A Physicist Solves the City

Geoffrey West doesn't eat lunch. His doctor says he has a mild allergy to food; meals make him sleepy and nauseated. When West is working — when he's staring at some scribbled equations on scratch paper or gazing out his office window at the high desert in New Mexico — he subsists on black tea and nuts. His gray hair is tousled, and his beard has the longish look of neglect. It's clear that West regards the mundane needs of everyday life — trimming the whiskers, say — as little more than a set of annoying distractions, drawing him away from a much more interesting set of problems. Sometimes West can seem jealous of his computer, this silent machine with no hungers or moods. All it needs is a power cord.

For West, the world is always most compelling at its most abstract. As a theoretical physicist in search of fundamental laws, he likes to compare his work to that of Kepler, Galileo and Newton. "I've always wanted to find the rules that govern everything," he says. "It's amazing that such rules exist. It's even more amazing that we can find them."

But the 70-year-old West, who grew up in Somerset, England, is no longer trying to solve the physical universe; he's not interested in deep space or string theory. Although West worked for decades as a physicist at Stanford University and Los Alamos National Laboratory, he started thinking about leaving the field after the financing for the Texas superconducting supercollider was canceled by Congress in 1993. West, however, wasn't ready to retire, and so he began searching for subjects that needed his skill set.

Eventually he settled on cities: the urban jungle looked chaotic — all those taxi horns and traffic jams — but perhaps it might be found to obey a short list of universal rules. "We spend all this time thinking about cities in terms of their local details, their restaurants and museums and weather," West says. "I had this hunch that there was something more, that every city was also shaped by a set of hidden laws."

And so West set out to solve the City. As he points out, this is an intellectual problem with immense practical implications. Urban population growth is the great theme of modern life, one that's unfolding all across the world, from the factory boomtowns of Southern China to the sprawling *favelas* of Rio de Janeiro. As a result, for the first time in history, the majority of human beings live in urban areas. (The numbers of city dwellers are far higher in developed countries — the United States, for instance, is 82 percent urbanized.) Furthermore, the pace of urbanization is accelerating as people all over the world flee the countryside and flock to the crowded street.

This relentless urban growth has led to a renewed interest in cities in academia and in government. In February 2009, President Obama established the first White House Office of Urban Affairs, which has been told to develop a "policy agenda for urban America." Meanwhile, new perspectives have come to the field of urban studies. Macro-economists, for instance, have focused on the role of cities in driving gross domestic product and improving living standards, while psychologists have investigated the impact of city life on self-control and short-term memory. Even architects are moving into the area: Rem Koolhaas, for one, has argued that architects have become so obsessed with pretty buildings that they've neglected the vital spaces between them.

But West wasn't satisfied with any of these approaches. He didn't want to be constrained by the old methods of social science, and he had little patience for the unconstrained speculations of architects. (West considers urban theory to be a field without principles, comparing it to physics before Kepler pioneered the laws of planetary motion in the 17th century.) Instead, West wanted to begin with a blank page, to study cities as if they had never been studied before. He was tired of urban theory — he wanted to invent urban science.

For West, this first meant trying to gather as much urban data as possible. Along with Luis Bettencourt, another theoretical physicist who had abandoned conventional physics, and a team of disparate researchers, West began scouring libraries and government Web sites for relevant statistics. The scientists downloaded huge files from the Census Bureau, learned about the intricacies of German infrastructure and bought a thick and expensive almanac featuring the provincial cities of China. (Unfortunately, the book was in Mandarin.) They looked at a dizzying array of variables, from the total amount of electrical wire in Frankfurt to the number of college graduates in Boise. They amassed stats on gas stations and personal income, flu outbreaks and homicides, coffee shops and the walking speed of pedestrians.

After two years of analysis, West and Bettencourt discovered that all of these urban variables could be described by a few exquisitely simple equations. For example, if they know the population of a metropolitan area in a given country, they can estimate, with approximately 85 percent accuracy, its average income and the dimensions of its sewer system. These are the laws, they say, that automatically emerge whenever people "agglomerate," cramming themselves into apartment buildings and subway cars. It doesn't matter if the place is Manhattan or Manhattan, Kan.: the urban patterns remain the same. West isn't shy about describing the magnitude of this accomplishment. "What we found are the constants that describe every city," he says. "I can take these laws and make precise predictions about the number of violent crimes and the surface area of roads in a city in Japan with 200,000 people. I don't know anything about this city or even where it is or its history, but I can tell you all about it. And the reason I can do that is because every city is really the same." After a pause, as if reflecting on his hyperbole, West adds: "Look, we all know that every city is unique. That's all we talk about when we talk about cities, those things that make New York different from L.A., or Tokyo different from Albuquerque. But focusing on those differences misses the point. Sure, there are differences, but different from what? We've found the what."

