots of positive feedback and social interactions. That positive

00:46:26 feedback is one that, of course, not only leads to more ideas, and to the theory of relativity and Google, but it leads to things getting faster and faster. And I'm not showing you a new theory, but you can understand that. And you feel it, very much feel that viscerally.

Okay, so the pace of live speeds up and you can predict it. And on the left, I showed you the heart rates decreasing, on the right, is some whimsical data taken in the '70s on the walking speed in various cities in Europe, (laughs) by some people at Princeton, actually. And we plotted it this way, and there you can see…you know, there are lots of variants in it, but it's very…I mean there are lots of much more serious things we've check the data on, to show that you can see this speeding up, and it's in agreement with the theory.

And just again, a whimsical thing: this is from about a year ago, I saw this in a British newspaper. It's a picture, as you can see, of a street walking, and I'll read it, you probably can't read it, I shall read. "Research revealed almost half the nation, United Kingdom found the slow pace of High Street to be their biggest shopping bug-bear." Meaning…can you believe it? Half the people are upset at going shopping, mostly because the other people aren't walking fast enough! So, this is a picture taken of the first day in Liverpool, where they initiated a fast lane for walking (laughter in audience), which you might have to do in Singapore. So this is just a funny old manifestation of this phenomenon we all feel.

So I want to do the growth, and then I will try to finish up with this. So, it's the same thing as we have before: you eat, (chuckles), see, you eat, it brings in stuff, but it brings…it's much more complicated now. It brings in all kinds of resources and then ideas, and then energy and so on, and I'm not going into all this, but you get the idea. That's analogous to the metabolic rate, there's a kind of social metabolic rate that you are bringing in. And what does that do? It maintains what's there, it maintains the building, the roads. It maintains the people, it has to have doctors, hospitals, that's a kind of maintenance. And then it grows new

00:48:55 stuff. It builds new buildings, and develops things, and it builds new people either by making them the usual way, or you immigrate, but you make new people. That's part of growth. All of that, it's to be put altogether. I'm not showing you any of the mathematics here. But the simpler version is actually biology, and I've showed you that, this graph, where sub-linear scaling led to bounding growth.

Here, this is just a cartoon for the moment. What the theory predicts, if you take that equation, that I…that statement of the equation that I just said a moment ago, and you put that into mathematics, instead of producing this, it produces this, which is great! That is *zoom*! [Onomatopoeic] you expand super exponentially, faster than exponential, which is actually what we've been doing, and that's great.

So the theory is very consistent. The network theory produces super-linear scaling, which we see. And super-linear scaling produces super-exponential growth, which we see. So it's a very nice compact theory, very simple in principle. But it has built into it a fatal flaw. I don't think the theory does, but the implications of theory has a fatal flaw, and that's illustrated by this dotted line, which in mathematics is called a finite time singularity.

And what it means in English is that in some finite time, whatever it is you are measuring on this axis, in any of these metrics—could be the GDP, could be the number of AIDS cases, whatever—that will go to some infinite number in a finite time, which is obviously crazy, you can't do that. That's because it's super exponential. By the way, if it's exponential—this is a side comment—if it's exponential, this is not a problem. Because it takes an infinite time to become infinite, technically, in an exponential… Super exponential, which is what is going on here, you do it in a finite time, meaning that in some finite time, could be five years, 10 years, a hundred years, you're all going to have a problem because you're going to run out of something inevitably.

00:51:26 And theory tells you what happens. It says, and that's what the right-hand side is, you go through the singularity, you stagnate and collapse. So, how do you avoid that? Well, we know how to avoid that, we've done it. Again, by a cartoon; when we go along here, we recognise that we are assuming, and we are of a shorter number of periods. It's true, that roughly speaking, nothing changes.

We discovered bronze, a long time ago, that started a whole lot of cycle of things, a whole new paradigm. You discover coal, you discover oil, you invent computers, you invent IT [information technology]. Each of these is a major innovation and what it does is during that period, this is how it grows and that gives you a hint as to how you avoid collapse, which would happen here, and that is that somewhere along here, you'd better make a major paradigm shift to avoid the singularity. And then you can take off again, and then of course the same phenomenon will occur again. You would collapse if you don't reinvent yourself and start over again. And so on. You have the same.

