CENTRE for LiveableCities SINGAPORE

SUBJECT: **Growth, Innovation, Economies of Scale and the Pace of Life: Developing a Quantitative, Predictive Science of Cities, Companies and Sustainability**

SPEAKER: **Dr Geoffrey West**

MODERATOR: **Mr Aaron Maniam**

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Note:

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Malevan (M) 00:00:01	Distinguished guests and fellow colleagues, a very good afternoon and welcome to today's CLC Lecture Series, the fourth in the 2016 series of lectures. My name is Malevan, I work at the Centre for Liveable Cities and I will be your MC for this afternoon. The Centre was jointly established by the Ministry of National Development and the Ministry of Environment and Water Resources in 2008 to distil, create and share knowledge on liveable and sustainable cities. The CLC Lecture Series is one of the platforms through which urban thought leaders share best practices and exchange ideas and experiences. For today's session, we're honoured to have with us, Prof. Geoffrey West, distinguished professor and former president of the Santa Fe Institute. He will discuss how the ideas used to solve complex and diverse issues in cities, could be extended to companies to address the implications for growth, development and long term sustainability. The presentation will be followed by a moderated panel discussion and a Q&A session with the audience, which will be moderated by Mr Aaron Maniam, director of the industry division at the Ministry of Trade and Industry and [indistinct] young leader. At this juncture, could I please invite you to please put your mobile devices to silent or airplane mode for the duration of the lecture. Let us now begin the lecture by inviting Professor West on stage. Professor. West please.
Geoffrey West (GW) 00:01:45 00:04:10	Thank you. Thank you for inviting me. Oh, you can't hear me if I walk away. I'll try and do this, sorry, cos I need to walk. So, a pleasure being here. I've been talking all day, so, this will be a part of a [indistinct] version of the conversation. I have this kind of 18th century title which sort of tells the whole story. Pretty much. And I will try to to cover an enormous amount of territory and I believe many [indistinct] maybe during the question period, the discussion period, we'll be able to cover. So, I think everybody is familiar with this extraordinary phenomenon because we are a part of it, of the fact that the planet is becoming, is becoming almost a tiny [indistinct] in terms of socio economic activity. Let me see, which is the one… [tries to work the projector]. Someone… . Ahhh… which one? Which one? This one. Alright, let's start again, sorry. Well

	whenever we're sort of living with this, and we're looking at this exponential expansion rather than the population of a particular, most of that population now is going into urbanisation. And this is the US figures. It's through almost the entire planet especially in the developing world, but, the United States was just a few percent urbanised 200 years ago, it's now over 80%. They made it across the halfway mark just a few years ago. It's going to move towards the 70, 80% level, towards the [indistinct] of the next century. And to just give you a sense of the scale of that… this slide. [Walks back to podium]. So this one is equivalent, it's equivalent roughly, through the averaging, it's equivalent to urbanising roughly one and a half million people a week. Which is equivalent to adding a New York City every couple of months. Or a Singapore down to its infrastructure, roughly speaking, every month. Now, continuously to 2050. And that is kind of extraordinary in terms of the stress on the resources, energy and in particular, on the social fabric. So, this is an enormous issue, an enormous challenge to the planet and we are all part of it. And we participate clearly in creating this extraordinary challenge, which has all kinds of amazing consequences, which I'd like to explore with you. So, here is China, which you're more familiar with than I am, I'm sure. But mainly, China has just crossed the [indistinct] to urbanisation but they crossed the halfway point just beyond now roughly, it's about half urbanised, half not. And it's heading on this exponential rise towards being 70 or so percent urbanised towards the end of the century. That means, of course, that it has to build, as it claims, two to three hundred new cities, each in excess of a million people in the next 15 to 20 years. Which is unbelievable. So, that's China.
00:06:33	But we also have India and we have Latin America, North Africa, sort of on this fast track urbanisation. So, this is an enormous challenge and the fight for, just to repeat myself, resources and energy, are going to be quite dramatic. So, any of you are familiar with this? The picture of the planet at night? If a picture like this had been possible when I was a young boy a long, long, time ago, it would have been dull. This would have been much

00:07:13	duller. And now we have this kind of virus that's taken over the planet. And that is of course, just the manifestation of the exponential growth of the population. Here it is. Human beings became communal, became socio economic. We're on this vertical rise on the grand scale that's associated with the exponential open-ended paradigm growth trajectory that we've invented basically a couple of hundred years ago and everything is now based on the idea that we need to sustain open ended exponential growth. So, the fate of the planet is determined to a large extent by the fate of our cities. Understanding what goes on in cities. Understand what the cities themselves, the dynamics of structure becomes something of urgency. So just to remind you [indistinct], what a city looks like. In cities, there's a view. And cities are associated with greater material well-being. Greater opportunity to jobs. Greater access to almost everything. Not just material well-being, but also cultural activities, various kinds of education and restaurants and so on. What is so attractive about cities? All of this has to be driven by energy. Energy is fundamental. None of this obviously can happen without energy supply. And if it's supplied by energy as the fundamental law of the universe and if you transform energy, you can't do it for nothing. You produce entropy somewhere. You produce pollution so to speak. You produce random behaviour and altered behaviour, when you try to organise, as you try to do in terms of cities. So some result of this is socio-economic entropy. And so by transforming that energy, building up extraordinary places like Singapore, somewhere, we have phenomenon like this happen. Or these kinds of phenomena are a result of that. And the inevitable result and the question is how we minimise them. But they are there and we have to deal with them. And if you look at this, which I also believe is the result of this extraordinary rate of expansion which we're in. of course it's put in the guise of politics and religion and so forth but fundamentally it has to do with this incredible stress that we have. That this hidden phenomenon that we're expanding exponentially. And the question is, is that what cities are going to look like in 50 or a hundred years? Is that what Singapore and New York and London are going to look

00:10:18	like in 50 or a 100 years or they could look like the pictures we saw earlier. So, I showed you the pictures, I showed you, of cities at the moment, are the kind of image that you have when you use the word “cities”. You think of buildings, cityscapes and so forth. Streets, gatherings, but what you really want in cities is people. That’s the whole point of cities is to facilitate the interaction of people. And I will return to that in a moment, that cities are people. And this is what a city really is. It is the interaction between people. Gathering of people both formally and informally. That’s Paris and Orchard Street here. And that’s a picture 120 years ago of New York City. And it pretty much says what a city is all about and what a city in a certain sense should be. In fact New York doesn’t look like that anymore. Of course it doesn’t look like this, because you see here, the platform of which all of this takes place, the infrastructure is still exactly the same as when this picture was taken. The buildings exist. The roads exists. And the activity here is the essence of a city. It’s people coming together. Interacting. Entrepreneurial activity. Ideas are created. A certain buzz. Wealth is being created. And so forth. So, that’s what a city is. It’s that churning, creating atmospheres like this for both innovation and growth creation to take place. And even though, as I said, all those buildings are still there, people are gathered like this, but the whole point of New York City, the whole reason for New York City, is for this to take place still, but maybe inside the buildings, maybe different format and so on but to create that kind of buzz and that’s what Singapore is here for.
00:12:02	Ok, so one of the aspects of this is that if you try to understand the cities, understand this interface between these two different pieces of the city. It's true of any complex system, it's true of life. But in particular, this tension, this integration between the physicality of the city in terms of energy resources which will go into the metabolism of the city, represented, as I said, by the physicality and infrastructure, has to be integrated with its exchange of information. The point of the city is to maximise its exchange of information, as I said, creating ideas as well. And that’s out of the

