

COMPLEXITY

The elegant law that governs us all

A physicist probes a phenomenon seen in cells, cities, and almost everything in between

By **Albert-László Barabási**

A dog owner weighs twice as much as her German shepherd. Does she eat twice as much? Does a big city need twice as many gas stations as one that is half its size? Our first instinct is to say yes. But, alas, we are wrong. On a per-gram basis, a human requires about 25% less food than her dog, and the larger city needs only 85% more gas stations.

If we double the population of a city, we also need roughly 15% fewer water pipes and electrical wires than linear thinking would predict. In other words, if you wish to live in a green city, you should forget bucolic rural settlements and consider Manhattan instead.

Moving to a city that's twice as big will not only offer you 15% more income on 15% less infrastructure, you'll also be 15% more likely to patent an invention. It is perhaps no surprise, then, that Boston, San Francisco, and New York City have emerged as the unbeatable incubators of creativity.

As Geoffrey West explains in *Scale*, the reason behind these intriguing phenomena is a universal law known as allometry—the finding that as organisms, cities, and companies grow, many of their characteristics scale nonlinearly.

West is a theoretical physicist who traded in particle physics for complex systems in 1997. He eventually landed at the Santa Fe Institute, a hotbed of complexity research, where he became an eloquent spokesman on behalf of his newfound subject.

Allometric scaling has deep roots in ecology, dating back to the century-old work of J. B. S. Haldane, D'Arcy Thompson, and Julian Huxley. Yet, for about a century, it remained a puzzling empirical observation. This changed two decades ago when West and collaborators offered the first quantitative explanation of allometric scaling. With that came a newfound enthusiasm toward the subject as researchers began discovering its relevance to everything from cities to companies.

Scale offers a fascinating journey into the genesis, applications, and implications of allometric scaling. Did you know, for example,

that regardless of size, all animals have about 1.5 billion heartbeats in their lifetime? And that thanks to this, the bigger an animal, the longer it lives? Only humans defy this law, living twice as long as allometric scaling predicts for our weight.

Readers also learn that, on average, people commute about an hour each day, regardless of city size or mode of transportation. Our walking speed, however, depends on the size of the city we live in: Big-city residents walk twice as fast as the locals of small towns, sometimes creating logjams when the two populations attempt to traverse the same streets. This observation prompted the British city of Liverpool to create fast walking lanes, offering an unobstructed path for city dwellers through the masses of leisurely visitors.

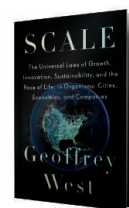
West's enduring contribution to our understanding of complex systems is his explanation of the roots of allometric scaling. He observes that complex systems—from cells to cities—require networks to ensure that every component has access to the resources needed. These networks have evolved to optimally transport resources, minimizing, for example, the energy our hearts exert to circulate blood or the time we spend traveling from work to home. In *Scale*, West patiently describes these foundational observations, eventually arriving

at the scaling laws that have resisted explanation for more than a century.

Given the central role that networks play in West's theoretical framework, it is puzzling the degree to which the narrative is divorced from network science, the field that focuses on the scaling properties of real networks. For example, a universal feature of all networks discussed in the book—from the metabolic network that supplies energy to a cell, to the social and professional networks that contribute to the amazing vitality of a big city—is the presence of major hubs that hold the smaller nodes together. Yet the scale-free property of these networks, which explains how the size of these hubs scales with the number of nodes in the

system, is never considered in allometry.

Scale offers a deeply personal narrative about the origins and evolution of allometric scaling that is enriched by West's distinctive voice. It's a journey with many fascinating digressions that do make the nearly 500-page book a true time investment. Yet, for those willing to commit, West's insightful analysis and astute observations patiently build an intellectual framework that is ultimately highly rewarding, offering a new perspective on the many scales with which nature and society challenge us. ■



Scale
Geoffrey West
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The metabolic rate of an animal that is twice the size of another is only approximately 75% greater than that of the smaller creature, an example of allometric scaling known as Kleiber's law.

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