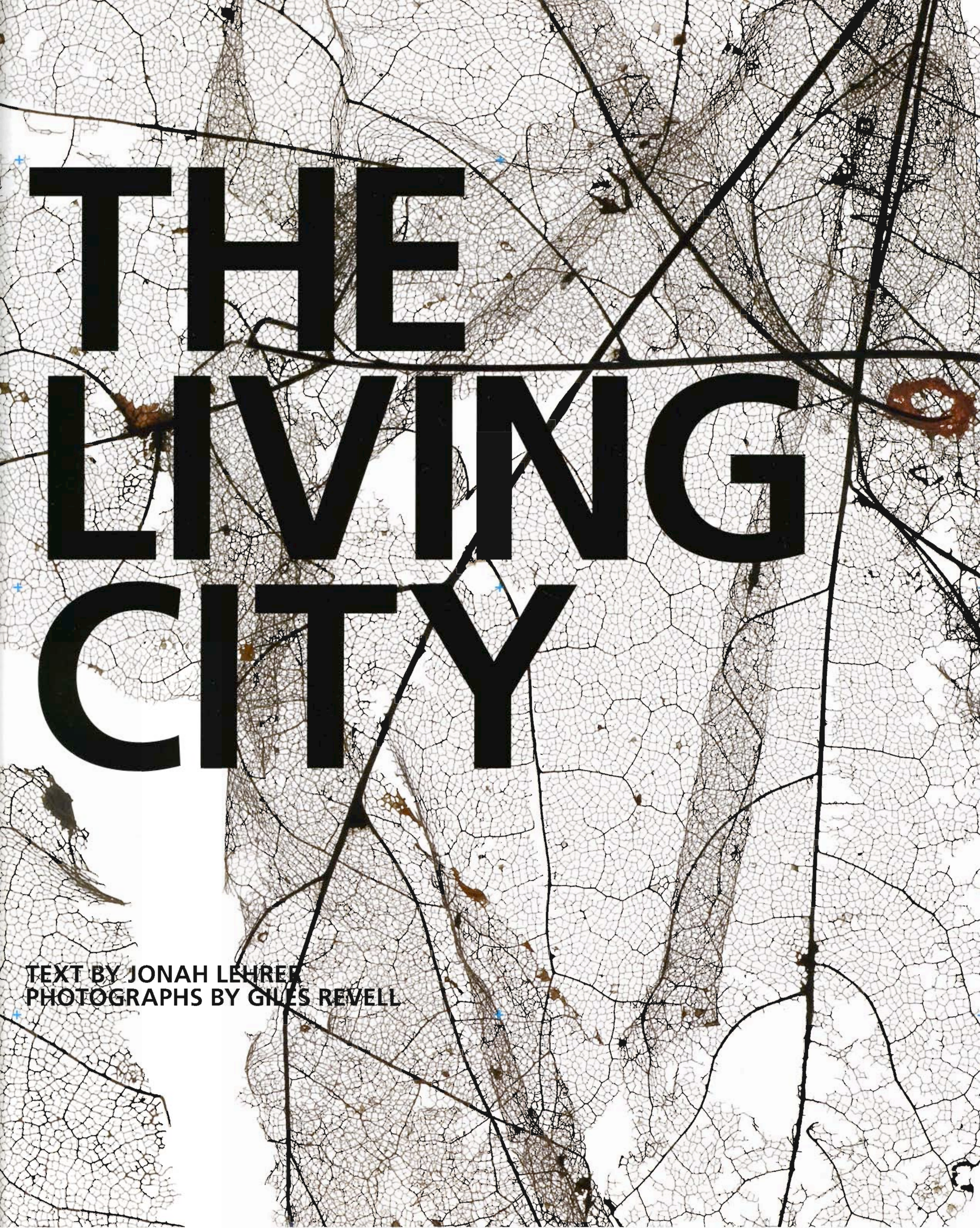