	genomics part of the city. Or the neuro part of the city. And these are not independent even though typically they are going through biology, to be considered, metabolics and genomics. They are totally integrated as they have to be in a city. So, all of the problems we are facing on the planet today, from climate change to the questions of resources. Energy. Water. Questions of health. Questions of pollution and so on. All of these have come to the fore because of this huge exponential expansion of urbanisation. So, all of these problems originate in cities because that's where most of the energy is being transformed and that's where most of the people live. So, cities are the origin of all of the problems that we face but also the solution because cities are the magnets, vacuum cleaners that suck up, not just people, but the smart people. All those ideas, all the innovation, all the wealth that is created most entirely in cities. So, the question is, is any of this sustainable? This is mainly the backdrop that we're talking about. Some of these questions and discussed [indistinct] the city. And most importantly is that, from this, I conclude that we are to have sustainable cities, if we are to have sustainable planet. And all of these are to survive, we desperately need to ask the question, "Is it possible to have a theory, a science, so to speak, of cities, that is quantitative and predictive. And now we know that's possible, it may just be impossible but I'm want to explore that with you. Of course it has to involve all of these kinds of concepts: resilience, evolvability, growth, scalability. So forth. And of course, in that, all of these various things, is a laundry list of all the various things that come together in the main socio-economic system, particularly in the city, I'm not going to go into them. The only point I want to make, is they all come together, each one is a complex, adaptive, evolving system. And most importantly, they're not independent. They're all coupled and they're all part of a systemic problem. And if you treat, one of the things you learn when you study complex adaptive systems, if you treat just one piece of it only, then you are very likely to have unintended consequences that will change everything else there.
00:15:20	So, it is important to recognise the holistic nature of these the fact that

	these are not independent and that they are highly coupled and it is dangerous just to think of solving just one particular problem even if it is something as grand as dealing with energy or somethings dealing with climate change or something that's dealing with health or something dealing with the environment. All these need to be thought of in one unified framework. So, I want to talk a little bit about that and I want to do it by, first, talking a teeny bit about biology. And I want to ask the question which can translate into cities and companies a little bit later. And here are questions, which are very generic questions that I assume some of you are wondering about. Why is it that your span of life is evolved over a hundred years? Maybe it's 80 years. Or why isn't it 200 years or 2000 year ors 2 million years or 2 years? Where the hell does that number come from? Why do we have that number? Where does it come from and how is it generated from the molecular dynamics that keeps you alive? Your cells and respiratory system and so on. All those tiny cells and molecular cells are very small. Where the hell does that hundred years come from? And why is it that if you were a mouse, which you might as well be because [indistinct] mice are not so different from you are in terms of the meat. Your flesh is pretty much the same, why is it if you're a mouse, you only live 2 or 3 years? So these are the kinds of questions. So, why does that happen and how is it related to this? That was Galileo. He aged and he died, like me soon. Why do... and how is it related to this? All these companies died. [indistinct] resurrected officially. What is the relationship? And hopefully, if we have more time, I will talk about immortality. So these are similar kinds of [indistinct] questions we can ask. Why do we need to sleep about eight hours each night? And so on. But coming more to the meat of the talk. First, are cities and companies biology? Are they… they came from biology. And we talk about the DNA of a company. The metabolism of a city. The ecology of the marketplace. All these kinds of metaphors. And the question is, are they just quantitative
00:16:58	

	metaphors or are they some serious substance. And the question I find most intriguing, which hopefully I have a little time to talk about is why is it that in fact, all companies as far as we can tell, are destined to die like everybody in this room. No company survives, doesn't matter how grand they are and how rich they are. They eventually disappear. But almost all cities survive. Very hard to kill a city. You can think of ancient cities that have disappeared. But most cities growing on this planet still exist. And you can even drop atom bombs on cities. 20, 30 years later, they're fine. But you don't have to do very much in terms of changing the economic forces of companies, if you like.
00:18:50	Ok, so in what sense is the bottom a reflection at the top? So, I'm gonna talk a little bit about us, that's us. We are one of the biggies. We're mammals. And we stretch ourselves over a range of 100 million in terms of weight. From the shrew to the whale. Amazing things, even though they look different, they have completely different environments, they are actually, to an extraordinary degree of accuracy, to have anything you can measure about them, scale versions of each other. Including us. I want to show you that immediately. This is a graph of the most fundamental quantity of any system from a particular animal, but it's also the most fundamental quantity ultimately of Singapore and the other cities and how much energy does it takes to keep the bloody thing going. That's the metabolic rate and it's plotted here on the vertical axis against the mass of a bunch of organisms and it's plotted along arithmetically, I assume everyone knows. It's obvious from this graph that the coordinates of this graph go up by factors of 10. One, 10, 100, 1000 for metabolic rate. That's because you have an elephant and a mouse on the same graph. And you have it over an enormous range. So, if you do that, you see something extraordinary, they're all lining up on a simple straight line approximately. And that is amazing because we believe in natural selection. We believe that every single one of these organisms has a unique history. It has evolved in a total unique environmental niche. Not only that, every organ in it, every genome, every cell type. Every sub-system has evolved with its

	own unique history. So, you would have expect it if you plot goes anything like this, that the points will be all over this graph, reflecting the historical contingency of the evolution of each one of these organisms. But in fact to a pretty good approximation they all line up on the same line. And even more amazing than the slope of that line is, even if you thought they might scale like this, I think at the most naïve level, that it would scale linearly, meaning that if you double the size of the organism, of course you double the number of cells, you double how much energy you need to keep him alive. Not the case at all. You don't want a slope like this, it's not one, that would be the case, this is three-quarters, very closely, which means when you double the size approximately, instead of needing twice as much energy, you only need 75% to go on. So as you get bigger, you get an increasing economy of scale. In a highly systematic way, the bigger you are, the more efficient you are. The more efficient way you use yourselves and so on. You are more efficient than your dog but a horse is more efficient than you are. That is kind of extraordinary but even more extraordinary is that the same kind of scaling holds true for any physiological variable than you can imagine or anything that measures life history. So for example, here's something about heart rates. The slope for that is minus one-quarter. Here is your brain. Your white matter, the computing part versus the cables so to speak, the processor versus the cable. You see extraordinary scaling, with a slope of five-quarters. That's a little more fluctuations here. This is the genes, genome length. Again, you see scaling, the slope very close to one-quarter. And I could show you 50 to 100 more of these. Everyone has exactly the same character. They all scale in this very simple way when plotted in this logarithmetic fashion. The slopes of the graphs are almost always some simple multiple of one-quarter.
00:23:22	So the kind of magic number of life, is 4. Something special about the number 4 for the way all life is governed, all ecology is governed. So even life span. I wrote this down. Life span, I should have shown the graph, has a slope roughly speaking, there's a lot of variants in it, of one-quarter,

	goes up by one-quarter. I just showed you heart rate decreases by one-quarter and those things can sort themselves out. This is the important point, so that the number of heart beats in a life time is the same for that little shrew that sits on the palm of my hand as much as the blue whale that is almost as big, it's much bigger than this auditorium. So there's something extraordinary about that and we had this idea of big things living slowly but for a very long time and little things living very quickly for a very short time. The pace of life systematically for everything that you can measure about rates slows down the bigger you are. And the question is, where the hell did all this come from? Why is it the way it is? Why is it that plants and trees which are complete different in design and evolution from you and me, have essentially the same scaling laws as we do as insects, fish, birds, cells and so on. And the idea is, that what is common among us all, despite appearances, despite the fact that the whale is in the ocean, and the tree grows to the earth and so on. Despite all of that, one thing that we have in common, apart from the fact that we all made from cells, is that we are sustained by networks. We are, if you think of it from this viewpoint, just a bunch of networks, your circulatory system, your renal system, your respiratory system, your bones, your neuro system, and so on. And they all have a similar characteristic. They are all hierarchical, and that's how it looks. That's the brain down on the left, that on the top right, that's inside your cells, no, that on the bottom right is inside your cells, and the top right is inside your mitochondria . And that is what you look like on the inside. This network. You can always say you know, it looks like a city in a way. And you see also, there's a kind of [indistinct: filling] space, that's a crucial thing, it has to go everywhere this network.
00:25:53	And so, I'm not going to show you any of the mathematics I'm just telling you, you have to take my word, that you can erect a complete theory based on generic properties of networks. The idea being that those properties transcend design and out of those, come all of the scaling laws, including many more that I haven't shown you, including by the way, how you scale

within you. These networks within you, how you scale from the aorta down to your capillaries or from your, what is this called anyway, your windpipe, all the way down to the alveoli at the end of your lungs. The theory explains all that and it has quantitive predictions, I’m not going to show you, because there's an infinite number of data it compares to and it agrees very well.

