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Say what you will about global warming or the Mona Lisa, "Apollo 9" or the canals of Venice—human beings may seem at first glance to be the planet’s most successful species, but there’s a strong case to be made for the ants. Measured by sheer numbers, ants—and other social insects such as termites—dominate the planet in a way that makes human populations look like an evolutionary afterthought. Ants and termites make up 30 percent of the Amazonian rain forest biomass. With nearly ten thousand known species, ants rival modern humans in their global reach: the only large landmasses free of ant natives are Antarctica, Iceland, Greenland, and Polynesia. And while they have yet to invent aerosol spray, ant species have a massive environmental impact, moving immense amounts of soil and distributing nutrients even in the most hostile environments. They lack our advanced forebrains, of course, but human intelligence is only one measure of evolutionary success.
All of which raises the question, if evolution didn't see fit to endow ants with the computational powers of the human brain, how did they become such a dominant presence on the planet? While there’s no single key to the success of the social insects, the collective intelligence of the colony system certainly played an essential role. Call it swarm logic: ten thousand ants—each limited to a meager vocabulary of pheromones and minimal cognitive skills—collectively engage in nuanced and improvisational problem-solving. A harvester ant colony in the field will not only ascertain the shortest route to a food source, it will also prioritize food sources, based on their distance and ease of access. In response to changing external conditions, worker ants switch from nest-building to foraging to raising ant pupae. Their knack for engineering and social coordination can be downright spooky—particularly because none of the individual ants is actually “in charge” of the overall operation. It’s this connection between micro and macro organization that got Deborah Gordon into ants in the first place. “I was interested in systems where individuals who are unable to assess the global situation still work together in a coordinated way,” she says now. “And they manage to do it using only local information.”

*Local* turns out to be the key term in understanding the power of swarm logic. We see emergent behavior in systems like ant colonies when the individual agents in the system pay attention to their immediate neighbors rather than wait for orders from above. They think locally and act locally, but their collective action produces global behavior. Take the relationship between foraging and colony size. Harvester ant colonies constantly adjust the number of ants actively foraging for food, based on a number of variables: overall colony size (and thus mouths needed to be fed); amount of food stored in the nest; amount of food available in the surrounding area; even the presence of other colonies in the near vicinity. No individual ant can assess any of these variables on her own. (I use her deliberately—all worker ants are females.) The perceptual world of an ant, in other words, is limited to the street level. There are no bird’s-eye views of the colony, no ways to perceive the overall system—and indeed, no cognitive apparatus that could make sense of such a view. “Seeing the whole” is both a perceptual and conceptual impossibility for any member of the ant species.

Indeed, in the ant world, it’s probably misguided to talk about “views” at all. While some kinds of ants have surprisingly well-developed optical equipment (the South American formicine ant *Gigantiops destructor* has massive eyes), the great bulk of ant information-processing relies on the chemical compounds of pheromones, also known as semiochemicals for the way they create a functional sign system among the ants. Ants secrete a finite number of chemicals from their rectal and sternal glands—and occasionally regurgitate recently digested food—as a means of communicating with other ants. Those chemical signals turn out to be the key to understanding swarm logic. “The sum of the current evidence,” E. O. Wilson and Bert Holldobler write in their epic work, *The Ants*, “indicates that pheromones play the central role in the organization of colonies.”

Compared to human languages, ant communication can seem crude, typically possessing only ten or twenty signs. Communication between workers in colonies of the fire ant *Solenopsis invicta*—studied intensely by Wilson in the early sixties—relies on a vocabulary of ten signals, nine of which are based on pheromones. (The one exception is tactile communication directly between ants.) Among other things, these semiochemicals code for task-recognition (“I’m on foraging duty”); trail attraction (“There’s food over here”); alarm behavior (“Run away!”); and necrophoric behavior (“Let’s get rid of these dead comrades”).

While the vocabulary is simple, and complex syntactical structures impossible, the language of the ants is nevertheless character-
ized by some intriguing twists that add to its expressive capability. Many semiochemicals operate in a relatively simple binary fashion—signaling, for instance, whether another ant is a friend or a foe. But ants can also detect gradients in pheromones, revealing which way the scent is growing stronger, not unlike the olfactory skills of bloodhounds. Gradient detection is essential for forming those food delivery lines that play such a prominent role in the popular imagination of ant life: the seemingly endless stream of ants, each comically overburdened with seeds, marching steadily across sidewalk or soil. (As we will see in Chapter 5, Mitch Resnick’s program StarLogo can also model the way colonies both discover food sources and transport the goods back to the home base.) Gradients in the pheromone trail are the difference between saying “There’s food around here somewhere” and “There’s food due north of here.”