There is something deeply strange about thinking of the metropolis in such abstract terms. We usually describe cities, after all, as local entities defined by geography and history. New Orleans isn't a generic place of 336,644 people. It's the bayou and Katrina and Cajun cuisine. New York isn't just another city. It's a former Dutch fur-trading settlement, the center of the finance industry and home to the Yankees. And yet, West insists, those facts are mere details, interesting anecdotes that don't explain very much. The only way to really understand the city, West says, is to understand its deep structure, its defining patterns, which will show us whether a metropolis will flourish or fall apart. We can't make our cities work better until we know how they work. And, West says, he knows how they work.

West has been drawn to different fields before. In 1997, less than five years after he transitioned away from high-energy physics, he published one of the most contentious and influential papers in modern biology. (The research, which appeared in Science, has been cited more than 1,500 times.) The last line of the paper summarizes the sweep of its ambition, as West and his co-authors assert that they have just solved "the single most pervasive theme underlying all biological diversity," showing how the most vital facts about animals — heart rate, size, caloric needs — are interrelated in unexpected ways.

The mathematical equations that West and his colleagues devised were inspired by the earlier findings of Max Kleiber. In the early 1930s, when Kleiber was a biologist working in the animal-husbandry department at the University of California, Davis, he noticed that the sprawlingly diverse animal kingdom could be characterized by a simple mathematical relationship, in which the metabolic rate of a creature is equal to its mass taken to the three-fourths power. This ubiquitous principle had some significant implications, because it showed that larger species need less energy per pound of flesh than smaller ones. For instance, while an elephant is 10,000 times the size of a guinea pig, it needs only 1,000 times as much energy. Other scientists soon found more than 70 such related laws, defined by what are known as "sublinear" equations. It doesn't matter what the animal looks like or where it lives or how it evolved — the math almost always works.

West's insight was that these strange patterns are caused by our internal infrastructure — the plumbing that makes life possible. By translating these biological designs into mathematics, West and his co-authors were able to explain the existence of Kleiber's scaling laws. "I can't tell you how satisfying this was," West says. "Sometimes, I look out at nature and I think, Everything here is obeying my conjecture. It's a wonderfully narcissistic feeling."

Not every biologist was persuaded, however. In fact, West's paper in Science ignited a flurry of rebuttals, in which researchers pointed out all the species that violated the math. West can barely hide his impatience with what he regards as quibbles. "There are always going to be people who say, 'What about the crayfish?' " he says. "Well, what about it? Every fundamental law has exceptions. But you still need the law or else all you have is observations that don't make sense. And that's not science. That's just taking notes." For West, arguments over the details of crustaceans were a sure sign that it was time to move on. And so, in 2002, he began to think seriously about cities.

The correspondence was obvious to West: he saw the metropolis as a sprawling organism, similarly defined by its infrastructure. (The boulevard was like a blood vessel, the back alley a capillary.) This implied that the real purpose of cities, and the reason cities keep on growing, is their ability to create massive economies of scale, just as big animals do. After analyzing the first sets of city data — the physicists began with infrastructure and consumption statistics — they concluded that cities looked a lot like elephants. In city after city, the indicators of urban "metabolism," like the number of gas stations or the total surface area of roads, showed that when a city doubles in size, it requires an increase in resources of only 85 percent.

This straightforward observation has some surprising implications. It suggests, for instance, that modern cities are the real centers of sustainability. According to the data, people who live in densely populated places require less heat in the winter and need fewer miles of asphalt per capita. (A recent analysis by economists at Harvard and U.C.L.A. demonstrated that the average Manhattanite emits 14,127 fewer pounds of carbon dioxide annually than someone living in the New York suburbs.) Small communities might look green, but they consume a disproportionate amount of everything. As a result, West argues, creating a more sustainable society will require our big cities to get even bigger. We need more megalopolises.