But what I want to do, I just want to tell you that because the talk is about warming up cities and so on. I’m going to show you one example of, very quickly, of this kind of scaling which you do, mainly you grow. And what we all do is we scale up and apply the ideas, the concepts of that theoretical framework. So you know how you grew. You ate, you metabolized the food, you sent that food through the networks, the network in particular, the circulatory system delivers metabolites to cells. When it gets to the cells, what does it do? It repairs damage. It replaces those that have died. There’s maintenance, and then it adds one. It adds cells, new cells. So there it is. That’s the picture and there it is in English. Roughly in its simplest possible form, you allocate it between maintenance and growth, and I’m not going to, again, I’m not going to write down all the equations and so on, but the theory, from the theory, you can derive mathematically, an equation for the growth. That’s an example. That line, the solid line, is the prediction of the theory and there’s the data points for us. Us is a rat, and you can see it’s pretty damn good. And importantly, I’m going to come to several important points I want to make. The parameters that determine this, are the same, the fundamental parameters are the same for all, certainly mammals, essentially the same for all animals. Parameters like the mass of the cell, how much energy do you need to create the cell, variable scale of metabolic rate and so on. This comes from the constraints of the network which also, of course, constrain metabolic rate, have this three-quarter scaling. But the second point I want to emphasize is that, there’s that growth, it’s a bounded growth, sometimes called sigmoid growth. Quickly at the beginning and then you stop and the reason you stop when you go back and look at the derivation, is because of

	the sub-linear scaling, the economy of scale invoked in metabolism, driven by the behaviour of the network, the constraints, the physics, the mathematics of the network which gives rise to that three-quarters power scaling, three-quarters less than one equals sub-linear. That is what says it should turn over and stop. Here it is for a couple of birds, fish and a cow and you can, with the same parameters you can determine any one of them.
00:29:45	In fact the theory and I'm not going to belabour this. The theory tells you that if you re-scale, as you re-scale the time, in a very clever way determined by the theory, every, all those growth curves collapse to a single curve and there is a kind of universality to the growth. Everybody, when you look back through the lens of these reduced parameters, grows in the same way, when you re-adjust accordingly. It's the theory telling you how to do that. So there it is, just a small sub-sample.
00:30:16	That's very nice and here it is when you have insects, and colonies already starting to get a teeny weeny bit of social organisation. And I just put this in for the hell of it, you can also apply to tumours and it's been done by others, applying the same theory to tumours, to understand the growth of tumours and just one tangential point to the whole, is that one of the things the theory says and supported later, is that tumours stop growing. Despite this image, this idea that tumours exponentially grow and you eventually die. Of course that's true but in fact, if you live long enough, tumours will stop, which gives you kind of an interesting speculative strategy for attacking cancer, that if you can somehow manipulate the parameters, given the theory in terms of those parameters, if you manipulate them for tumours, maybe it's ok to grow tumours. You just grow them, but then they stop, and they only reach a tiny size and so they're not …[indistinct]. So just to summarize this then we move to cities. Biology from this viewpoint, it has these extraordinary scaling laws, that are highly non-linear but they're very systematic. They express an extraordinary economy of scale, the bigger you are, the less you need per capita. The pace of life

	systematically slows down the bigger you are. Growth stops at some stage and by the way, that plays a critical role in the fact that life is incredibly resilient. We stop growing and that's one of the reasons why life has been around for several million years and also I didn't say this but there's also part of the theory that you grow then you stop and then you die. That's it. And all of this can be explained in terms of this sort of network theory. What I will now do is take this idea over into the question of cities and then if I have time, a little bit into companies.
00:32:36	Ok. So first thing I want to point out is that this, this curve, is beautiful for biology. In fact some of you at some point must have been concerned in your life, why it is when you're eating, when you were eight years old you kept growing and your mommy and daddy told you to keep eating so you grow to be a big boy and girl and then at some stage you stopped. We still go on eating but we didn't grow any bigger except [indistinct]. This explains it and it is crucial in biology but it is considered disastrous in socio economic systems. The president of the United States gets clobbered if he says the growth of this quarter was only 1.2% not 3% as I'm sure you will be concerned here. Even though 1.2% is still exponential growth. There, that's the U.S. GDP. Always has to be doing that. Onward and upward. The yellow is exponential. By the way, just a side comment, that's exponential, this was from 1870 onwards, you know all those dips and bumps, all the crashes and all the rest are sort of irrelevant in the big picture. If you can go through, it just keeps going and that's the paradigm. That's what we live in and it goes on. Now I want to examine some of the origins of this.
00:34:32	So the first question when we move into this, are cities and companies for that matter, scaled versions of each other? Is there any universal behaviour? So Singapore, needless to say, you are only too well aware of, is unique. It is not part of any urban system. It is the only place on the planet basically. In United States, you can ask, is New York scaled up a Los Angeles, which is a scaled up Chicago, which is a scaled up Stanford,

a small town? Well when you look at them they look quite different. They have different histories, geographies, Los Angeles is spread out, New York has the skyscrapers and so it is not clear. On the other hand, you think of biology, whales in the ocean, the giraffe has a long neck, the elephant has a trunk, we walk on two feet, [indistinct] but in fact, it's a kind of 80, 90% level, anything you can measure which is the only thing that is important here, we are all scaled versions of one another. So the question is, is that true of cities despite the fact that they look different. Of course you can't argue about that. All you can do is look at data, so I want to show you data. I want to show you the answer to that and part of it is motivated, once we have this paradigm that we have in biology, by the fact that cities are of course network systems. There are all the roads and pipes and all the cables that you can't see. There is this extraordinary network, transport networks. This one I got from the web. It's one I believe is Singapore. And of course it is all supplied by networks so you might think, gee whiz, maybe there is some possibilities we can apply the same ideas, the same paradigm. But I said earlier, but I pointed out Shakespeare of course understood better than all of us, cities are not only buildings and roads and the rest of that, they really are people. And here's people. This is a social network. In each of these nodes is a person, and all those lines take them to people they are connected to and so forth. So this is a classic social network and that is what people, social interactions in their cities, [indistinct], they are all connected in some way. But it is not only how well we are connected, we are modular. We are part of a family. We are part of maybe a group or the department, a part of a business. In some way we have modular, modularity in these networks.

This is kind of a pictorial representation about the tension, about the integration that I talked about earlier, the physicality with the information.

So let's take a look at how the cities scale.