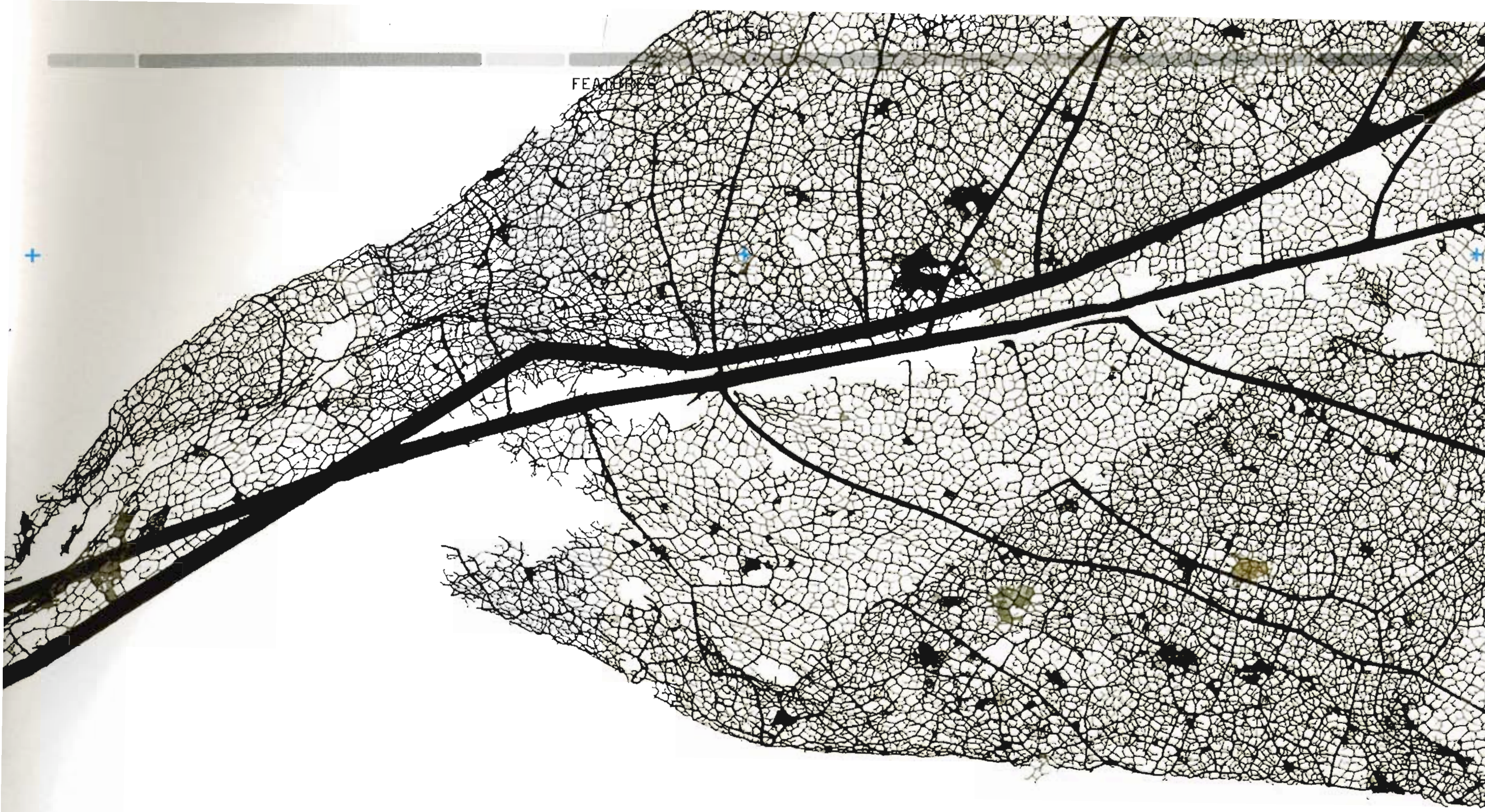