Like most of their relatives, the harvester ants that Deborah Gordon studies are also particularly adept at measuring the frequency of certain semiochemicals, a talent that also broadens the semantic range of the ant language. Ants can sense the difference between encountering ten foraging ants in an hour and encountering a hundred. Gordon believes this particular skill is critical to the colony’s formidable ability to adjust task allocation according to colony size or food supply—a local talent, in other words, that engenders global behavior.

“I don’t think that the ants are assessing the size of the colony,” she tells me, “but I think that the colony size affects what an ant experiences, which is different. I don’t think that an ant is keeping track of how big the whole colony is, but I think that an ant in a big colony has a different experience from an ant in a small colony. And that may account for why large old colonies act different than their small ones.” Ants, in Gordon’s view, conduct a kind of statistical sample of the overall population size, based on their random encounters with other ants. A foraging ant might expect to meet three other foragers per minute—if she encounters more than three, she might follow a rule that has her return to the nest. Because larger, older colonies produce more foragers, ants may behave differently in larger colonies because they are more likely to encounter other ants.

This local feedback may well prove to be the secret to the ant world’s decentralized planning. Individual ants have no way of knowing how many foragers or nest-builders or trash collectors are on duty at any given time, but they can keep track of how many members of each group they’ve stumbled across in their daily travels. Based on that information—both the pheromone signal itself, and its frequency over time—they can adjust their own behavior accordingly. The colonies take a problem that human societies might solve with a command system (some kind of broadcast from mission control announcing that there are too many foragers) and instead solve it using statistical probabilities. Given enough ants moving randomly through a finite space, the colony will be able to make an accurate estimate of the overall need for foragers or nest-builders. Of course, it’s always possible that an individual ant might randomly stumble across a disproportionate number of foragers and thus overestimate the global foraging state and change her behavior accordingly. But because the decision-making process is spread out over thousands of individuals, the margin of error is vanishingly small. For every ant that happens to overestimate the number of foragers on duty, there’s one that underestimates. With a large enough colony, the two will eventually cancel each other out, and an accurate reading will emerge.

If you’re building a system designed to learn from the ground level, a system where macrointelligence and adaptability derive from local knowledge, there are five fundamental principles you need to follow. Gordon’s harvester ants showcase all of them at work:
More is different. This old slogan of complexity theory actually has two meanings that are relevant to our ant colonies. First, the statistical nature of ant interaction demands that there be a critical mass of ants for the colony to make intelligent assessments of its global state. Ten ants roaming across the desert floor will not be able to accurately judge the overall need for foragers or nest-builders, but two thousand will do the job admirably. “More is different” also applies to the distinction between micromotives and macrobehavior: individual ants don’t “know” that they’re prioritizing pathways between different food sources when they lay down a pheromone gradient near a pile of nutritious seeds. In fact, if we only studied individual ants in isolation, we’d have no way of knowing that those chemical secretions were part of an overall effort to create a mass distribution line, carrying comparatively huge quantities of food back to the nest. It’s only by observing the entire system at work that the global behavior becomes apparent.

Ignorance is useful. The simplicity of the ant language—and the relative stupidity of the individual ants—is, as the computer programmers say, a feature not a bug. Emergent systems can grow unwieldy when their component parts become excessively complicated. Better to build a densely interconnected system with simple elements, and let the more sophisticated behavior trickle up. (That’s one reason why computer chips traffic in the streamlined language of zeros and ones.) Having individual agents capable of directly assessing the overall state of the system can be a real liability in swarm logic, for the same reason that you don’t want one of the neurons in your brain to suddenly become sentient.

Encourage random encounters. Decentralized systems such as ant colonies rely heavily on the random interactions of ants exploring a given space without any predefined orders. Their encounters with other ants are individually arbitrary, but because there are so many individuals in the system, those encounters eventually allow the individuals to gauge and alter the macrostate of the system itself. Without those haphazard encounters, the colony wouldn’t be capable of stumbling across new food sources or of adapting to new environmental conditions.

Look for patterns in the signs. While the ants don’t need an extensive vocabulary and are incapable of syntactical formulations, they do rely heavily on patterns in the semiochemicals they detect. A gradient in a pheromone trail leads them toward a food source, while encountering a high ratio of nest-builders to foragers encourages them to switch tasks. This knack for pattern detection allows meta-information to circulate through the colony mind: signs about signs. Smelling the pheromones of a single forager ant means little, but smelling the pheromones of fifty foragers in the space of an hour imparts information about the global state of the colony.