What is plotted here, is something very mundane and simple. There are a number of petrol station, it's plotted logarithmetically. They go up by

	factors of ten. And this faculty does for four European countries and what you see is, it looks just like biology, just a little more variants. But you can see that there is good evidence of scaling. Not only that. The scaling is some linear, the slope is less than one, not surprisingly, double the size of the city, you don't need twice as many gas stations. You have an economy of scale, but what is interesting is the slope of all these, are sort of approximately the same. And the slope of those are not like biology, not 0.75, three-quarters, they're much more like point 0.85. So double the size of the city, you don't need twice as many gas stations, you only need, roughly speaking 85% more. So that's kind of interesting. What is more interesting is, if you look across all European countries, this the same way. But it turns out of you look at any country across the globe, any urban system across the globe, it's the same. Latin American countries, China, Japan and so on.
00:38:55	They all look just like this. They all have slopes, roughly point 85 but what is even more interesting is that any infrastructural quantity you want to look at, you can measure, like the length of all the rows, length of the electrical cables, the water lines, gas lines, whatever, all behave in exactly the same way with this 15% saving every time you double. So that seems to be a bizarre universal economy of scale that has manifested in urban systems across the globe. That's interesting. It's the physicality, the physical infrastructure of a city but much more interesting is the real city, which is you and me – people. So now I'm going to look at socio-economic quantities. So these are quantities that did not exist on this planet and for all we know, didn't exist in the universe, until we started learning languages, and started forming communities and cities and add on things like wages. Smart people like everybody in this room, super creative people. And what you see again, is good evidence of scaling, even though there's much more variance here than you saw in the biology. But what is really important here, is that the slope of these is no longer less than 1, three-quarters or 0.85, it's bigger than 1. 1.12, 1.15 and what that says is the bigger you are, instead of having less per capita, you have more per

	capita. So the bigger the city systematically, you have higher wages per capita, more sexy, interesting people, creative people, professional people per capita, more ideas per capita, the slope is closer to 1.2. More ideas, number patterns produced per capita, more crime per capita. More police per capita. More tax per capita. More construction per capita. More debt per capita. More restaurants per capita. Anything that involves sexy interaction between people, buzz of the city, increases with city size.
00:41:09	There's the graph which we put together, just to show a few of them lying on top of one another. And you can see there's quite a bit of noise in the system so to speak, but what you see is they all have pretty much the same kind of slope. And we have looked at data from everywhere we can get from around the world. As I said earlier, Latin America cities, Columbia, Chile, Mexico, Brazil, and so forth, china, Japan, European cities. The cities that are missing from this study by the way, are Africa and India, only because we can't get credible data. We'd love to get it and maybe we will one day.
00:41:59	So here it is in English. The good, the bad and the ugly. If you double the size of the city, on the average, there's a systematic increase of all the socio-economic quantities. All the good things – income, wealth, patents, colleges, creative people, restaurants [indistinct]. All the bad, [indistinct] disease, aids, flu, crime, all of these increase by about 15% every time you double and at the same time, you save 15% on all the infrastructure. Big cities are good and bigger cities are better from this viewpoint. I don't know about individual lives, but from just this viewpoint, they are better in a sense and no wonder, people flock to cities, and we're having this exponential urbanisation because, because people are very good at ignoring all these things and they get attracted to all these things, opportunity, job opportunity and all good things that they see about cities are attractive and they ignore the other so that's very good, considered very good, attractive on the individual level and this is very good at the collective level.

00:43:18	So the question then is [indistinct] how can it be that cities in Portugal, cities in Germany, France, Chile, Colombia, China, Japan, United States, all scale in the same way? There wasn't a congress in 1848 to decide how we should construct not just cities, but the entire urban system. What was, what is underlying this? What is the universal mechanism that cities that essentially had no interaction during their evolution, ended up in terms of urban systems having the same common behaviour? So let me go back to answer that, to the one thing that is common to all cities, that again like biology they may look quite different, but in fact the one commonality is that all cities actually have people in them. They're there for people. And I emphasize that because one of the things that I've learnt and maybe people in this room, urban planners, urban economists, urban geographers, one of the things that I've learnt, was that cities primarily, in the professional literature, are thought of as bricks and mortar. And people are sort of added in there somehow like salt and pepper rather than cities are people and we have constructed this amazing phenomenon in order to facilitate our lives and in particular our interactions. So that was a preliminary statement.
00:44:58	The question is why. So it's people and the idea is that the social networks of people, when people interact, are the same across the globe at this kind of level and regularity. The fact that there are different histories, culture and geographies, that we look different, and so forth, at this level, is irrelevant. They all have essentially identical biology, we have identical genes, effectively, and it manifests in the way we interact. We have pretty much the same number of children, depends on development a little bit, but we pretty much have the same number of children. And we pretty much, and there are studies to give you a sense, anthropological studies, psychological studies, where people claim, that across the globe, if you ask how many people does the average person have powerful interactions with, love or hate, I suppose, usually consider the family. How many people is there on average? Across the globe, it's always between 4 and 6. It's not 150 Facebook friends. It's 5, roughly, people. Usually your family,

	parent, children, lovers, whatever, could be very close friends, and so on. And there's kind of a hierarchy. You know, there's maybe 15 people that you have, you are very good friends with but maybe not intimate, as you would be with the first 5. So there's a structure that seems to have a kind of universal quality to it that transcends culture. If you know, culture often manifests itself quite differently. And the idea is, the conception idea is that when you put this into mathematics, that's what actually being manifested, and amazingly, that is determining why cities look the way they are. Amazing idea.
00:47:07	So, we have to test this. I don't have time to go through mathematics but let's try to test this theory. So here is this graph, of this 1.15 and the idea is, the reason that all these different things – income, GDP, crime and patents, which seem completely different, have all lined up with the same slope, is because they all are derived from all of us talking to one another, interactions between each other, have led to all these things. You can't commit, well I suppose you can commit some crimes, almost all crimes invoke interactions. I didn't put disease. Disease typically involves interaction. Getting income does, getting GDP does, getting patents does. All these involve something to do with social interaction. Therefore, and that's why the claim is they're all the same, and they're the same across the globe. But how would you test this? So the idea is if you could measure, the degree of interaction, social interactions, the function of city size, it should just follow this. So how do you do that? Well, one of the great things that have happened, with the IT revolution, is because of the IPhone, not the IPhone, cell phone, mobile, IPhone is a particular instance. But it's because of the mobile phone that all of you I'm sure carry, and if everybody carries it, I'm sure you're very well aware of this, big brother knows pretty much where you are, what you've been doing and who you've been talking to. So I presume you all know, that telephone companies keep records of when you start to call, when you finish your call, where you are, and who you're talking to and where they are. So

	there's records, billions and billions of these. Well, in collaboration with friends at MIT, the media lab, they've got all of this data, this mobile phone data, and we can look at the data, analyze it and ask from it, have the number of interactions. Interactions being defined I call you, and within some given period of time, which you would define as a week, 6 months, 6 weeks, you call me back. We just define that you and I have a relationship. And we just count those numbers of those relationships because we have the record of everybody talking, and we assumed that's representative, and just plotted the function of the city size which made the call, and that's it down on the right, you see it follows, it's scaled, city size, it scales just like these do. Roughly speaking, the same slope. And there are 2 countries there, Portugal and United Kingdom, right on top of one another. So that's quite extraordinary and it gives credence to this idea that social networks underline it.
00:50:32	So with this idea of cell phone data since we know everything, if you think about it, it's extraordinary, you know what it's like. It's like if you had a little detector, on every molecule in this room, every molecule in this room, you knew what its speed was, which direction it was moving in, what are the molecules it was colliding with, and so on. Useless for physics, absolutely useless for physics, but extraordinary if you want to understand how the cities are working, this mish mash of a city. So here's the first thing you should realize, which I did not appreciate, you know when you think of a city, when many people bring up metaphors of a city, I talked about the biological one. But people often have kind of [indistinct] or reactors, look at Singapore and there's all this stuff going on, it's moving around and it's kind of crazy, everything's moving. Actually, if you look at all those, when you think about it, you look at all those journeys, almost everybody is going from their home to their job and back or from their home to the store and back or the home to cinema and back or home to pick up their kids school and back, but they are all very specific journeys, there and back. So that's an extraordinary structure.