THE LIVING CITY

TEXT BY JONAH LEHRER
PHOTOGRAPHS BY GILES REVELL



I'm underneath New York City, a few blocks east of Times Square. I've entered through a manhole in the middle of the street and descended a few feet down a slippery ladder. At first glance, there's not much to see: just a tangle of wires and sewer lines that carry our electricity, our conversations, our shit. It's the landscape of rodents and repairmen, a world that we notice only when something goes wrong, when a water main bursts or a sinkhole appears. But once my eyes adjust to the dim light, I begin to sense the quiet pulse of the place. There is the slow swoosh of anonymous liquids, punctuated now and again by the rumble of a subway train. The mechanical pumps keep a steady beat, like some sort of rusted heart. The city seems alive, and I'm inside its insides.

Cities have long been compared to organisms—Plato talked about the city as a corporeal body—but being underneath the street makes the metaphor literal. These are the guts of the city, the metal intestines that allow suburbs to sprawl and skyscrapers to rise. The fiber-optic cables are nerves, and the subway tunnels are thick jugular veins. Energy is distributed, and waste is digested. All this generates a sort of animal heat, which escapes from the grates in the gutters. The foul steam is exhaled breath.

But how true is this metaphor? Are cities really like living things? A team of physicists and economists led by Geoffrey West of the Santa Fe Institute recently set out to answer these questions. It turns out that, in many respects, cities act just like creatures. They obey the same metabolic laws that govern every organism. Their infrastructure follows a distinctly biological design, which helps explain why cities are able to grow. According to data the team published in April, the urban spaces we've created have come to resemble their creators. A city is just a body writ large.

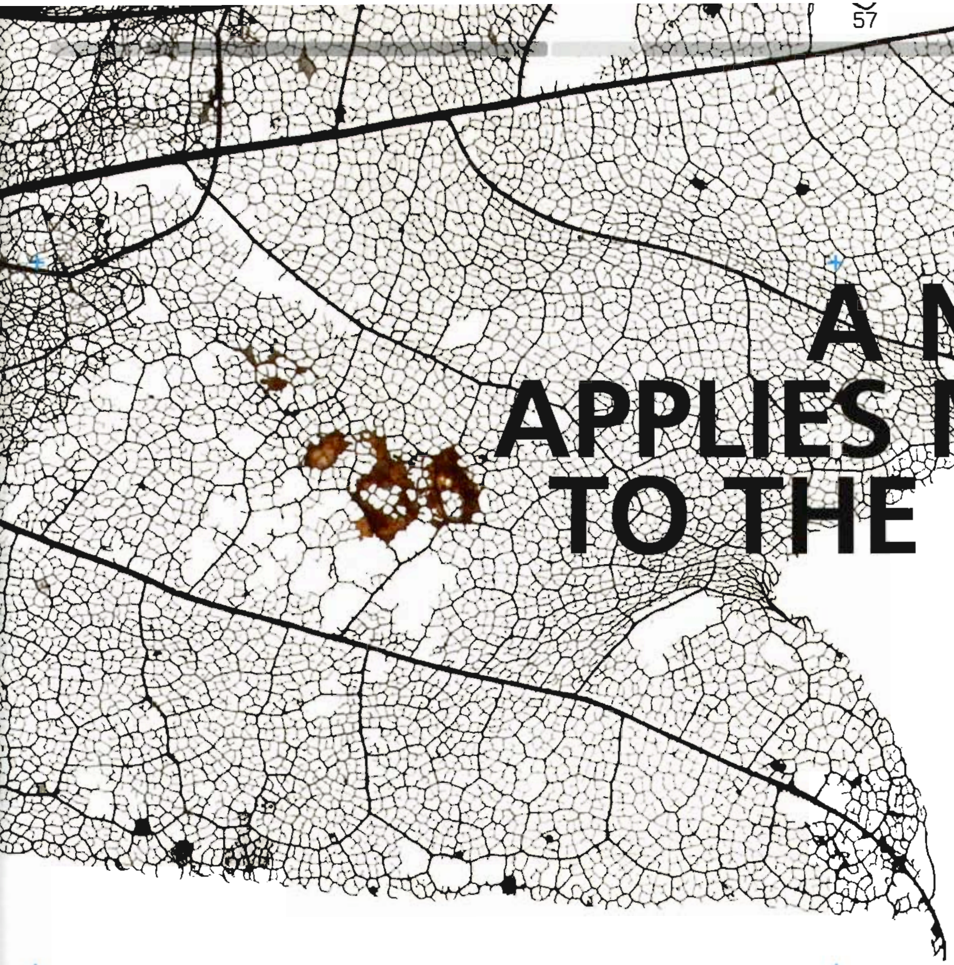
And yet, the researchers also found that cities are an unprecedented phenomenon. When it comes to social variables—things like economic activity that don't have any clear biological analogue—cities break every rule. They are free from the constraints of ordinary living things and are instead subject to an entirely new set of requirements. "Once men and women started to form themselves into stable communities," West says, "they introduced a completely new dynamic to this planet, perhaps even the universe." By analyzing the metropolis using mathematics, West and his colleagues are able to look beyond the superficial differences separating Manhattan from Mumbai, or Chicago from Shenzen. They can see the constants of city life.