So you have this kind of theorem that you can prove. If you demand an open-ending growth, then what you must have is not just cycles of innovation, but that cycles of paradigm shifts. But here's what's also important, is that they are accelerated, the time between here and here is always longer then the next one. So the time to the next paradigm shift, when you reinvent yourself and make a major innovation is going to be less than, necessarily, the time from the last one; and that's less than the time before in a systematic way. So, that's what the theory says if you just follow it through.

And this is not mine, I have no idea who this guy is, but I found it on the web, and it just looked like what I had said, so I show it. And what's nice about it, if you take…now my point is, how long did it take for…to have 10 million customers on the telephone, on the cable, on the fax and so on. So, it's just an arbitrary metric this guy invented. So here they are: it just gets shorter and shorter to get to 10 million. And if you take these

00:53:52 numbers, they follow exactly the prediction of the theory, and even more so, if you take this, the word singularity has come associated with the name Ray Kurzweil, who has this—someone in my mind, and I don't mind saying publicly— loony idea that very soon, we're all going to be cyborgs, and that's what the major paradigm shift is.

But in fact, so…but this is his graph basically, and he didn't put in, but these are all these things down here and what this is, so that everybody's on the same page, this is when the paradigm shift happened, how long it took to happen.

So, cells took a billion years, almost a billion years to evolve. And it happened, roughly speaking, a billion years ago. And so all the way down to here, here is the Internet, happened about 10 years ago, on this scale, 20 years ago, and it took, you know, less than 10 years to evolve, which is all on the same graph. And that line is exactly what is predicted by this theory that I told you. So this is somewhat speculative, but there it is, the data is supported by the data. And so, the question is: when you go back to this, you are suddenly confronted with a reductio ad absurdum argument that sooner or later, and in fact sooner, you're going to have to be innovating at a kind of…not just every 15 or 20 years, but every five years, then every year. I mean, not just innovating, an innovation as big as the internet. It's nuts. So, if you believe this, that's what's going to happen, and the data supports it. I don't know. It's speculative, but it's good to be left at that.

Nevertheless, you can think of it…this is, I've expanded the argument now to the entire system. But at an individual and city level, this is also true. But you need always to be…if you want to sustain yourself with open-ending growth, this is what you need to do. And I just show you here, a bunch of…this is just arbitrary data, I picked up, but I just want to show you some data. This is in the eyes of the beholder. This is New York City, and this some analyses we did trying to eke out these paradigm shifts, and we did it. That's what these lines are, and what this

00:56:17 is, is showing the deviations from a nice smooth curve of population growth and showing that the shifts up and down has a cyclical behaviour, which is getting…whose frequency is getting faster and faster. So we just did a very detailed analysis of New York to show that.

Patterns Observed in Cities of Today

00:56:41 And I think I'm going to finish here and just tell you, in two minutes, some of the things I haven't talked about that might come up in conversation. One is this: that the scaling curve represents the idealised city, that satisfy some fundamental principles which I didn't have time, really, to talk about, just as in biology, which I didn't have time to talk about, what the principles of the network are, but coming from the idealised structures of these networks. And so, of course, each city only does…very few cities sit exactly on the line, whatever the metrics is it you use. But then you could use that as a way of characterising cities.

So this is ranking of patterns and so on. But this is a way of asking about the ranking of cities and then asking how much do they over or underperform relative to the scaling curve to that of what they should be doing for a city of their size, as a function of time. So this is their trajectory as a function of time, as to how well they have performed. And one of the other things you see from this, is that cities are very resilient. If they're doing well now, they're probably going to do well in the next 30 years. If they are crappy now, they are going to be crappy in 30 years' time. Very little change. Despite that fact that all of these cities are growing fast and getting better in that sense.