Pay attention to your neighbors. This may well be the most important lesson that the ants have to give us, and the one with the most far-reaching consequences. You can restate it as “Local information can lead to global wisdom.” The primary mechanism of swarm logic is the interaction between neighboring ants in the field: ants stumbling across each other, or each other’s pheromone trails, while patrolling the area around the nest. Adding ants to the overall system will generate more interactions between neighbors and will consequently enable the colony itself to solve problems and regulate itself more effectively. Without neighboring ants stumbling across one another, colonies would be just a senseless assemblage of individual organisms—a swarm without logic.

Gordon’s harvester ant colonies contain another mystery. If we understand how local interactions can lead to global problem-solving, we still don’t have an answer to the question of how colonies develop over time. This is one of those scientific questions
that nobody thought to ask, because the phenomenon had gone unobserved. And that phenomenon had gone unobserved because people had been thinking about ants—and watching ants—using the wrong scale. Until recently, entomologists studied colony behavior in snapshots, surveying a given nest for days or months at a time, then moving on to other nests or back to the lab. But successful colonies can live as long as fifteen years—the life span of the egg-laying queen ant, whose demise signals the final death of the colony itself. Entomologists had been looking at individual colonies in the scale of weeks or months. But to understand how colonies develop, you needed to work on the scale of decades.

In the mideighties, when she first began doing fieldwork in Arizona, Gordon made a bold research gamble that turned out, in hindsight, to be brilliant: she decided to track individual colonies year to year, following them through their birth at the end of a successful mating flight all the way to their fifteen-year-old senescence. After a half decade or so in this time-consuming project, the results began to come in, and they were fascinating. Like a stop-motion film of a vine winding its way around a branch, Gordon’s research transformed the way that we think about ants by transforming the temporal scale with which we perceived them. The colonies cycled through a clearly defined infancy, adolescence, and mature phase over their fifteen-year existence. “I had never thought about it, or read anything about it, because without long-term data, nobody really knows the ages of their colonies,” she says now. “So it wasn’t until I had been watching the same colonies year after year, and began to be able to count how old the colonies were, that I could start to see that young colonies were more active.” As she continued her observations, a number of differences emerged between colonies of varying ages, differences that were eerily reminiscent of other developmental cycles in the animal kingdom.

For one, younger colonies are more fickle. “I’ve done experiments that mimic the kinds of changes in environment that a colony usually experiences—say, a change in the availability of food,” Gordon tells me. “If I do the same experiment week after week with older colonies, I get the same results: they respond the same way over and over. If we do the same experiment week after week with a younger colony, they’ll respond one way this week, and another way next week, so the younger colonies are more sensitive to whatever’s different about this week than last week.”

“Typical teenagers,” I say, laughing.

“Maybe.” She smiles. “And the other thing that might be more typical of teenagers would be the difference between older and younger colonies in the ways that they respond to their neighbors. Neighboring harvester ant colonies meet when foragers from the two colonies overlap and search the same places for food. If older colonies meet a neighbor one day, the next day they’re more likely to turn and go in the other direction to avoid each other. The younger colonies are much more persistent and aggressive, even though they’re smaller. So they meet one day and they’ll go right back the next day—even if they have to fight.”

The developmental cycles of colonies may be intriguing enough at face value, but consider this additional fact: while the overall colony evolves and adapts over fifteen years, the ants that make up the colony live no longer than twelve months. Indeed, the hapless male ants—who only show up once a year for the mating flight—only live for a single day. (Their life span is so abbreviated that natural selection didn’t bother to endow them with jaws to eat, since they don’t live long enough to get hungry.) Only the queen ant lasts for more than a year, and yet she does nothing but lay eggs and is entirely uninvolved with the behavior of worker ants out in the field. The colony grows more stable and less impetuous as it develops, and yet the population of the colony starts over from scratch.
EMERGENCE

each year. How does the whole develop a life cycle when the parts are so short-lived?

It would not be wrong to say that understanding emergence begins with unraveling this puzzle. The persistence of the whole over time—the global behavior that outlasts any of its component parts—is one of the defining characteristics of complex systems. Generations of ants come and go, and yet the colony itself matures, grows more stable, more organized. The mind naturally boggles at this mix of permanence and instability. We can understand it when we stumble across, say, a Tudor house in the Cotswolds whose every plank and beam and brick has been replaced at least once in its lifetime, because those bricks are being replaced by “master plann[ers]”: craftsmen or residents who know what the house itself is supposed to look like, and who deliberately follow the original blueprints. Gordon’s ant colonies are more like a house that automatically replaces its skin once a year, without anybody helping out. Or better yet, given that ant colonies grow more durable over time, it’s like a house that spontaneously develops a sturdier insulation system after five years and sprouts a new garage after ten.