This new science of cities wouldn't exist without the work of a little-known Swiss-American biologist, Max Kleiber, who spent most of his career studying dairy cows. In the early 1930s, Kleiber began measuring the metabolic rate of a vast range of different animals. He discovered a striking pattern: In virtually every species, the metabolic rate is equal to the mass of the animal raised to the ¾ power. (Or, the metabolic rate increases on a scale three-quarters that of mass.) This simple equation could describe cows and humans and elephants and mice. It didn't matter what the creature looked like, or where it lived, or how it evolved. The formula always worked.

Kleiber's equation has important implications. The key part of the equation is the exponent, which is less than 1. This means that animals with a bigger mass will consume less energy per pound than smaller animals. As life grows, it develops enormous economies of scale. The elephant is much more metabolically efficient than the mouse. Humans are more efficient than hummingbirds. Girth is a good thing, at least from the perspective of energy consumption.

Subsequent researchers discovered a series of related equations, all of which also revolved around quarter-power exponents. For example, an animal's lifespan can be roughly calculated by raising its mass to the ¼ power. Heartbeats scale in the opposite direction, so that bigger animals have a slower pulse. The end result is that every living creature gets about a billion heartbeats worth of life. Small animals just consume their lives faster.

Scientists couldn't explain these equations. And as the decades passed, and biology became increasingly molecular, these quarter-power scaling laws faded into obscurity. They were curious artifacts from a different time, inductive laws neglected by a reductive science.



A NEW SCIENCE APPLIES METABOLISM TO THE METROPOLIS

Fast-forward to 1993. Geoffrey West, then a physicist at Los Alamos National Laboratory, was looking for a new subject to study. He'd spent most of his career exploring the esoteric branches of theoretical physics—"dark matter, quarks, string theory, that sort of stuff," he says—but the dearth of funding left him disillusioned. He reasoned that biology was "the science of the 21st century" and set out to find a biological problem that needed the skills of a theoretical physicist.

That's when West stumbled upon the work of Max Kleiber. He was enthralled by the existence of quarter-power scaling laws. "I couldn't believe that biologists hadn't thought more about this," West says. "As a physicist, I knew that laws like this aren't accidents. They are telling us something very deep about the order of things. Life is the most complex and diverse physical system in the universe, and yet it seems to obey these absurdly simple scaling laws."

West wanted to figure out the physical mechanisms underlying these laws. What made diverse forms of life obey such minimalist formulas? Why were the equations so universal? He teamed up with two ecologists, Jim Brown and Brian Enquist of the University of New Mexico, who both studied scaling laws. (Enquist had previously discovered that the same scaling laws also fit many different plants.) Their key insight was that the supply networks of life could be described in the language of fractal geometry, since each section of the network shared the structure of the whole. "It doesn't matter if you're talking about the skeletal system or the nervous system or the cardiovascular system," West says. "These systems all share the same underlying logic, which is independent of the particulars or species." Because every living thing relies on these fractal networks—the only difference between a mouse and an elephant is the sheer scale of the network—the varieties of life could all be modeled as variations of the same design.