Okay, and here are correlations between various things. I was going to go on to talk about firms, I'm not. And I was going...two things I will just say. One is firms: the number of firms go linearly, double the size of the city, you get twice as many businesses. And here's what's interesting, this is the United States, it's a fascinating statistic. Each time the

00:58:44 population increases by about 21 people in the United States, you would add a new business. Whether it's in a town of 15,000 or some 15 million, exactly. It's amazing! It's a remarkable statistic. And at the same time, each business employed, on the average, 12 people. So, that's good to know, I'd like to know things like that.

And the last thing, and I'm going to stop, is that we did a whole bunch of work on the diversity of cities and how important diversity is, and in terms of their success, and in terms of the universality of diversity. Certainly the distribution of diversity, meaning the different kinds of jobs and employment opportunities, is essentially the same in all the cities despite the fact that some cities are more specialised than others.

I'll finish there. I had a whole section that I apologise that I didn't get through on the companies, and the mortality of companies, or companies that fall somewhere between [inaudible] and cities. But…and that's important because one needs to understand that the amazing thing about cities is cities sort of go on forever, in this picture. But all the people in them, all the businesses die. And that's a very interesting situation. So how is that…so it's all to do with the fundamentals of evolution and natural selection, it's important and crucial for people to die, and for businesses to die, so that new things can emerge. And it is the city, it's the engine that we have invented for keeping that churning, going and getting more positive feedback through our social network. And it's all beautiful and wonderful, and we are privileged to be part of it. But it's all going to collapse, unless we do some major new paradigm shifts. And I'll leave you with one suggestion.

Ah, I don't have this thing up. Don't pay any attention to any of this. This is all irrelevant, everything.

Two things: I didn't say this, but everybody in this room desperately waiting for me to finish, is operating at about 100 watt, you're operating at like a light bulb. And so are you. All that 2,300 calories per day, it

01:01:23 becomes a light bulb. If you're asking about your social metabolic rate. And by the way, that's what you evolved…everybody up until maybe, certainly 10,000 years ago, this is what they were operating on. Your social metabolic rate, which is how much energy you actually need to be in this room, and you can get on the train, or get to your car, you can go home and have a nice home, and all the rest of this stuff, that goes from roughly 100 watts to—if you're in the United States—11,000 watts. Probably not so different in Singapore. That's a hundred times bigger, so each person in this room is behaving like a 30,000 kilogramme gorilla, or 12 elephants.

And there are seven and half billion people on this planet, and I would wager that every single one of them, regardless of their geography, history and culture, would love to be operating at 11,000 watts.

So, that's a huge jump. It's a huge jump because the only way you can do that is to innovate. [Is handed a microphone] Oh yeah, this. The only way to do it is to innovate and that innovation and positive feedback leads to collapse. So you have to ask yourself, what kind of paradigm shift can we do to get out of it? And that paradigm shift has to be qualitatively different than all previous paradigm shifts, because when we think about paradigm shifts and innovation, we inevitably think of technology. Every paradigm shift that was mentioned there in terms of the modern era is technology—internet, driverless cars, et cetera. The next paradigm shift or one of the next paradigm shifts has to be a social, cultural change. So I'll leave you with that thought. I apologise for going on so long. Thank you. (Applause)