The ant colony may amaze us with its capacity to grow and evolve while discarding entire generations of worker ants, but as it turns out, we’re not all that different from social insects like ants, termites, or bees. As the science writer Matt Ridley observes, “The relationship between body cells is indeed very much like that between bees in a hive. The ancestors of your cells were once individual entities, and their evolutionary ‘decision’ to cooperate, some six hundred million years ago, is almost exactly equivalent to the same decision, taken perhaps fifty million years ago by the social insects, to cooperate on the level of the body; close genetic relatives discovered they could reproduce more effectively if they did so vic-

ariously, delegating the task to germ cells in the cells’ case, or to a queen, in the case of bees.”

The human body is made up of several hundred different types of cells—muscle, blood, nervous, and so on. At any given time, approximately 75 trillion of these cells are working away in your body. In a very real sense, you are the sum of their actions; there is no you without them. And yet those cells are dying all the time! Thousands probably died in the time it took you to read the last sentence, and by next week, you will be composed of billions of new cells that weren’t there to enjoy the reading of that sentence, much less enjoy your first step or your high school prom. Cells are dying all the time in your body—and most of them are being replaced at a tremendous clip. (Even brain cells turn out to regenerate themselves far into adulthood.) And yet somehow, despite that enormous cellular turnover, you still feel like yourself week to week and year to year. How is this possible?

Some readers might be inclined to object to this point that humans are in fact closer to that endlessly rebuilt Tudor house than an ant colony, because in the case of human development we do have a master planner and a blueprint that we can follow: those coils of DNA wrapped neatly in every cell in our body. Our cells know how to build our bodies because natural selection has endowed them with a meticulously detailed plan, and has seen to it that 75 trillion copies are distributed throughout our bodies at any given time. The tyranny of DNA would seem to run counter to the principles of emergence: if all the cells are reading from the same playbook, it’s not a bottom-up system at all; it’s the ultimate in centralization. It would be like an ant colony where each ant started the day with a carefully planned agenda: forage from six to ten; midden duty until noon; lunch; and then cleanup in the afternoon. That’s a command economy, not a bottom-up system.

So does this mean our genes are secret Stalins, doling out the
fixed plan for growth to the Stakhanovites of our cells? Are we more like a socialist housing complex than an ant colony? No one questions that DNA exerts an extraordinary influence over the development of our cells, and that each cell in our body contains the same genetic blueprint. If each cell were simply reading from the chromosomal playbook and behaving accordingly, you could indeed make the argument that our bodies don't function like ant colonies. But cells do more than just follow the dictates of DNA. They also learn from their neighbors. And without that local interaction, the master plan of our genetic code would be utterly useless.

Cells draw selectively upon the blueprint of DNA: each cell nucleus contains the entire genome for the organism, but only a tiny segment of that data is read by each individual cell: muscle cells read from the lines of code that concern muscle cells, while blood cells consult the passages that relate to blood cells. This seems simple enough, until you ask the question, how did a muscle cell get to be a muscle cell in the first place? And that question underlies one of the most fundamental mysteries of emergence, which is how complicated organisms, with a wide variety of building blocks, can develop out of such simple beginnings. We all start life as a single-celled organism, and yet by the end of our development cycle, we're somehow composed of two hundred variations, all intricately connected to one another, and all performing stunningly complex tasks. How does an egg somehow know how to build a chicken?

The answer is not all that different from the solution that ant colonies rely on. Cells self-organize into more complicated structures by learning from their neighbors. Each cell in your body contains an intricate set of tools for detecting the state of surrounding cells, and for communicating to those cells using various chemical messengers. Where ants used pheromones to inform each other of their activities, cells communicate via salts, sugars, amino acids— even larger molecules such as proteins and nucleic acids. The messages are partially transmitted through cell "junctions," small passageways that admit molecules from one cell's cytoplasm to another. This communication plays an essential role in all cellular activity, but it is particularly critical for embryonic development during which a single-celled organism self-organizes into a mouse or a roundworm or a human being.

We all begin life as a single-celled embryo, but seconds after conception, the embryo divides itself into two compartments: a "head" and a "tail." At that point, the organism has joined the ranks of multicellular life, being composed now of two distinct cells. And those two cells—the head and the tail—have separate instructions for growth encoded in their DNA: one cell turns to the "head" chapter, the other to the "tail" chapter. At this early stage of development, the instructions follow a predictable pattern: divide into another "head" and "tail." Thus, in the second round of embryonic development, there are four cells: the head of the head, the tail of the head, the head of the tail, and the tail of the tail. Those four units may not sound like much, but this cycle of cell division continues at a blistering clip. A frog embryo self-divides into nearly ten thousand cells in a matter of hours. The runaway power of geometric progression is not just a mathematical oddity—it is also essential to the very origins of life.