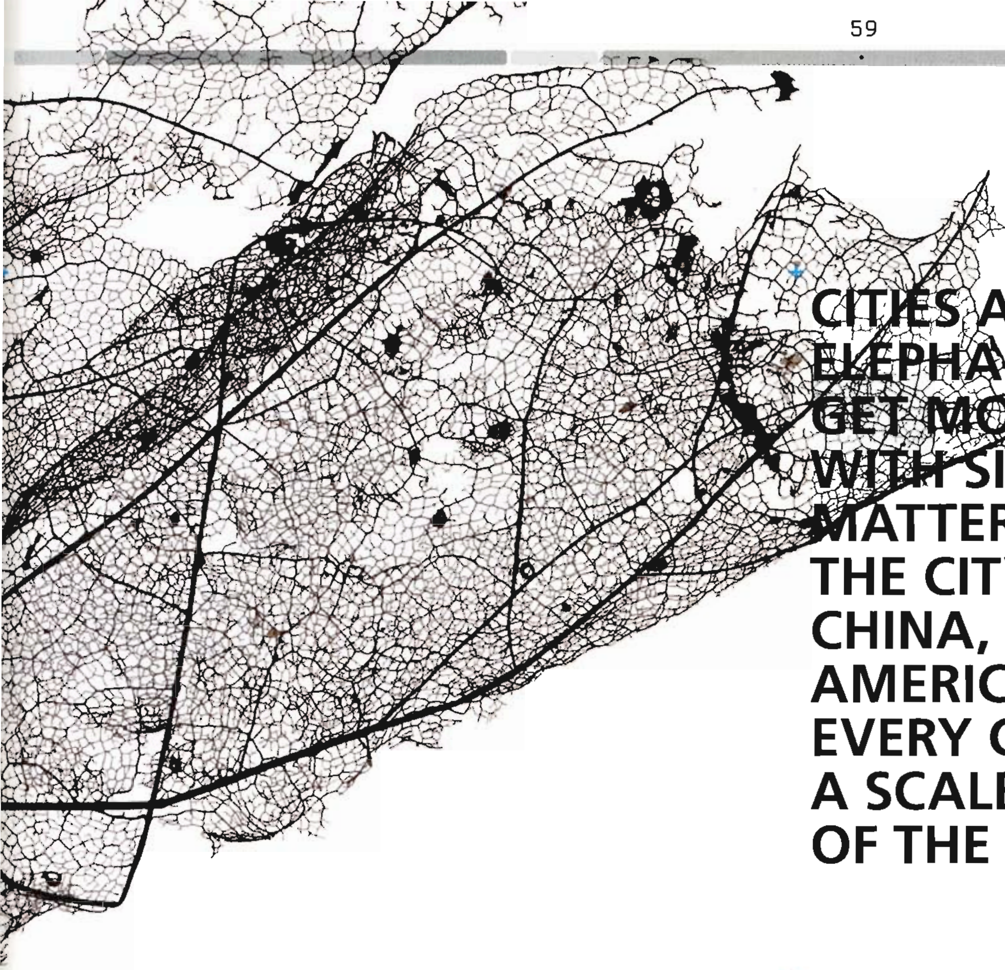
Since their first paper was published in 1997, West, Enquist, and Brown have continued to refine their model, adding variables and layers of complexity. "This work has engendered extraordinary praise and engendered a lot of hostility," West says. "There isn't a strong tradition of theory in biology—the field is still in its Copernican phase—so people always think that demonstrating a few exceptions somehow invalidates the whole theory. 'What about the crayfish?' they say. There will always be exceptions to the rule. Theories in physics have exceptions too. But that doesn't make the theory invalid."

A few years ago, West started to wonder if social organizations, like cities, could also be described with a set of simple equations. Did cities behave like living things? What were the constants of urban life? Or was each city its own city, an eminently local construction?

The first problem was finding the data. Modeling a metropolis requires a vast amount of information. "It wasn't easy to locate this stuff," says Luis Bettencourt, a physicist at Los Alamos and a lead researcher on the project. "We ended up looking at all sorts of crazy statistics. I never thought I'd know so much about the electrical consumption of German cities."