Panel and Q&A Segment

Ms Hwang 01:03:13	It's always such a privilege to hear Professor West talk, and I don't think you went on too long. I wish you went on longer because there was so much interesting insights. I saw this quote from Rolling Stone that characterised Sante Fe Institute [SFI] as the Justice League of renegades who are all, you know, the geeks who are thinking of all the big questions. So, it's really amazing to see how Professor West brings the ideas from biology and physics into cities, and really tried to address the question of complexity in cities. And it's quite beautiful how some of the equations turned out in all your investigations and explorations, that there are these super-linear and sub-linear rules that kind of address them. One question is this question of bounded growth. Have we, by now, found any clear sign of the tipping point? What is the tipping point? Is it a population size, or is it other network kind of effects that would give us some clue to what is the tipping point?
Geoffrey West 01:04:20	Well, is this on? Yes. Yeah, that's of course the crucial question. I mean the crucial question is, in a way, I am interpreting your question anyway, this way: that can we devise a set of metrics that we can use to tell us, "It's sort of right there…it's going to happen in the next five or 10 years." I don't know, really, the answer to that, other than, and to do the kinds of analyses that we've done here. But I think the one thing that this doesn't tell you at all, really, is what the nature of the next tipping point is going to be. All it tells you is that there has to be one. What it does say is that within a certain period of time, and here, in this case, it's about 25 years. So within the next…actually, less, it's about 30 years from when you might think that IT really took off. And we have no idea what that might be, but there will be one, I believe. And you know, it could be something as, again, I use the word "mundane" as driverless cars, because it's not very sophisticated in a

01:05:48	way; but that could have very profound effects on the way we live in our cities and the way we design our lives. I'm sceptical of that, frankly. I mean I think that it's a wonderful idea, but I'm sceptical that we can do it. But so this, in no way predicts it, but I do think…what I try to present here was a big framework with the…trying to be a little bit tantalising to say that what's really required here is much more in depth research than has been done. Much, much more. This is just scraping the surface, really, to tell you the truth. I mean …and it needs to be thought through with people from many different academic disciplines, but also equally importantly, from many different kinds of practitioners, such as yourself, for example, the people that are dealing with many of these problems. But…and my pessimism, to be honest, is that we're not doing that. We're not…there isn't sort of a…. Well, I once used the phrase, we need to devise a grand unified theory of sustainability, and it should have the same urgency. It should have not the same, it should have much, much more urgency than we had, say than the US had with the Manhattan project and the building of the atomic bomb, or even the Apollo programme to send a man to the moon. I think it needs to be much more urgent than that, and is, in fact, much more urgent, I believe. And I'm disappointed that it's hard to get traction, certainly within United States, but even internationally, to have this sort of bigger picture approach integrated with the necessary work which is most of it, actually, done in the trenches on the details.
Ms Hwang 01:07:52	I think that's why I'm pretty excited about the MOU that CLC has signed with SFI. I think there's potential there that we can really use complexity science as a way to better inform how city planning and city-planning policies could be driven, and to look at it not in a reductionist way, which is typically the kind of more silo approach that has been taken to urban-planning science, but to look at it more holistically.

01:08:20	So...but it will be a journey because it's a journey of discovery, the answers are really not quite there yet. And I think we'll work quite closely together.
Geoffrey West 01:08:25	No, I'm very excited about it actually, because I think...I mean Singapore is a wonderful case study, wonderful lab from a scientific viewpoint, and there's the possibility of getting some really detailed data that can feed into this. And at the same time, you have a country, a city, and an administration that really has had a history and has maintained that history of wanting to solve some very important problems. And it's in a very unique position on the globe, of course.
Ms Hwang 01:09:02	Well, I'm very happy to see that many of our fellow agencies are on board with us and really interested to see how we can use complexity science to kind of look at that. Maybe at this juncture, I would like to open up the questions, Q&A, to the floor. Please identify yourselves and post your questions. Lena, please, on the left, and then this gentleman on my left later.
Lena Chan 01:09:42	I'm Lena Chan from the National Parks Board. Two questions. One; you mentioned that we have to shift our paradigm, shorter and shorter period of time. But our biology, our physiology can't cope with that kind of a change. So, how do we then, with put this changing paradigm shift at the rate...because at this present moment, the paradigms shifts are already putting such a toll on our mental health and physical health. So that's question number one. Number two: If the paradigm shift doesn't happen, what's going to happen? Does that mean that all the whole world will collapse, cities will collapse, or will more resilient cities survive? What will happen?
Geoffrey West 01:10:34	Well, they're both, of course, very good and extremely challenging questions. The first one, and they are connected actually. The first one is...I'll try to address the first one. Yes, and I completely agree with you, and if I had even more time, I would have talked a little bit about that, I would have mentioned that. That it's one of the big issues is that

01:10:56 we're…our social interactions sort of sped up what we call time. What we…the time we use on our daily basis is this weird time that has to do with the earth spinning on its axis and going around the sun. But we've created this new time, which is this treadmill time of getting faster and faster from social interactions.