But a city is not just a frugal elephant; biological equations can't entirely explain the growth of urban areas. While the first settlements in Mesopotamia might have helped people conserve scarce resources — irrigation networks meant more water for everyone — the concept of the city spread for an entirely different reason. "In retrospect, I was quite stupid," West says. He was so excited by the parallels between cities and living things that he "didn't pay enough attention to the ways in which urban areas and organisms are completely different."

What Bettencourt and West failed to appreciate, at least at first, was that the value of modern cities has little to do with energy efficiency. As West puts it, "Nobody moves to New York to save money on their gas bill." Why, then, do we put up with the indignities of the city? Why do we accept the failing schools and overpriced apartments, the bedbugs and the traffic?

In essence, they arrive at the sensible conclusion that cities are valuable because they facilitate human interactions, as people crammed into a few square miles exchange ideas and start collaborations. "If you ask people why they move to the city, they always give the same reasons," West says. "They've come to get a job or follow their friends or to be at the center of a scene. That's why we pay the high rent. Cities are all about the people, not the infrastructure."

It's when West switches the conversation from infrastructure to people that he brings up the work of Jane Jacobs, the urban activist and author of "The Death and Life of Great American Cities." Jacobs was a fierce advocate for the preservation of small-scale neighborhoods, like Greenwich Village and the North End in Boston. The value of such urban areas, she said, is that they facilitate the free flow of information between city dwellers. To illustrate her point, Jacobs described her local stretch of Hudson Street in the Village. She compared the crowded sidewalk to a spontaneous "ballet," filled with people from different walks of life. School kids on the stoops, gossiping homemakers, "business lunchers" on their way back to the office. While urban planners had long derided such neighborhoods for their inefficiencies — that's why Robert Moses, the "master builder" of New York, wanted to build an eight-lane elevated highway through SoHo and the Village — Jacobs insisted that these casual exchanges were essential. She saw the city not as a mass of buildings but rather as a vessel of empty spaces, in which people interacted with other people. The city wasn't a skyline — it was a dance.

If West's basic idea was familiar, however, the evidence he provided for it was anything but. The challenge for Bettencourt and West was finding a way to quantify urban interactions. As usual, they began with reams of statistics. The first data set they analyzed was on the economic productivity of American cities, and it quickly became clear that their working hypothesis — like elephants, cities become more efficient as they get bigger — was profoundly incomplete. According to the data, whenever a city doubles in size, every measure of economic activity, from construction spending to the amount of bank deposits, *increases* by approximately 15 percent per capita. It doesn't matter how big the city is; the law remains the same. "This remarkable equation is why people move to the big city," West says. "Because you can take the same person, and if you just move them to a city that's twice as big, then all of a sudden they'll do 15 percent more of everything that we can measure." While Jacobs could only speculate on the value of our urban interactions, West insists that he has found a way to "scientifically confirm" her conjectures. "One of my favorite compliments is when people come up to me and say, 'You have done what Jane Jacobs would have done, if only she could do mathematics,' " West says. "What the data clearly shows, and what she was clever enough to anticipate, is that when people come together, they become much more productive."

West illustrates the same concept by describing the Santa Fe Institute, an interdisciplinary research organization, where he and Bettencourt work. The institute itself is a sprawl of common areas, old couches and tiny offices; the coffee room is always the most crowded place. "S.F.I. is all about the chance encounters," West says. "There are few planned meetings, just lots of unplanned conversations. It's like a little city that way." The previous evening, West and I ran into the novelist Cormac McCarthy at the institute, where McCarthy often works. The physicist and the novelist ended up talking about Antarctic icefish, the editing process and convergent evolution for 45 minutes. Of course, these interpersonal collisions — the human friction of a crowded space — can also feel unpleasant. We don't always want to talk with strangers on the subway or jostle with people on the sidewalk. West admits that all successful cities are a little uncomfortable. He describes the purpose of urban planning as finding a way to minimize our distress while maximizing our interactions. The residents of Hudson Street, after all, didn't seem to mind mingling with one another on the sidewalk. As Jacobs pointed out, the layout of her Manhattan neighborhood — the short blocks, the mixed-use zoning, the density of brownstones — made it easier to cope with the strain of the metropolis. It's fitting that it's called the Village.