The researchers began by analyzing the data on urban infrastructure. They wanted to know if big cities were more "metabolically" efficient than smaller cities. Living things utilize economies of scale. But what about urban areas? Does efficiency scale with population?

After analyzing the statistics, the answer was clear: Cities are like elephants. They get more economical with size. It doesn't matter whether the city is located in China, Europe, or the American Midwest; every city is simply a scaled version of the same city. In metropolis after metropolis, the indicators of urban "metabolism"—like the per-capita consumption of gasoline or the surface area of roads or the total length of electrical cables—scaled to an exponent of $(\text{population})^{0.8}$, which is very similar to the biological equivalent of $(\text{mass})^{0.75}$. This means that a city can double its population without doubling its resource consumption. "One of the basic principles of cities is that it's more efficient to bring people together," West says. "You need a little bit less of everything per person. It's the exact same way in biology. As animals get bigger, they require less energy to support each unit of tissue."



CITIES ARE LIKE ELEPHANTS. THEY GET MORE ECONOMICAL WITH SIZE. IT DOESN'T MATTER WHETHER THE CITY IS LOCATED IN CHINA, EUROPE, OR THE AMERICAN MIDWEST; EVERY CITY IS SIMPLY A SCALED VERSION OF THE SAME CITY.

This simple observation has some unexpected consequences. When most of us think about environmentally friendly places, we imagine rural landscapes and bucolic open spaces, a terrain untouched by concrete. Cities, in contrast, seem like ecological nightmares. They are polluted, artificial environments where nature consists of cockroaches, pigeons, and florist shops.

But according to Bettencourt and West, the conventional wisdom is exactly backward. Cities are bastions of environmentalism. People who live in densely populated places lead environmentally friendly lives. They consume fewer resources per person and take up less space. (On average, city dwellers use about half as much electricity as people living outside the city limits.) And because efficiency scales with the size of the population, big cities are *always* more efficient than small cities. An environmentally friendly place is simply one with lots and lots of people. While rural towns might look green—all those lawns and trees are reassuring—their per-capita rates of consumption and pollution are significantly higher. The secret to creating a more environmentally sustainable society is making our big cities bigger. We need more metropolises.

Of course, cities are not simply a mass of efficient infrastructure. An urban area benefits from economies of scale, but we don't cram into cities just to save money on the electric bill. The real reason cities exist is because they further human interaction. Every metropolis represents an unprecedented density of social activity. Only ants live closer together, and ants don't have brains.

When the scientists began to analyze social phenomena in cities, the Platonic metaphor of the city-as-body broke down. They could no longer model metropolises as massive biological organisms. Instead, the team needed to come up with an entirely new set of equations.

The easiest way to grasp the difference between a city and a living thing is to observe a city street. Look at the pedestrians. They are walking fast, scurrying along the sidewalk. Everyone seems to be rushing somewhere. The data backs up the cliché: In bigger cities, people literally move faster.