And at the same time, our biological times have remained essentially constant, including you know, our neurological development is, we are, roughly speaking, identical to hunter gatherer human beings of 10, 20, 50, a hundred thousand years ago. And yet, we have to adapt faster and faster. And that is no doubt the cause, in fact, I'm surprised that it isn't even more dissociation and loss of meaning—I don't know what words to use—that we are seeing, even though we are seeing a lot of it everywhere across the globe.

But it does play into your second question, which is… I obviously don't know the answer to that, exactly, other than I think the first signs of it will be significantly more social unrest. I think social unrest…in fact, I interpret a lot of the social unrest that we see across the globe as actually a reaction to this problem of speeding up time. And I also see the migration of, especially in the United States and now in Europe, the political migration to more autocratic rule as being also a reflection of this feeling of out of control that people feel. Because it's sort of extraordinary when you think about it.

The standard of living has continued to rise, you know. I mean it just continues to rise, it hasn't been any major drop. Some people are certainly being left behind, but the standard of living of people near the bottom is probably higher than a significant number of people 50 years ago, much…maybe 30, 40%, you know, the whole thing has gone up. Yet people are feeling dissatisfied and that's of course to do with the fact that the differential is getting bigger. But I also believe that it's to do with this fact of being on this accelerating treadmill, not being able to keep up. It's you know, I think we all feel it in varying degrees.

01:13:49	I certainly do, I'm quite old now and I just get so irate at having to learn things. I mean, I think one of the great achievements of my life was to be able to learn to write in tech at a fairly advanced stage, and then to learn how to do…I can't remember what it is, but you know, all the very marvellous things you have to do on social media. And that was quite something to learn, you know, when you're getting old. And enough is enough already, but it keeps going! (Laughter). And this is tongue in cheek I'm talking, obviously, I mean. It's also…there's a positive side to that, because it's also very satisfying, of course, to be able to learn new things. But I think in the general public, I think we have this problem of feeling out of control. I don't know what the answer is, obviously, to what happens if we don't make it through. Things will collapse, I believe.
Ms Hwang 01:15:04	Do you think cities will collapse, or individuals?
Geoffrey West 01:15:06	I think the countries will collapse. I think some will remain, some not, but I think social unrest will dominate everything. That's why I think it's sort of so hard to speculate, I think. And you can speculate about what the end result might be in the worst possible case, that we have a nuclear war or we end up being hunter gatherers again, which actually, being hunter gatherers again might be great for all I know. People say they lived a very…you know, that may not be so terrible. So, I don't know. They are very good questions.
Ms Hwang 01:15:43	And let's take the question on the side.
Geoffrey West 01:15:45	And one should write a book about that.
Ms Hwang 01:15:46	Your next book, Professor West.
Andre Chaszar 01:15:48	Andre Chaszar, O Design and Research Consulting. I really appreciated your comment about the need for paradigm shift and pointing out that

01:15:58

the necessary paradigm shift is probably not going to be technological, but rather social or sociological. So I'm wondering whether you might consider a certain kind of innovation as potentially filling that bill. Let's say we talk about closing the loops, you've talked a lot about metabolism and the waste products obviously present in most metabolic processes. So what if we work on really closing the loops so that what is today waste, actually becomes an input, sort of radical recycling, cradle-to-cradle, whatever you call it. **Do you think that's far enough from being a purely technological solution to do what you think needs to be done?**

Geoffrey West
01:16:50

Well, I'm all for what you say, I mean, I'm very, very enthusiastic about the idea of… a closed loop. Seeing a closed loop system and you know, and certainly, it seems a no-brainer that we have to move from fossil fuel to renewable and so forth. I mean, that's built into the physics of the system which you can't go on just with burning stuff that surrounds you. And you have to also, at the same time, do what you said, is see the waste as potential fuel or potential resource for something.