	Furthermore, most of those people are trying to do it in as shorter time as possible and in as straight route as possible. If you take all those ideas and you put them into mathematics, you could prove something that's quite surprising and that there's a flux of people, the number of people, it's that cube there, there's a function, so let me back up a second. Take Singapore, which I'm going to show you in a minute, and you choose some piece, some spot, some little area, tiny area in Singapore, where we are, I have no idea where we are, you choose this and then you ask how many people are coming here to this little area from distance "r" away, so many "f" times a week. That could be once a week, once a month, once a year. A distance of 1 kilometre, 5 kilometres, 10 kilometres. And the theory says, that should go inverse square. That's what this says. And, uh, I'm not going to do this in detail. But you look at the top left. What is plotted there, there is a flux of people. That's the distance on the horizontal axis, and those slopes are for different frequencies. So there are different points for different groups. And in fact they all follow this inverse square as does this one, where it's plotted "r" times "f", frequency times the distance, and you can see that's the theory, the straight line, and on the right, it's quite astounding really, what's plotted is that same quantity versus this quantity "r" times "f" and the theory is that dotted line, and on it are Boston, Dakar and Singapore, Lisbon in Portugal and Singapore in Singapore. And what you see, is that they all follow the same inverse square.
00:54:18	It's kind of astounding. So what it looks like chaos and mish mash has extraordinary regularity to it. So this is Boston. And each one of those lines is the inverse square. And these are different parts of the Boston area. So you just choose these points and you do the analysis, look at them, all lined up. And here is you. You are unquestionably, a part of this data. This is Singapore. And what you see, Singapore also obeys it, it's not quite extraordinarily detailed, not quite as good as Boston but it's damn good. Now, it turns out that there are some exceptions to this. This is very important in science. If you see an exception, you can either say the whole thing is rubbish or rather say no, it's there but there is good reason for that.

	And I want to show you 2 in Boston. Only 2 we could find. One was the airport, one was the stadium, the big football stadium. Of course, that's reasonable, because those are very special places, people don't sort of gather to go there. It's not representative of the city. It's very special. But here's what's weird. The only place in Singapore that violates this even though it's scaled, is on the right, Raffles Place. Now unless there is some great big bloody mall there or something, some of this horrific Singapore things, that attract all kinds of people, but something is weird about that and it's kind of interesting but it tells you something about the dynamics and mobility of Raffles Place. It's very important. It should be understood so that you can manipulate or do whatever you do, to make it line up or say maybe this is better. But this is now a window for understanding something about what's going on in that area. More importantly, this, knowing this, it's a fantastic tool in helping design cities in terms of development and mobility and so on.
00:56:36	Let me move on quickly. I started late..[indistinct] I mentioned the sub-linear behavior of biology gave rise to bounded growth but also to the pace of life slowing down. Turns out, the network theory that gives rise to super-linear scaling, the bigger you are, the more per capita, makes life speed up, everything goes faster the bigger you are and this is one amusing example, on the left is biology, look at the one on the right walking speed versus city size showing this systematic increase quite a lot of variance there but you see it's pretty good, it agrees pretty well with the theory. You walk faster because you are somehow part of this network, conscious, subliminally conscious for people. And this increase in city size has some amusing consequences. This is something that happened just a couple of months ago. People were getting pissed off that people were not walking fast enough in the downtown. They were getting in the way because the speed of life has speeded up so much and so they put in, Liverpool initiated a fast lane for walking for pedestrians and it's created a whole [indistinct]. Many cities now are considering this innovation. It's pathetic

but it's true.

Ok, so I want to take now these ideas, take them into growth of cities and some of the implications. It's the same kind of idea. You have all these stuff coming in, both the physical aspects, resources, energy and so on and so forth but you but you are also creating a source. I won't go into detail but that drives, that goes into maintaining the city, kee ping the streets [indistinct], the pipes and so on and then growing it. Just a very simplistic way of talking about it. You can make this quite fancy and sexy. You remember, when we took that equation, that was what it was for biology, this is what it is for cities, driven by super-linear behavior, coming from the social network which invokes this continuous, positive feedback mechanism of social interactions. And I just got a cartoon version and you can see this exponential growth which is what we see. So that's great. This whole thing is consistent, the system is nice but it has a dire consequence. The dire consequence is that what it says is that the system cannot continue. It must collapse at some stage. That's what that line is and that graph shows it collapses. That's very bad, we want to avoid that. And the way we have avoided it is to recognize that when you grow like this, you are growing within some paradigm, some innovative paradigm. So I'm talking about the big picture now. We can't go on with specifics, I won't have time to talk about this, let me talk in bigger picture. So you discover iron, whenever it was, 20,000 years ago. You discover iron. That changes it. That changes a whole bunch of things. More recently, we discovered coal. Starts the Industrial Revolution. More recently, we invent computers. Changes things. Discover IT. So each one of those major innovations, so to speak, resets the clock. So it tells you how we can avoid collapse. You're going along this curve. Life is getting faster. You would collapse. So somewhere along there, you better reset the clock, by inventing computers or whatever. That means that you would start again and go on. Of course, it would eventually collapse for the same reason. So you better make another innovation. A new innovation. And so it goes. You have to keep going and so that's a kind of theory. If you want to have open-ended

	growth which is what we have demanded, then you have to be continuously on innovation cycles. Which is what you are familiar with. You have to be resetting the clock or reinventing yourself in some way. But there's another catch.
01:01:01	The catch is, when you normally go along one of these curves, you're getting bigger, life is getting faster, but the time between those innovations is getting shorter is what the theory says. So something that might have taken a hundred years to develop five hundred years ago, now only takes 15 years. And the next innovation should take less than 15 years, maybe 10 or 12 years. So what it says is if you want to continue on this trajectory, and believe this speculation from this, then we have to have in the next 15 to 20 years, another major innovation comparable to the IT revolution if we are going maintain this open-ended growth. So that's the idea. And I'm going to show you, this is not me, I have no idea who this person is, but I found this on the web because it illustrates it and it's a similar thing and [indistinct], but here's another version of it, this is the innovation. Innovation, what you see, major innovation, I'm sorry I have to go here, time to the next life, life took several billion years to evolve and it happened several billion years ago. Down here, this happened just recently, hardly any time, it took very short time to develop. So you have this continually piling up, and the theory predicts that red line. I'm not going to go into it but so this is actually applied to specific cities, I am not going to have time to go into it, on the right that's New York City, that's analysing the growth of New York City. And just to give you a sense, very quickly, is that if you look at the time between these various little perceived bumps in it, little scalped events, they're supposed to be getting closer and you can see there are evidence that they are getting, these oscillations are getting closer.
01:03:04	Can I take 2 more minutes maybe? What do you think? I am going to give you one other thing because it's relevant for Singapore. And that is, you know, these scaling curves represent some average idealized city. But

every city, you saw these fluctuations, these cities, either over-performs or under-performs relative to it. When you look at one of these scaling curves, so you can rank cities on how well they've over-performed. Are they gaining more patents than they should for a city of their size? Or less patents for a city of their size? Are they having many [indistinct] or no [indistinct]. So that's what we plotted here. That line, that horizontal line is, if you like, exactly on the scaling curve and this is for patents. And you can add ranks to this whole bar. Oregon in that year is the most innovative city in the United States, least innovative was Abilene, Brownsville, Texas. San Jose was innovative because of Silicon Valley but you can gauge, you can also look at how they change. 1950s all the way to the present. This is how that metric change. You can see they don't change very much for an individual city. Cities are very hard to change. And of course, this is incredibly useful, for gauging the success and the performance of cities. And the big issue for Singapore is you're not part of the urban system so you have nothing to mobilize yourself against. You should be mobilizing yourself if not for a historical accident with Kuala Lumpur and all these other places, you should be part of that system, but you're not. You're independent. You're by itself. You're unique but what you have now is part of the global urban system but no one knows what that is. How can you prepare unless you know what is in the global urban system? What is it? All the rubbish about oh you're Paris, London, Shanghai, these are global cities. But what does that mean? What does that mean? We know what it means when we say Chicago is part of the US urban system but this is very important. Because I've been talking today, urging Singapore to think about what the hell does it mean to be a global city. Is there a global urban system? And where do we sit? Are we over-performing which appears to be the case? Or maybe under-performing in some things and what is that trajectory?