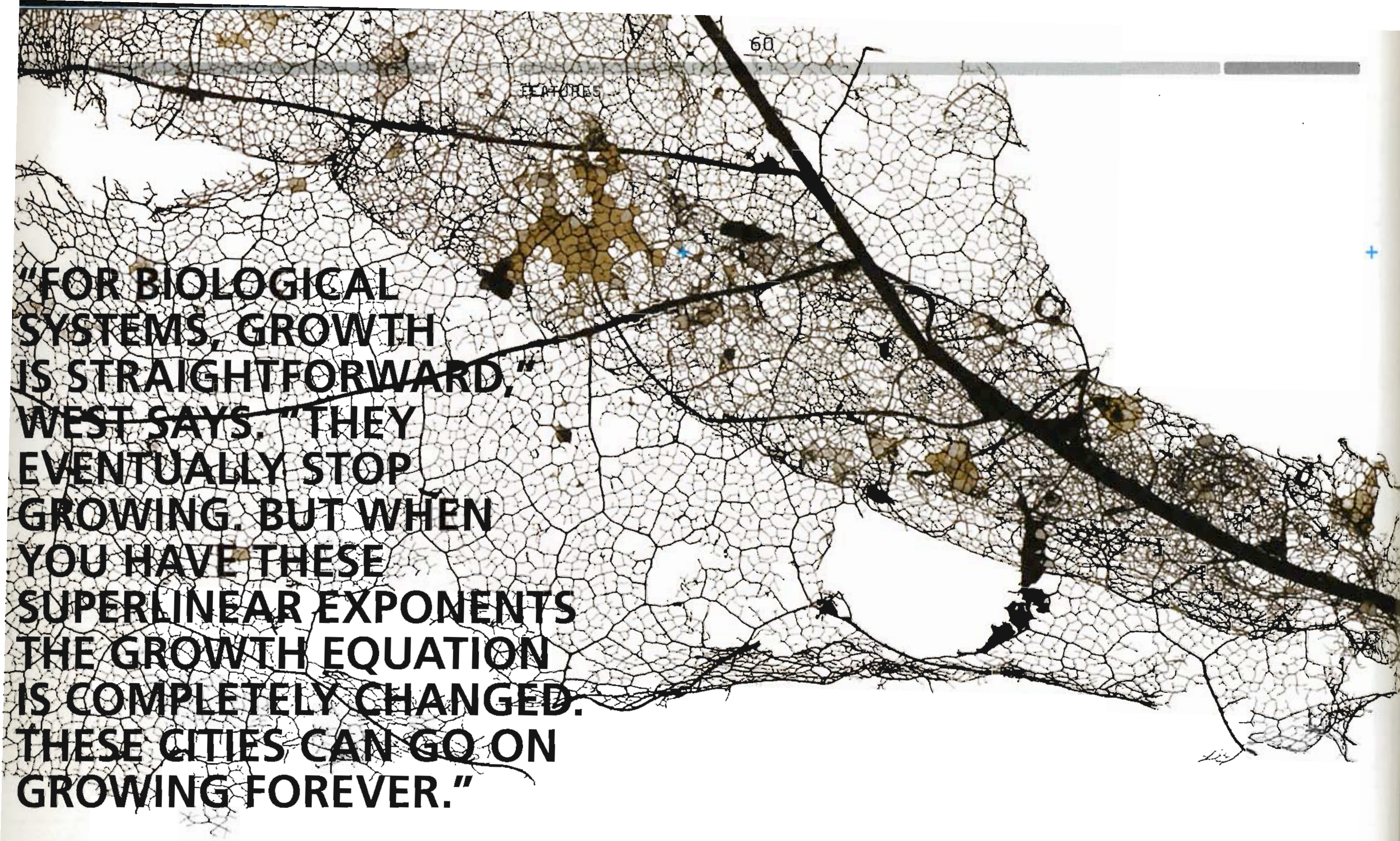
In biological systems, the opposite trend occurs. As creatures get bigger, their bodies slow down. Pulse rates decelerate. A brake is applied to the heart. This is why elephants live longer than mice: Their bodies operate at a more leisurely setting.

The fast pace of the metropolis isn't reflected only in the speed of pedestrians. When the researchers examined quantitative data that results from social interaction—these include measurements like GDP, patent filings, and wages—they discovered that, as cities got bigger, each individual got more productive. A doubling of population led to a more than doubling of creative and economic output. (The scaled equations for these social variables had exponents greater than 1.) The end result is a positive feedback loop: A bigger population means more economic activity for each person, which encourages more people to move to the city, which results in more economic activity, and so on. Imagine an elephant that never stops growing, and whose growth just encourages more growth. That's what a city is like.

"For biological systems, growth is straightforward," West says. "They eventually stop growing. Economies of scale can take you only so far. But when you have these superlinear exponents [exponents greater than 1], the growth equation is completely changed. These cities can go on growing forever."

All this potential growth has a dark side. At a certain point, every city runs out of resources. Their superlinear exponents, tilted toward infinity, collide with the practical demands of reality. The positive feedback loop exhausts itself.