But I would say, first off, I see that as a technological solution. On the other hand, it has a presupposition in it that is social and revolutionary. Because I don't think any society has operated that way. You know, even very early societies, I don't think operated at all that way. So it does require, it would require a radical revolutionary shift in the way we think about who we are, and our relationship to each other, and the environment. So, in that sense, it could be, could be what you say. And…but it also requires, I think, and I may be wrong in this, that I've sort of concluded as I started thinking about this and especially when I wrote my book, was that I began to see it as greed, as sort of the most fundamental motive of what's going on. That is, we all, including me, want more of whatever it is. You know I mean I have much more than I need. And yet I still…it's not conscious, but I sort of unconsciously want more, you know. And that seems to drive most people. And there somehow is a linkage between that, and not taking care of one's waste, if you see what I mean. I'm not articulating it very well, but so, somehow,

01:19:16	I think your cultural revolution requires also the revolution of being less narcissistic, less self-oriented and less greedy. So what we need, I think, is a sort of anti-Trump, if you see what I mean, because he manifests all those other things, many of which have brought us to this place. I think what he manifests is sort of one's image of rampant 19th century individualistic capitalism, which you know, for all its faults, brought us a lot of this. And he is sort of returning to that stage, including America First, and all the rest of that stuff. So, somehow, if we had someone with his charisma, that could…I mean what he did it's not him, he awakened in people what was already there. It's not, you know…we all have that, and so, he brought that to consciousness. What we now need is the opposite to that, to bring the things that you're talking about, or implied in what you're saying, to consciousness. I mean it sounds a bit flaky, but you know, to love, and humanistic values and caring for others and caring for the environment, believing in truth, believing in science, and so forth, all those things. We need a sort of Nelson Mandela or Martin Luther King or a Jesus Christ or…I don't know, some messianic person that sort of galvanises that positive side of the human spirit to do what you're saying, and that is revolutionary. Not that all of those people didn't bring along with them also unintended consequences by the way, as a cautionary note.
Ms Hwang 01:21:22	Thank you. One last question here, in the front?
Professor Quek Tong Boon 01:21:35	Hi, I'm Quek Tong Boon from the National Robotics Lab at MTI [Ministry of Trade and Industry). I want to get a view on whether the scaling laws that you mentioned will need to be revisited if we reach a stage where there's a convergence between biology and physics. For example, there's a hypothesis that the evolution…today we are talking about evolution being dominated by the law of natural selection. What happens if it's a stage where not only law of natural selection influences evolution, but the maybe the law of inorganic life as well? Not necessarily for us to be become a cyborg. For example, with a lot more precision

01:22:17	medicine today, we are able to live longer without the heart beat slowing down, for example. And what is the impact of that on the growth of cities?
Geoffrey West 01:23:17	No, but that is **the** question. (Laughs) It's not just your question and I don't know the answer. Because we in that sense—you know, this is a bad way of saying it—you know, what we discovered, which was so phenomenal, sort of violated those rules. I mean it doesn't violate…obviously didn't violate them because they exist, but it went outside of what had evolved by natural selection. And the question is, can we…I mean the way I've often thought about it, could we…is it conceivable to get back to that? So that we have the sustainable part of biology and yet have this? I think that's the way I think about it. That is, have this kind of socio-economic life that we have and it's…to put it slightly differently, you know, the way I have often thought about it is, that I don't know how many Nobel prizes that are in economics, there's about…I suppose there is about 120, I don't know. Whatever there have been. But you know, I think if you scratch the surface of any one of them, built into it is the assumption that you have an open-ending growth forever. Right, that's sort of built into the whole idea. And economists have rationalised that by saying that you could have an open-ended growth because…and stop collapse coming from exponential growth by continuously innovating. So they just…it's a mantra, it's like a mantra—innovate, even though, as far as I can tell, they know very little themselves about innovation and technology. But they're willing to say that's what's going to happen—and you know, that's been true and that's why all the people that have come before and have said, you know, we're doomed, or the world is going to collapse, have been wrong! Rightly criticised because they…those arguments ignored the whole creative process of innovation. And I'm very conscious of that. And that's why I use the word, when I'm talking about, I'm speculating, obviously. But the point is that if you take