In recent decades, though, many of the fastest-growing cities in America, like Phoenix and Riverside, Calif., have given us a very different urban model. These places have traded away public spaces for affordable single-family homes, attracting working-class families who want their own white picket fences. West and Bettencourt point out, however, that cheap suburban comforts are associated with poor performance on a variety of urban metrics. Phoenix, for instance, has been characterized by below-average levels of income and innovation (as measured by the production of patents) for the last 40 years. "When you look at some of these fast-growing cities, they look like tumors on the landscape," West says, with typical bombast. "They have these extreme levels of growth, but it's not sustainable growth." According to the physicists, the trade-off is inevitable. The same sidewalks that lead to "knowledge trading" also lead to cockroaches.

Consider the data: When Bettencourt and West analyzed the negative variables of urban life, like crime and disease, they discovered that the exact same mathematical equation applied. After a city doubles in size, it also experiences a 15 percent per capita increase in violent crimes, traffic and AIDS cases. (Of course, these trends are only true in general. Some cities can bend the equations with additional cops or strict pollution regulations.) "What this tells you is that you can't get the economic growth without a parallel growth in the spread of things we don't want," Bettencourt says. "When you double the population, everything that's related to the social network goes up by the same percentage."

West and Bettencourt refer to this phenomenon as "superlinear scaling," which is a fancy way of describing the increased output of people living in big cities. When a superlinear equation is graphed, it looks like the start of a roller coaster, climbing into the sky. The steep slope emerges from the positive feedback loop of urban life — a growing city makes everyone in that city more productive, which encourages more people to move to the city, and so on. According to West, these superlinear patterns demonstrate why cities are one of the single most important inventions in human history. They are the idea, he says, that enabled our economic potential and unleashed our ingenuity. “When we started living in cities, we did something that had never happened before in the history of life,” West says. “We broke away from the equations of biology, all of which are sublinear. Every other creature gets slower as it gets bigger. That’s why the elephant plods along. But in cities, the opposite happens. As cities get bigger, everything starts accelerating. There is no equivalent for this in nature. It would be like finding an elephant that’s proportionally faster than a mouse.”

There is, of course, a very good reason that animals slow down with size: All that mass requires energy. Because the elephant has to eat so much to feed itself, it can’t afford to run around like a little rodent. But the superlinear growth of cities comes with no such inherent constraints. Instead, the urban equations predict a world of ever-increasing resource consumption, as the expansion of cities fuels the expansion of economies. In fact, the societal consumption driven by the process of urbanization — our collective desire for iPads, Frappuccinos and the latest fashions — more than outweighs the ecological benefits of local mass transit.

West illustrates the problem by translating human life into watts. “A human being at rest runs on 90 watts,” he says. “That’s how much power you need just to lie down. And if you’re a hunter-gatherer and you live in the Amazon, you’ll need about 250 watts. That’s how much energy it takes to run about and find food. So how much energy does our lifestyle [in America] require? Well, when you add up all our calories and then you add up the energy needed to run the computer and the air-conditioner, you get an incredibly large number, somewhere around 11,000 watts. Now you can ask yourself: What kind of animal requires 11,000 watts to live? And what you find is that we have created a lifestyle where we need more watts than a blue whale. We require more energy than the biggest animal that has ever existed. That is why our lifestyle is unsustainable. We can’t have seven billion blue whales on this planet. It’s not even clear that we can afford to have 300 million blue whales.”

The historian Lewis Mumford described the rise of the megalopolis as “the last stage in the classical cycle of civilization,” which would end with “complete disruption and downfall.” In his more pessimistic moods, West seems to agree: he knows that nothing can trend upward forever. In fact, West sees human history as defined by this constant tension between expansion and scarcity, between the relentless growth made possible by cities and the limited resources that hold our growth back. “The only thing that stops the superlinear equations is when we run out of something we need,” West says. “And so the growth slows down. If nothing else changes, the system will eventually start to collapse.”

How do we avoid this bleak fate? Constant innovation. After a resource is exhausted, we are forced to exploit a new resource, if only to sustain our superlinear growth. West cites a long list of breakthroughs to illustrate this historical pattern, from the discovery of the steam engine to the invention of the Internet. “These major innovations completely changed the way society operates,” West says. “It’s like we’re on the edge of a cliff, about to run out of something, and then we find a new way of creating wealth. That means we can start to climb again.”

But the escape is only temporary, as every innovation eventually leads to new shortages. We clear-cut forests, and so we turn to oil; once we exhaust our fossil-fuel reserves, we’ll start driving electric cars, at least until we run out of lithium. This helps explain why West describes cities as the only solution to the problem of cities. Although urbanization has generated a seemingly impossible amount of economic growth, it has also inspired the innovations that allow the growth to continue.