And I'm going to stop here because we've gone on too long but part of this theory also has built into it, one thing I do want to show, this, one of the thing we can do with this theory, is look at the diversity of cities, in terms

	of their size as an urban system. So that's, the top is New York, these are various cities. We have done 465 various cities and what you see, what it is is how many businesses there are at a give time. So if you look at the top of the line there, that purple thing, is the largest number of offices, of any business, what is in New York, their position? Doctors, the biggest business in New York. And the next one, is I think lawyers. And so forth. And then there's another city Chicago and then I'll be done. We've analyzed this in great detail. So here they are and here's what's amazing. Even though each city has its own spectrum, businesses, if you try to put this into a theory, the theory says if you know what to do, all of these collapse to one curve. All the same. They all have the same distribution of jobs, all of them. And we can do all this and you can then assess cities and start talking about the future of cities and you can even predict what the trajectory of lawyers will be in Phoenix, Arizona, from this. Well, you can't do that with Singapore. You can't do anything with Singapore. Unless [indistinct] you say oh Mexico City, Tokyo and so on. But but you can't. it's comparing, it's not even comparing apples with oranges. It's comparing apples and, I don't know, mice.
01:087:00	Ok, so I'm going to finish this, I'm going to finish here, the major part that I left out is about businesses. We've done a great deal of work about businesses. The businesses scale is Walmart, small businesses scaled up and from that we understood questions about the dynamics of businesses, structure of businesses but the mortality of businesses which I started to talk about [indistinct]. If you look at publicly traded companies, and you ask what is the half life of a company, that is already posted on the US Stock exchange, it's already gone through its initial child birth so to speak, the mean life, the half life, is about 10 years. Half of the companies that are posted on the exchange are dead in less than 10 years. Very very few companies last more than 50 years. 100 years is rare. 200 years is extremely rare. 400 years is, there's a few. So one of the things is to

	construct a theory just like that of cities and to be able to gauge when Google will disappear, Microsoft because they surely will. Just like the ones I showed you earlier, TWN. Oki, I'll finish now. I've gone on too long. I apologize. We were supposed to have a discussion. Thank you.
Emcee 01:10:03	Thank you Prof. West for that insightful lecture. We'll now be proceeding to the moderated discussion and Q and A section. During the Q and A we ask that you please state your name and organization before asking questions or making any comments. You raise your hand and my staff will walk to you with microphones. I would now like to invite Mr Aaron Maniam to join Prof West on stage for the moderated discussion and Q and A.
Aaron Maniam (AM)	Thanks very much Geoff for that encyclopedic examination of so many different things. I was very struck by the fact that we often differentiate between Engineering Systems, those cold rigid things and ecological systems. And I think what you showed us today about cities are both at the same time. There are certain universal laws that they subscribe to and yet they are also dynamic and living and breathing all the same time. I was thinking maybe we could take up a couple of questions at a time. We have 40 minutes until 5:30. So maybe a couple of questions at a time. I've tried three before and they are often a little bit difficult the kind of level of material so maybe two will enable us to get through a good number. Usually we have problems with the first question so I will go straight to the second
GW	I wanted to, not a disclaimer exactly but I purposely tried to make this more provocative. I was a bit too hyperbolic at times.
AM	OK we've got one question there and then you after that.
Q	Would you say that Detroit deviated from your curve, exponential…

AM	Can you let us know who you are as well?
Q	My name is Mok [indistinct]. That curve that you had with all the different American cities, all with the same pattern, exponential, yea, increase. Would you say the Detroit completely deviated from that because it has been contracting?
AM	Shall we take a couple more? Yes sir. Just in front here, gentleman in white.
Q 01:12:29	Professor, you are an optimist because from the newspaper and from the news I listen all over the radio there are many prophets of doom. We have increasing carbon footprint in the world, we have global warming, we have industries dying, we have commodities prices plunging and yet your talk is very very optimistic about the future of the world. And I'm very familiar with this American phrase, "The death of Cities – why cities die". And every now and then I come across the same phrase. And indeed our politicians in Singapore also mutter the same phrase. And suggest that as we don't stop [indistinct], which you correlated very well then you will surely have a different rate of growth. So I'm quite encouraged by your talk how much of it is [indistinct] theory? Because you tend to cover more than just a short life span of Detroit but over the next 500 years would you say that Detroit will survive? Or some crime-infested city in Mexico will survive? Thank you.
AM	So the basis of the optimism right? And Liming you have got a question as well?
Q	Liming from CLC. It is not a very complicated question it is just an elaboration of a point. I'm very interested to know what singularity means for cities? I mean, we hear singularity being discussed a lot in science of the universe and so on. So what does it mean when you reach singularity in cities?
AM	Can we do yours in the next segment? We will get to you I promise. We

	will go to you first in the next round. Why don't we try these three first? Detroit and the curve. Causes for your optimism and singularity for cities.
GW 01:15:11	I don't think anyone has ever called me an optimist. Detroit. Yes. Detroit gets a huge amount of press for good reason. And it is too bad I didn't get to the company stuff because Detroit suffered because it became an inflexible and part of that is to do with its lack of diversity, which is similar to this curve we talked about. Indeed Detroit is an outlier on the diversity curve. Any resilience for the system is closely related to, to some extent anyway, to being diverse, to being able to adapt to changes. But having said that, Detroit also gets a bit of a bad rap because we use the word Detroit for the political city but Detroit is actually a contiguous metropolitan area. So if you ask, I don't remember some of these numbers are probably wrong, but the spirit of them is correct, the population of Detroit in the fifties when the automobile industry was booming, was over two million people. Detroit City. It is now, I don't know, less than a million, 500,000, I don't know the exact number. So it's down by well over 50% and indeed the centre of Detroit is a bit like wasteland. However if you look at Detroit as a metropolitan area, the whole contiguous area, because you know the city's just an arbitrary line that was drawn at some stage. But if you look at the entire metropolitan area its population in 1950, was 3.8 million people. It's now like 4.3 million people. And Detroit if you look, I showed the other graph, showed very quickly at the end, was the performance of cities relative to the baseline. If you look at that Detroit's performance as a metropolitan area has not changed very much actually. What happened is that the action shifted as it started decaying in the middle, the outsider ring blossomed. It has very productive pharmaceutical industry, high tech. It's got a lot of impetus from the University of Michigan in Ann Arbor and so on and so forth. That has worked extremely well. But what is happening now it's just beginning is the reversal and people are beginning to migrate back into the city. So much so that I would say that if any of you has a lot of money and you want to be rich in 25 years, buy in the centre of Detroit. So that's my

	answer for Detroit.
GW 01:19:28	Optimism. Well I left the conclusion, the conclusions about the bit about growth, to the audience. Because what is very clear is that you can't sustain the powerful resources and everything else, you cannot sustain that continuous innovation cycle because it's not that you can't innovate it's just that you have to do it fast and faster. And we know it. All the metrics of innovation follow those curves in fact. I just showed that big one, but any of the more detailed the ones I could have shown also follow that. And so, I would say my own conclusions from this work of that, it's quite the opposite, quite pessimistic. It's destined for collapse unless we make a major complete revolutionary change to the whole system. Because you know, if you take the argument sort of, reductio ab absurdum, you are going to eventually have to innovate every year. You know a major innovation every year. So that's kind of crazy. So the idea that you can have this continuous open-ended growth is not conceivable. So I'm actually a pessimist and don't think the system will survive because each one of those curves, is an increase in the pace of life as if you are on a treadmill that is going faster and faster. But then, that's bad enough but then every once in awhile and you have to jump from that treadmill to another treadmill that's going even faster. And you have to make that series of jumps faster and faster. So it is like a double acceleration. So it's hard not to see that the socio-economic system will have a heart attack. Something very serious will happen. Of course what I think, now this is all total speculation, my speculation is that it will manifest itself not in the kinds of things I was talking about but in social unrest. Social unrest will start to get more and more serious and as various segments of population around the world find themselves caught in this phenomenon, and they can't, basically they can't keep up, they're not keeping up and so forth. You know, this is tangential to it, but you know I'm an old man now and I find adapting to this stupid idea that my computer every two years has to change and I have to learn a new system and all my old files are useless, my iPhone. I mean it is making me nuts. My inbox I delete at some