Once the embryo reaches a certain size, cell "collectives" start to form, and here matters get more complicated. One group of cells may be the beginning of an arm, while another group may be the first stirrings of the brain's gray matter. Each cell has somehow to figure out where it is in the larger scheme of things—and yet, like the ants, cells have no way of seeing the whole, and they have no fixed address stamped upon them when they come into the world, no factory serial number. But while cells lack a bird's-eye view of
the organism that contains them, they can make street-level assessments via the molecular signals transmitted through the cell junctions. This is the secret of self-assembly: cell collectives emerge because each cell looks to its neighbors for cues about how to behave. Those cues directly control what biologists call “gene expression”; they’re the cheat sheet that enables each cell to figure out which segment of DNA to consult for its instructions. It’s a kind of microscopic herd mentality: a cell looks around to its neighbors and finds that they’re all working away steadily at creating an eardrum or a heart valve, which in turn causes the cell to start laboring away at the same task.

The key here is that life does not simply reduce down to transcribing static passages from our genetic scripture. Cells figure out which passages to pay attention to by observing signals from the cells around them: only with that local interaction can complex “neighborhoods” of cell types come into being. The Nobel laureate Gerald Edelman calls this process topobiology, from the Greek word for “place,” *topos*. Cells rely heavily on the code of DNA for development, but they also need a sense of place to do their work. Indeed, the code is utterly worthless without the cell’s ability to determine its place in the overall organism, a feat that is accomplished by the elegant strategy of paying attention to one’s neighbors. As Ridley writes, “The great beauty of embryo development, the bit that human beings find so hard to grasp, is that it is a totally decentralized process. Since every cell in the body carries a complete copy of the genome, no cell need wait for instructions from authority; every cell can act on its own information and the signals it receives from its neighbors.” And so we have come full circle back to Gordon’s ants, and their uncanny ability to generate coordinated global behavior out of local interactions.

* * *

Neighbors and neighborhoods. The words seem more attached to the communities of human settlements than the microscopic domains of muscle cells or harvester ants. But how do we extend our vision up one more level on the chain of life to the cultural “superorganism” of the city? Certainly it is possible to model the behavior of cities by using the tools of swarm logic. Computer-based simulations can teach us a tremendous amount about complex systems: if a picture is worth a thousand words, an interactive model must be valued in the millions. But a quick look at the software best-seller lists will tell you that city simulations are more than just an educational device. Will Wright’s SimCity franchise has now sold millions of copies; it’s likely that the number of virtual towns created using Wright’s tools exceeds the number of real towns formed in modern human history. Some games attract our attention by appealing to our appetite for storytelling, following a linear progression of move and countermove, with clearly defined beginnings and endings; other games catch the eye by blowing things up. SimCity was one of the first games to exploit the uncanny, bottom-up powers of emergence. Wright’s genius was not simply in recognizing the fun of simulating an entire metropolis on your screen. He also hit upon a brilliant programming trick that enabled the city to evolve in a more lifelike way—a trick that closely resembles the behavior of ant colonies and embryos.

Much has been made of the fact that you can’t ever “win” at SimCity, but it’s probably more important to note that you don’t really “play” SimCity either. At least the way we talk about playing conventional games. Users *grow* their virtual cities, but the cities evolve in unpredictable ways, and control over the city’s eventual shape is always indirect. You can create commercial zones or build a highway, but there’s never a guarantee that the neighborhood will take off or the crime rate go down. (It’s far from random, of course—longtime players learn how to push their virtual citizens in certain
For most people, the sight of their first digital town sprouting upscale neighborhoods and chronically depressed slums is downright eerie, as though the hard math of the digital computer had somehow generated a life-form, something more organic and fluid, somewhere between the rigid dictates of programming and pure randomness.

How did Wright create this extraordinary illusion? By designing the game as an emergent system, a meshwork of cells that are connected to other cells, and that alter their behavior in response to the behavior of other cells in the network. A given city block in SimCity possesses a number of values—the price of the land, say, or its pollution level. As in a real-world city, these values change in response to the values of neighboring blocks; if the block to the west drops in value, and the eastern neighbor develops a higher crime rate, then the current block may well grow a little less valuable. (A sophisticated SimCity player might counter the decline by placing a police station within ten blocks of the depressed area.) The algorithms themselves are relatively simple—look at your neighbors' state, and change your state accordingly—but the magic of the simulation occurs because the computer makes thousands of these calculations per second. Because each cell is influencing the behavior of other cells, changes appear to ripple through the entire system with a fluidity and definition that can only be described as lifelike.