There is a serious complication to this triumphant narrative of cliff edges and creativity, however. Because our lifestyle has become so expensive to maintain, every new resource now becomes exhausted at a faster rate. This means that the cycle of innovations has to constantly accelerate, with each breakthrough providing a shorter reprieve. The end result is that cities aren't just increasing the pace of life; they are also increasing the pace at which life changes. “It's like being on a treadmill that keeps on getting faster,” West says. “We used to get a big revolution every few thousand years. And then it took us a century to go from the steam engine to the internal-combustion engine. Now we're down to about 15 years between big innovations. What this means is that, for the first time ever, people are living through multiple revolutions. And this all comes from cities. Once we started to urbanize, we put ourselves on this treadmill. We traded away stability for growth. And growth requires change.”

While listening to West talk about cities, it's easy to forget that his confident pronouncements are mere correlations, and that his statistics can only hint at possible explanations. Not surprisingly, many urban theorists disagree with West's conclusions. Some resent the implication that future urban research should revolve around a few abstract mathematical laws. Other theorists, like Joel Kotkin, a fellow in urban futures at Chapman University, in Orange, Calif., argue that the working model of Bettencourt and West is already obsolete and fails to explain recent trends. “In the last decade, suburbs have produced six times as many jobs,” Kotkin says. And these aren't just unskilled service jobs. Kotkin says the centers of American innovation are now low-density metropolitan areas like Silicon Valley and Raleigh-Durham, N.C. “For a supposedly complete theory” of cities, Kotkin says, “this work fails to explain a lot of what's happening right now.”

The theoretical physicists aren't discouraged by these critiques. While they admit their equations are imperfect, they insist the work remains a necessary first draft. “When Kepler found the laws that govern planetary motion, he didn't get the laws exactly right,” West says. “But the laws were still good enough to inspire Newton.” In the meantime, West and Bettencourt continue to search for new statistics (they have just received a data set from the I.R.S.) that they hope to feed back into the model. Nevertheless, West says they believe that their essential theory — those superlinear and sublinear laws — will remain intact. The math is scientifically sound.

In fact, West is so satisfied with his urban research that he's already becoming a little restless. Recently, he and Bettencourt, led by this impatience, began exploring yet another subject: the corporation. At first glance, cities and companies look very similar. They're both large agglomerations of people, interacting in a well-defined physical space. They contain infrastructure and human capital; the mayor is like a C.E.O.

But it turns out that cities and companies differ in a very fundamental regard: cities almost never die, while companies are extremely ephemeral. As West notes, Hurricane Katrina couldn't wipe out New Orleans, and a nuclear bomb did not erase Hiroshima from the map. In contrast, where are Pan Am and Enron today? The modern corporation has an average life span of 40 to 50 years.

This raises the obvious question: Why are corporations so fleeting? After buying data on more than 23,000 publicly traded companies, Bettencourt and West discovered that corporate productivity, unlike urban productivity, was entirely sublinear. As the number of employees grows, the amount of profit per employee shrinks. West gets giddy when he shows me the linear regression charts. “Look at this bloody plot,” he says. “It's ridiculous how well the points line up.” The graph reflects the bleak reality of corporate growth, in which efficiencies of scale are almost always outweighed by the burdens of bureaucracy. “When a company starts out, it's all about the new idea,” West says. “And then, if the company gets lucky, the idea takes off. Everybody is happy and rich. But then management starts worrying about the bottom line, and so all these people are hired to keep track of the paper clips. This is the beginning of the end."

The danger, West says, is that the inevitable decline in profit per employee makes large companies increasingly vulnerable to market volatility. Since the company now has to support an expensive staff — overhead costs increase with size — even a minor disturbance can lead to significant losses. As West puts it, "Companies are killed by their need to keep on getting bigger."

For West, the impermanence of the corporation illuminates the real strength of the metropolis. Unlike companies, which are managed in a top-down fashion by a team of highly paid executives, cities are unruly places, largely immune to the desires of politicians and planners. "Think about how powerless a mayor is," West says. "They can't tell people where to live or what to do or who to talk to. Cities can't be managed, and that's what keeps them so vibrant. They're just these insane masses of people, bumping into each other and maybe sharing an idea or two. It's the freedom of the city that keeps it alive."

Jonah Lehrer is the author, most recently, of "How We Decide."