01:25:51	into account, innovation, that gets you out of the problem. You still have this problem that you have to innovate faster and faster. So there's a new problem that's occurred, and that is the fact that time is speeding up. So, going back to your question more specifically, you know, that is something that is outside of biology and unless you can somehow find an economic system that has no growth but still has, built into it, wealth creation and the maintenance of the quality and the standard of living, you can't do that. And that's why I think the only way we can do it is two things. One is we need to think in terms of a revolutionary change in social, cultural behaviour, coupled with a major effort to bring together the various stakeholders, in terms of the academic community and the practitioners to start to think seriously about the question of sustainability—everything from the local scale: how do you sustain this neighbourhood, how do you sustain Singapore, to the question of how do you sustain the planet? And I think until we sort of focus on that, until we get that dialogue going and get a serious programme going, I remain quite pessimistic. Because I don't…you can't do…I believe you can't do what you're hoping you could do.
Ms Hwang 01:27:34	But Professor West, given that we don't really know where the next paradigm shift or innovation is coming from, I guess it'll be good to hear from you what advice you would have for say policy makers and urban planners, as to what's the shape of the programme that you talk about, to strengthen our resilience and ability to be sustainable, going forward.
Geoffrey West 01:27:56	Well, I mean, of course you're doing many of the things already. I mean, you're thinking about the various things that are threatening, but I don't know. I can't speak to Singapore, because I don't know. But my concern is much more that there's a systemic problem here. You know, it's not…there are individual issues, you know, I'm even concerned that if we just, in quote, focus on climate change as the issue…I think that's very worthy and I'm obviously, I would be very…and I am very supportive and even work on it. But I think unless that's seen as integrated with

01:28:44	everything else, well, we won't solve these problems. We certainly won't solve them globally, but we won't solve them locally. I think locally, we also have to think of them in much more integrated terms. So it's again, you know, on a local level, doing what I hope this MOU will end up doing, is bringing together the various stakeholders and the people that have been concerned, everything from the roads and the rising sea levels to what are you going to do with the fact that people are living longer and so on. All these various things that come in, that different agencies, for example, who we typically deal with, really bringing them together but to start getting a much more…bigger conceptual framework so that we can start to generate a matrix in which we see how all these things interconnect, to formulate a policy, so that we can mitigate unintended consequences. Because you will never get rid of unintended consequences. But really, minimise unintended consequences of the various actions that are typically taken.
Ms Hwang 01:29:57	Yeah. I think in Singapore, we are already planning in a fairly integrated and holistic manner. So, complexity science, what it offers is to give us a better framework and potentially more tools that we can tap on to explore the different dimensions of how the issues will interrelate and impact each other. So that's a very promising angle that we hope to give us more insights on. And I think with that, we'll call it to the end since we are running out of time.
Geoffrey West 01:30:42	And read my book! (Laughs).
Ms Hwang 01:30:44	Yes, and it's a very good read, I must say, Professor West. The book is very readable, very interesting. So do take the opportunity to read that book. Okay, back to the emcee, Yu Ting, thank you.
Yu Ting 01:30:58	Thank you Ms Hwang and Professor West for the lively an engaging discussion. Could we give a round of applause for the two of them, and also for everyone for this discussion. (Applause). [Transcript ends at 1:31:06]

LECTURE INFORMATION

TITLE
Scale: The Complex Science of Cities

SPEAKER
Prof Geoffrey West
Distinguished Professor; Former President, Santa Fe Institute; Associate Fellow, Green-Templeton College, Oxford University; Visiting Professor, Nanyang Technological University

MODERATOR
Ms Hwang Yu-Ning
Acting Deputy CEO; Chief Planner, Urban Redevelopment Authority

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