The resemblance to our ants and embryos is striking. Each block in SimCity obeys a set of rigid instructions governing its behavior, just as our cells consult the cheat sheet of our genes. But those instructions are dependent on the signals received from other blocks in the neighborhood, just as cells peer out through gap junctions to gauge the state of their neighbors. With only a handful of city blocks, the game is deathly boring and unconvincingly robotic. But with thousands of blocks, each responding to dozens of vari-

ables, the simulated cityscape comes to life, sprouting upscale boroughs and slums, besieged by virtual recessions and lifted by sudden booms. As with ant colonies, more is different. "Great cities are not like towns only larger," Jane Jacobs writes. "They are not like suburbs only denser. They differ from towns and suburbs in basic ways." She was writing, of course, about real-world cities, but she could just as easily have been talking about SimCity's networked algorithms, or the teeming colonies of Arizona harvester ants.

Economists and urban sociologists have also been experimenting with models that can simulate the ways that cities self-organize themselves over time. While actual cities are heavily shaped by top-down forces, such as zoning laws and planning commissions, scholars have long recognized that bottom-up forces play a critical role in city formation, creating distinct neighborhoods and other unplanned demographic clusters. In recent years, some of those theorists—not to mention a handful of mainstream economists—have developed more precise models that re-create the neighborhood-formation process with startling precision.

The economist (and now New York Times editorialist) Paul Krugman's 1995 lectures, "The Self-Organizing Economy"—published as a book the following year—include a remarkably simple mathematical model that can account for the "polycentric, plum-pudding pattern of the modern metropolis." Building on the game-theory models that Thomas Schelling developed to explain how segregated cities can form, Krugman's system assumes a simplified city made up only of businesses, each of which makes a decision about where to locate itself based on the location of other businesses. Some centripetal forces draw businesses closer to one another (because firms may want to share a customer base or other local services), and some centrifugal forces drive businesses farther apart (because firms compete for labor, land, and in some cases cus-
tomers). Within that environment, Krugman’s model relies on two primary axioms:

1. There must be a tension between centripetal and centrifugal forces, with neither too strong.
2. The range of the centripetal forces must be shorter than that of the centrifugal forces: business must like to have other businesses nearby, but dislike having them a little way away. (A specialty store likes it when other stores move into its shopping mall, because they pull in more potential customers; it does not like it when stores move into a rival mall ten miles away.)

“And that’s all that we need,” Krugman continues. “In any model meeting these criteria, any initial distribution of businesses across the landscape, no matter how even (or random), will spontaneously organize itself into a pattern with multiple, clearly separated business centers.”

Krugman even provides a chart demonstrating the city’s self-organization in time—an image that captures the elegance of the model. Scatter a thousand businesses across this landscape at random, then turn on the clock and watch them shuffle around the space. Eventually, no matter what the initial configuration, the firms will gather into a series of distinct clusters evenly spaced from each other. There’s no rule for clustering that the businesses are directly obeying; their motives are strictly local. But those micromotives nevertheless combine to form macrobehavior, a higher order that exists on the level of the city itself. Local rules lead to global structure—but a structure that you wouldn’t necessarily predict from the rules.

Krugman talks about his “plum pudding” polycentrism as a feature of the modern “edge city,” but his model might also explain an older convention: the formation of neighborhoods within a larger metropolitan unit. Neighborhoods are themselves polycentric structures, born of thousands of local interactions, shapes forming within the city’s larger shape. Like Gordon’s ant colonies, or the cells of a developing embryo, neighborhoods are patterns in time. No one wills them into existence single-handedly; they emerge by a kind of tacit consensus: the artists go here, the investment bankers here, Mexican-Americans here, gays and lesbians here. The great preponderance of city dwellers live by those laws, without any legal authority mandating that compliance. It is the sidewalk—the public space where interactions between neighbors are the most expressive and the most frequent—that helps us create those laws. In the popular democracy of neighborhood formation, we vote with our feet.

A friend of mine who moved to California a few years ago once remarked to me, with a straight face, “The class segregation in Los Angeles is not nearly as bad as you might think. You’d be surprised how many low-income areas I pass on the freeway when I’m driving into work.”

It was one of those comments that reveals an entire weltanschauung. “It’s not an encounter with the working class,” I thundered back, “if you’re gazing down at them from the overpass.” But he had a point. In a dispersed, car-centric city like Los Angeles, highways are the connecting nodes, one of the few zones where the city’s different groups encounter each other—albeit at sixty-five miles an hour.

Ever since Death and Life was first published in the early sixties, Jacobs-inspired critics have lambasted the dispersed communities of L.A. and Phoenix, and their even more anonymous descendants—the “edge cities” that have sprouted up around convenient freeway intersections or high-volume parking lots, the way towns once nestled up to harbors or major rivers. Progressive
urbanists bemoaned the mallification of the American city, with vibrant public streets giving way to generic, private shopping complexes. The sidewalk carnivalesque that had so vividly been captured by Wordsworth and Baudelaire in the previous century seemed headed the way of the horse and buggy, and in each case, the culprit turned out to be the same: the automobile, which necessitated all the injuries of sprawl—mixed-use zoning, gated communities, deserted or nonexistent sidewalks.