How do cities deal with this dismal limitation? They *innovate*. "The only way to avoid stagnation from a shortage of resources," West says, "is to change something. You have to reset the clock, reset the initial parameters of growth. We call this an innovation cycle, and they are clearly apparent throughout history. There's the invention of the steam engine, the car, the digital revolution. What these advances all have in common is that they allowed cities to continue growing." West quotes a Bob Dylan lyric to make his point: "He not busy being born is busy dying." A city that isn't innovating is on the verge of collapse.



"FOR BIOLOGICAL SYSTEMS, GROWTH IS STRAIGHTFORWARD," WEST SAYS. "THEY EVENTUALLY STOP GROWING. BUT WHEN YOU HAVE THESE SUPERLINEAR EXPONENTS THE GROWTH EQUATION IS COMPLETELY CHANGED. THESE CITIES CAN GO ON GROWING FOREVER."

There's a disturbing wrinkle buried in this theory of growth and innovation. As the population of a city expands, each innovation has a smaller relative return. It's harder to redesign a metropolis than a small town. The end result is that the bigger a city is, the quicker it must innovate in order to continue its patterns of growth. It needs to undergo increasingly frequent periods of wrenching social change just to survive. The mathematical equations describe this acceleration—the positive exponents ensure that everything speeds up.

"You can see this trend in human history," West says. "Back in the bronze age there were thousands of years between major innovations. Then by the middle ages the pace of change was down to hundreds of years. But now we are living in an age where the time between innovations needs to be shorter than the average human lifespan. We are all going to live through multiple cycles of incredible innovation. Is this pace sustainable? What does this mean for society? Nobody knows the answer to those questions."

Cities are the driving force behind these accelerating innovation cycles, but this doesn't mean cities can take innovation for granted. According to West, they must continually nurture the institutions that make innovation possible. "Cities need to encourage companies that spend money on research and development," he says. "They need to attract universities and improve their educational system." But West notes that cities often cut back on these sources of innovation precisely when they are most needed. "A city that's going through a tough time always cuts education first," he says. "Corporations act the same way. Their first reaction to bad news is to economize, lay people off, and slash the R&D budget. But over the long term this is a bad idea, since you reduce your ability to innovate." West cites Detroit as a city that has failed to reinvent itself and suffered the consequences.

While certain institutions can foster innovation, the researchers are quick to point out that the innovative abilities of cities are ultimately rooted in the one thing that every city has in common: lots of human interaction. "Cities concentrate our social interactions," Bettencourt says, "and that's what leads to this explosion in knowledge creation and innovation."

This is a mathematical demonstration of an old idea. Jane Jacobs, in her seminal work *The Death and Life of Great American Cities*, argued that every healthy city was defined by its ability to facilitate social interaction. She saw the busy sidewalk as an improvisational "ballet," in which information freely flowed between city dwellers. Her book identified the specific urban ingredients—from short city blocks to mixed-use neighborhoods—that encouraged "the intricate mingling of diversity." When strangers were forced to communicate, Jacobs wrote, the city developed the "innate ability...to invent what is required to combat its difficulties." Interaction and innovation were intertwined.

There are many ways to define a city. From a distance, a city is simply a point in space, a grid of streets and concrete that can be fit on a map. But every city is also a collection of individuals, a pulsing mass of strangers, friends, neighbors, and lovers that never stops moving. The next step for West and his team is to figure out how, exactly, the social interactions of the urban street translate into new kinds of knowledge. While their initial work focused on discovering the universal properties of every city—what West calls "coarse-grained modeling"—their future research will require them to compare different cities with each other so that they can detect subtle correlations between variables. (The urban areas they plan to focus on include Phoenix, Detroit, and New Orleans.) Do faster pedestrians lead to more new patents? What's the relationship between population density and GDP? Are busy sidewalks good for wage growth? Just as West used fractal geometry to explain the scaling equations of life, the scientists want to understand the generic social mechanics that make urban life possible.

The elegance of this new urban science is that it reveals how these different ways of looking at a city are just incomplete glances of the same underlying dynamic. Like a living organism, the city emerges from the complex interplay of its parts. When people come together in a place that lets them interact, they create an entirely new form of life. ∞