	extraordinary rate and I answer, well I answer slowly. I don't like to write because I'm old, I like to write letters in my e-mail. I don't like to write great idea and send it back. I like to explain, it is totally, it has to be tweeted so to speak. That's the way it is you know. I'm not adapted to that, I can't. I don't want to even. Definitely don't want to. But you know, each one of us feels this. My inbox just grows and grows no matter how many messages I delete or respond to. It just keeps growing. It's like these damn curves. So that's just some teeny stupid little tiny piece but it is indicative of this whole phenomenon and I should say by the way, personally, on a personal level, I'm an optimist. I basically believe in human beings. I believe that you know, good will win over evil. The only thing that's truly important in life is love. I'm a very optimistic person. I'm sort of like, in the United States, I'm a little like a right wing Republican that is like, oh well, all the signs and all this stuff, we will get through all that. Somehow it is all going to vanish. Then because I become myself, my scientific self, completely the opposite. Because what these equations are telling you, and strongly supported by the data, is that without some fundamental change the system will collapse. The open-ended growth paradigm which brought us all the wonderful things around us, that we love, just is not sustainable, unless something fundamental changes and by the way while we're on it, rambling on, is that had we been thinking along these lines, 75 years ago, we might have been able to do something about it. The big issue is not that we can't make change, it's that we can't make it fast enough. That's my concern to be honest, rather then it's impossible to do it. It's simply you know, we are right at the edge of the cliff. I'm a pessimist.
AM	[indistinct] unless a fundamental change happens right now. That's not for today's lecture right. Singularity for cities.
GW 01:26:24	Yes so, oh gosh, let's see. So those equations, the growth equations for cities, because of this super-linear scaling, coming from social networks giving continuous positive feedback, building up, building up, building up,

	that gives rise to this open ended growth. That has built into what we called a finite time singularity. A finite time singularity simply means in English, that the system, what ever we are plotting, it could be GDP, it could be patents, one of these metrics, that, in some finite time has to go to infinity. Which is crazy. You know exponential means that you go to infinity but in an infinite time, so you never get there. But these equations that tell you the solution, that's what the data supports, is that you would get to infinity at some finite time, that's what the finite time, that's the singularity. Then the system collapses when it gets close to that. So the point is that you have to avoid that, and we do avoid that. We avoid it by innovating, by reinventing ourselves, doing all the things that we do. In terms of, so to speak, naturally. At the same time we naturally speed up. By the way of thinking of time, you know this interesting pseudo fact that there seems to be this interesting innate quality to human beings that we spend 1 hour a day, traveling, that's all we can deal with. So that sets the size of cities in the past. You could walk five kilometres, walk 5 kilometers an hour. So if you're there and back that's five kilometres. What is interesting about this is that as we innovated, made vehicles that could go faster, instead of saving time, which is what you think we would do, we didn't. We just moved further away and so the city grows. That's the idea. This is not my idea. A man named [sic:Marketti], two people did this. And so this is a kind of expansion of the city in order to accommodate time. You know it is a very interesting phenomenon, the way we try to accommodate increase in speed. That's just a pseudo fact.
AM 01:29:56	Great. Second round of questions. We have quite a few now. Let's take Lina first. We got his question at the back. Ya, and then Lina after that and then..
Q	Dr. West. Can I ask you a question about your super-linearity and your sub-linearity. I think it is not moved so much [indistinct] or organisms, more like super-linearity is related to open system and your sub-linearity really related to a closed system. So come back to Singapore, like a global

	city, instead of hitting your singularity, your singularity, your remedy is to do innovation. But a place like Singapore, a true global city, can we escape this paradigm by interconnecting? You know go out and do trading, or foreign relationship. Can I ask another question? A very simple one. Now related to an organism like a human being. Take an example of Stephen Hawkins. He's more a machine then man. So his interconnection, his networking that's supporting life is more like, if his machine works and we can put a lot of machines there, can that actually defeat your paradigm? In other words he can live indefinitely because all we need to do is to support that interconnection to his brain. A corollary to this is, like Terminator. We put smart prosthetics, or stem cells. We can keep on increasing our interconnection so to speak. So it is not a closed system, it becomes an open system. Like Singapore would be, if we are a global city, keep on interconnecting? Two questions there.
AM	Two questions on the same theme actually. Interconnection.
Q	Open and closed.
AM	Great thank you. Lena?
Q 01:32:10	It's interrelated. Number one. We're all governed by our genes in the sense that our DNA decides what we can cope with and not cope with. And you talk about innovation going up up up, but we are limited by what we can adapt and change. So that is one. The other thing is that the history of human beings is such that it's been so many millions of years and we are surrounded by biodiversity, and with this changing society, we have got concrete environment. We are not connecting with what we grew up with, or evolved with. So actually with the innovation, it still doesn't address that biological characteristic of ours. So in the third very much related, it's all related in the sense that Jared Diamond...wrote that we are governed by the limitation of our resources. [indistinct] basically I want to bring back this question, which is, would the city which is more biophilic, loving nature, be able to connect with nature, help us to survive?

AM	Great. Raymond?
Q 01:34:12	[indistinct] I would like to ask the question whether we are able to determine what will be a reasonable or optimal size of the city which make it extreme. I think that what we need to do is to have some indication to see whether we are reaching the melting point. Can we do something? I think you mentioned that. Related to that, with technology are we able to flip the coin, and say actually I would love to live outside in the rural but I just come to the city for fun. So the city is basically a place where we have coffee, chat and can do work and do every other thing. Just try to imagine how can we make our living even more tolerable?
AM	Great. So super and sub linearity, open and closed systems, interconnections. One set of themes. Biophilic cities, do they survive better? And optimum size.
GW 01:35:43	Good questions. All of them. And they all involve speculation. They are all speculative. Some of them science fiction-y. Well it's not quite that it is open and closed. And an open system is super-linear - I agree but it remains, it depends what you mean by open. For example, I have a very technical way of thinking about open and closed and that's in terms of thermodynamics. A planet is an open system in the sense that it gets energy from the sun and that is why life could develop and be sustained and so forth. It's been extraordinarily successful, until part of it changed, changed you know 200 years ago. Something dramatic changed. Because you know human beings we evolved with other animals and we evolved just like them. I showed you and these 50 to 100 scaling curves of animals and you took human beings and we fit perfectly on it, I will come back to this for your question, we fit perfectly on it in terms of our various physiological and life history events and so forth, just what it should be. Our metabolic rate is just what it should be, our hearts beat the way it should, blah blah blah. So then we discovered language, we made cities, but we were still supported primarily by the sun until 200 years ago. Some of us weren't because we discovered we could burn wood. That changed

	things a little bit. But when we discovered coal, we discovered stored energy, and then oil, we changed the open system to a closed system. We no longer, the sun plays almost no role relatively speaking in running most of the urban aspects of the planet. It does of course in terms of our agriculture. But in terms of the urban side of the equation, we are now a closed system. But that doesn't stop it. It doesn't stop a city from behaving super-linearly. What it does do is that it completely changes the thermodynamics of the system and that in fact is one of the reasons how we put ourselves at risk by having the closed system rather than going back to just one of the potential solutions - renewable energy - by using the sun. So that isn't a 1 to 1 correspondence. There are two different concepts in my opinion. There is the concept of open vs. closed. And there is the concept of sub-linear economies of scale versus super-linear increasing returns.
GW 01:39:41	Now you also brought up this very interesting question which I'm going to translate differently. You took this weirdo Hawking thing that many people believed in, we're all going to be cyborgs, maybe it's true, it's possible obviously. At the moment (though) we barely understand how the brain works so it seems to be [indistinct] in the extreme, that it's going to be just taking my MacBook Air and plugging it into my ear, into my brain, [indistinct]. So that's the image. Maybe it could happen, I'm not ruling it out. But it's all obviously, a huge leap, enormous leap. However it does bring up some very extremely interesting questions, one of which I'll make it much more modest, it was implied in what you said and that is, maybe the invention and discovery of IT and the fact that we could communicate instantly and across enormous distances, now globally, maybe that's the way out of this. The IT revolution represents that we, in a kind of stumbling way of figuring out the solution without even realizing it, by inventing mobile phones and the Internet. I must tell you when I first did all this work that's what I thought. My god it's fantastic, it's marvelous, there's no real problem. But then you know I started to do much more reading about innovations in the 19th century and what I