At the core of this lamentable transformation was the street itself, and the interactions between strangers that once took place on it. The brilliance of Death and Life was that Jacobs understood—before the sciences had even developed a vocabulary to describe it—that those interactions enabled cities to create emergent systems. She fought so passionately against urban planning that got people “off the streets” because she recognized that both the order and the vitality of working cities came from the loose, improvised assemblages of individuals who inhabited those streets. Cities, Jacobs understood, were created not by central planning commissions, but by the low-level actions of borderline strangers going about their business in public life. Metropolitan space may habitually be pictured in the form of skylines, but the real magic of city living comes from below.

Part of that magic is the elemental human need of safety. Chapter 2 of Death and Life investigates the way dense urban settlements collectively “solve” the problem of making themselves safe, a solution that has everything to do with the local interactions of strangers sharing the public space of the sidewalks:

Under the seeming disorder of the old city, wherever the old city is working successfully, is a marvelous order for maintaining the safety of the streets and the freedom of the city. It is a complex order. Its essence is intimacy of sidewalk use, bringing with it a constant succession of eyes. This order is all composed of movement and change.... The ballet of the good city sidewalk never repeats itself from place to place to place, and in any one place is always replete with new improvisations.

After a long and wonderfully detailed portrait of one day’s choreography, Jacobs ends with one of the great passages in the history of cultural criticism:

I have made the daily ballet of Hudson Street sound more frenetic than it is, because writing it telescopes it. In real life, it is not that way. In real life, to be sure, something is always going on, the ballet is never at a halt, but the general effect is peaceful and the general tenor even leisurely. People who know well such animated city streets will know how it is. I am afraid people who do not will always have it a little wrong in their heads—like the old prints of rhinoceroses made from travelers’ descriptions of the rhinoceroses.

On Hudson Street, the same as in the North End of Boston or in any other animated neighborhoods of great cities, we are not innately more competent at keeping the sidewalks safe than are the people who try to live off the hostile turf of turf in a blind-eyed city. We are the lucky possessors of a city order that makes it relatively simple to keep the peace because there are plenty of eyes on the street. But there is nothing simple about that order itself, or the bewildering number of components that go into it. Most of those components are specialized in one way or another. They unite in their joint effect upon the sidewalk which is not specialized in the least. That is its strength.

Again, we are back to the world of the ants: random local interactions leading to global order; specialized components creating an
unspecialized intelligence; neighborhoods of individuals solving problems without any of those individuals realizing it. And safety is only part of the story: there are many “uses of sidewalks” in Death and Life, some of which we will encounter in later chapters.

The key here is that sidewalks are important not because they provide an environmentally sound alternative to freeways (though that is also the case) nor because walking is better exercise than driving (though that too is the case) nor because there’s something quaintly old-fashioned about pedestrian-centered towns (that is more a matter of fashion than empirical evidence). In fact, there’s nothing about the physical existence of sidewalks that matters to Jacobs. What matters is that they are the primary conduit for the flow of information between city residents. Neighbors learn from each other because they pass each other—and each other’s stores and dwellings—on the sidewalk. Sidewalks allow relatively high-bandwidth communication between total strangers, and they mix large numbers of individuals in random configurations. Without the sidewalks, cities would be like ants without a sense of smell, or a colony with too few worker ants. Sidewalks provide both the right kind and the right number of local interactions. They are the gap junctions of city life.

This is one of those instances where thinking about a social problem using the conceptual tools of emergence sheds genuinely new light on the problem, and on the ways it has been approached in the past. Since Death and Life, the celebration of sidewalk culture has become an idée fixe of all left-leaning urbanists, an axiom as widely agreed upon as any in the liberal canon. But the irony is that many of the same critics who cited Jacobs as the initial warrior in the sidewalk crusade misunderstood the reasons why she had embraced the sidewalk in the first place. And that is because they saw the city as a kind of political theater, and not as an emergent system. The clash and contradiction of city streets—versus the antiseptic segregations of suburbia—became a virtue in and of itself, something that people should be “exposed to” for their own good. The logic was a kind of inverted rendition of the old bromides about kids watching too much television: if people were somehow deprived of the theatrical conflicts of city sidewalks, they’d all end up hollow men—or worse, Republicans.

This turns out to be an aesthetic agenda wrapped up in a thin veil of politics. Some critics carried their paens to sidewalk diversity to laughably condescending extremes. “Poor people have taught us so much about what we know about being fully alive in public,” Marshall Berman wrote in an early-eighties essay called “Take It to the Streets.” “[They’ve taught us] about how to move rhythmically and melodically down a street; about how to use color and ornamentation to say new things about ourselves, and to make new connections with the world; about how to bring out the rhetorical and theatrical powers of the English language in our everyday talk.” Paraphrase: Those poor people have so much rhythm!