	learned, my interpretation, is that innovations in the 19th century relatively speaking, were much greater impact than the innovations we have now. Think of what the train did, opening up. You know most people on this planet, they didn't move more than a few kilometres during their whole bloody lives. Once you have that kind of transportation, you could move serious distances. You can move a horse, miles and so on. But until the train came, you couldn't move vast distances. No wonder. You could have the United States, this vast territory, all interconnected. That had a truly profound impact. But then the telephone was invented. My god. That was, you could start talking to someone in real time over vast distances. The transatlantic cable was laid already in the 19th century. So these had profound effects, socially and politically. And what did they end up doing, they didn't change any of this. They sped up life, that's all they did. That's all they did. Everything just got faster and faster. And my belief is that the IT revolution is doing exactly the same. It's just making everything so much faster. By the way when I was a little boy, and people were, there were lots of futurists in the late forties and fifties. I was born in 1940. And in the fifties there were all kinds of futurists. It was post Second World War, people's optimism was beginning and people were very much struck by innovation. [indistinct] People like John Maynard Keynes, the great economist, I have quotes from him and Charles Darwin, the Charles Darwin, both saying that the biggest challenge in the future, is how are we going to cope with all the spare time we have? People, you know you only need a few people working, they say 15 hours a week, in order to make machines and innovate but everybody else, you know what are they gonna do. You know they only have to work productively for 15 hours. What are we going to do? We have to invent. That was a huge issue. I remember that as a boy. That's why I did some work to go back and find the various papers that these eminent people wrote. Well they were completely wrong. They were exactly wrong. We don't have time for anything as far as I can tell. Now you could of course, say that maybe they were right in the sense that maybe the way we solved the problem that we had so much time, is

	the invent all the rubbish that we do. Facebook, Twitter and the Internet and all the other crap that we have to deal with that takes up the e-mail. Most of it is rubbish. So maybe you can just, I'm just giving you an interpretation, I'm not saying I believe all that, that's there. You could think of it like Marx's theory, religion is the opiate of the people. Facebook, Twitter, email, all that is the opiate of the 21st century. It's keeping us occupied so that we don't have revolutions or whatever we are supposed to be doing.
AM 01:46:25	There is a nice segue between what you just talked about and Lena's question. Is there some solution to that in a biophilic situation?
GW	One of the interesting things about Lena's question is the issue that life has sped up so that the clock which we operate socio-economically, in our daily lives, is not the clock by which we evolved. The clock by which we evolved is the earth rotating and then the earth rotating on its axis, and then rotating around the sun. That's the clock that's on that wall and on my watch. That is actually not the clock that is determined, that is that other thing, the accelerating treadmill, that is sort of a cartoon way of looking at it. And that sped everything up. Another curious thing is expanded lifetime because we live much longer. Most people in this room, almost everybody in this room, if they lived to the average life span 150 years ago, we would be dead. That life span was in the forties early forties, until about 1840, 1850, it started to rise. So life span has almost doubled and all this other stuff has gone on but despite all of these things, this, what's going on inside here, is pretty much the same. It's the same as it was when we were hunter-gatherers. We evolved that way, the genes determined it, and the crucial thing in terms of the way you put it is, is that the problem and understanding, the problem we are facing is that, the timescales of evolutionary change socio-economically, is now much shorter than the lifespan of the individual. Which is completely different then all evolution that preceded it where the evolutionary timescales, were minimum hundreds of thousands of years, hundreds of millions of years. Changes

	took place. So you live your life, I live my life and I have not evolved. By the Darwinian sense, I have not evolved. Takes many many generations. But my god, has my socio-economic life evolved. Completely different, than 1948 in London. It's completely different than 2016. Completely different. Singapore in 1948 is unrecognizable from Singapore in 2016. Not just physically but everything you do. So our brains though evolved, not to deal with evolution. I don't know. It just means that it's a source of incredible anxiety. I think it means, we are not going to be bored, if somebody is bored to death, which is what Keynes and Darwin are worried about, we are being accelerated to death by anxiety, psychotic breakdowns and so on. Very few people in cities live relaxed lives.
AM 01:50:30	It's the psychological effects of urban life.
GW	The psychological impact is phenomenal. We are all going nuts.
AM	So how many of us are going to go nuts together? [indistinct]
GW	So that's also a very interesting question. City size. So there is, coming back to the biology first. Turns out that all theory, amazingly, predicts the minimum and maximum size of a mammal for example, predicts that you can't have a functioning mammal, that's the size of a shrew, 2 or 3 grams. That's it. Anything below it cannot function. But it also predicts that if you make it too big, it also can't function. And roughly speaking, it's the size of a blue whale. Interesting actually. You might get one twice as big but you can't get one 10 times as big. Or 10 times smaller. So you ask, is that true of a city? Well, a city, there's no minimum size, little villages, they're still cities, and by the way, we have looked at, started looking at microscopic areas. We've also looked at micro areas. And you know what's amazing. The scaling laws go down to cities, towns, villages, that are just a few thousand. But there's huge variance. You know what I mean. There's great great variance. [indistinct] so the question is, is there anything limiting the maximum? And in this theory the answer seems to be

	no. you just go on. Now if you ask realistically, about cities, could you have Tokyo? Tokyo is 35 million people. Could it be 100 million? Could Los Angeles be, it's 10, 12 million. Could it be 100 million? Let's take Los Angeles because I love Los Angeles. So you ask could you have 100 million people here? Well, I would say, in principle, the answer is yes. You just build and keep building. However, if it's going to be a real city, meaning that it's an integrated unit, then you have a problem. Because if it's going to be an integrated unit, all those people, all those 100 million people somehow have to be connected. In some way there has to be so I'm going to take a slight detour and raise the question, which is what this does, the definition of a city. So the definition of a city, from this perspective, is not again, all the buildings. The buildings don't define the city. What defines the city is that connectivity of the social network. You have your part of the city. If you are connected to the network, or you connect twice a year, or twice a month, or twice a day, you can define the threshold however you like. But you have to be connected in that network. That defines the city. So if you are going to have that 100 million people, you have to have a transport system to accomplish this. Now in principle, if you built a city from scratch, you might plan that. If you tried to retrofit the city, like Los Angeles. Los Angeles already has freeways that are 12 lanes wide. So if you are going to have 100 million people, it's going to have to be 20 or 30 lanes wide. And the railroad tracks instead of being two tracks or four tracks, it might end up being a dozen or 20 tracks. That's impossible because you are not going to tear down most of the city in order to just have this transportation. So it ain't gonna work. What will happen, you can still ask, why can't you just build it anyway? The answer is you could, but it would no longer be one city. What's going to happen is the city will bifurcate, disintegrate into various pieces, which you already see in some places. You could imagine just a thought experiment, that Los Angeles could effectively be split into two cities which are physically contiguous but effectively highly dependent on each other. Because we see bits of that in places. So I think that's what's going to happen. The answer

	is not a yes or a no. It depends on the definition of a city. But what I think it is an important definition of a city, important operational definition of a city – cities can't go on. They can go on in principle but they won't in practice.
AM 01:56:32	I think we've reached the end of our time. We've gone through six very very rich questions. That's true because there were some sub parts. Thank you Geoff, for the number of thoughts there. I always maintained that the best lectures of these kinds tantalizes a little bit but never fully answers the questions. I suspect there are plenty of us out there with follow-up questions and things that we want to think out in our heads, you have given us plenty of fodder to do that. So thank you very much for being here with us and thinking everybody for your questions.
	[Recording ends at 1:58:42]