However much Berman might resist the idea, the very same morality play underlies my friend’s ode to L.A. freeway culture: both perspectives assume that seeing racial and economic diversity is intrinsically good for you, like some kind of political cardiovascular workout. From this perspective, what was laughable about my friend’s observation was the idea that he could truly take in the “melodic movements” or hear the “rhetorical” flourishes of South Central while driving on the highway. The exposure itself is assumed prima facie to be good for the soul. The only question is whether my friend was getting a big enough dosage from his car.

This is all perfectly commendable, if a little patronizing, and for all I know we might indeed turn out to be more charitable and expansive people if we encountered more diversity on our streets. But that diet has nothing to do with the Jacobs understanding of
sidewalks and their uses. According to the gospel of *Death and Life*, individuals only benefit *indirectly* from their sidewalk rituals: better sidewalks make better cities, which in turn improve the lives of the city dwellers. The value of the exchange between strangers lies in what it does for the superorganism of the city, not in what it does for the strangers themselves. The sidewalks exist to create the “complex order” of the city, not to make the citizens more well-rounded. Sidewalks work because they permit local interactions to create global order.

From this angle, then, the problem with my friend’s sojourns on the Santa Monica Freeway—and indeed the problem with all car-centric cities—is that the potential for local interaction is so limited by the speed and the distance of the automobile that no higher-level order can emerge. For all we know, there may well be something psychologically broadening in gazing out over the slums from your Ford Explorer, but that experience will do nothing for the larger health of the city itself, because the information transmitted between agents is so hamstrung and so fleeting. City life depends on the odd interaction between strangers that changes one individual’s behavior: the sudden swerve into the boutique you’ve never noticed before, or the decision to move out of the neighborhood after you pass the hundredth dot-com kid on a cell phone. Encountering diversity does nothing for the global system of the city unless that encounter has a chance of altering your behavior. There has to be feedback between agents, cells that change in response to the changes in other cells. At sixty-five miles an hour, the information transmitted between agents is too limited for such subtle interactions, just as it would be in the ant world if a worker ant suddenly began to hurtle across the desert floor at ten times the speed of her neighbors.

And so this is the ultimate lesson of Jacobs’s sidewalks, and of her way of thinking about cities as self-organizing systems. The information networks of sidewalk life are fine-grained enough to permit higher-level learning to emerge. The cars occupy a different scale from the sidewalks, and so the lines of communication between the two orders are necessarily finite. At highway speed, the only complex systems that form are between the cars themselves—in other words, between agents that operate on the same scale. Unlike the ballet of the pedestrian city, these are global patterns that would be familiar to any resident of Los Angeles. We call them traffic jams.

An important distinction must be drawn between ant colonies and cities, though, and it revolves around the question of volition. In a harvester ant colony, the individual ants are relatively stupid, following elemental laws without anything resembling free will. As we have seen, the intelligence of the colony actually relies on the stupidity of its component parts: an ant that suddenly started to make conscious decisions about, say, the number of ants on midden duty would be disastrous for the overall group. You can make the case that this scenario doesn’t apply at all to human settlements: cities are higher-level organisms, but their component parts—humans—are far more intelligent, and more self-reflective, than ants are. We consciously make decisions about where to live or shop or stroll; we’re not simply driven by genes and pheromones. And so the social patterns we form tend to be substantially more complex than those of the ant world.

Even Gordon herself is sympathetic to the objection. “In a human society, every person always thinks they know what they’re doing, even if they’re wrong,” she says to me near the end of my visit. “It’s very hard to imagine any human society in which people would go around responding to what happened at the moment without any conception of why they’re doing what they’re doing.
That’s why I’m always hesitant to make analogies from ants to people, because ants are so unlike people. In fact I think it’s the alienness of ants that makes them so intriguing.

Gordon’s caveats are important, and as we have already seen, cities involve countless elements that are the exact opposites of those bottom-up systems. (Even SimCity has a mayor!) But the fact that humans think for themselves, and the fact that city organization relies on both hierarchies and heterarchies, does not mean that Wordsworth’s “ant-hill on the plain” belongs purely to the world of metaphor. Certain key elements of traditional urban life—indeed, some of the elements that we most cherish about our cities—belong squarely to the world of emergence. What ants do and what cells do and what sidewalks do should be seen as instances of the same idea, the same activity built out of varied material, like a musical score played by different instruments. But to see beyond the objections of individual human volition, we need to think about cities on the right scale. The emphasis on free will only matters on the scale of the individual human life. We need to think about cities the way Gordon thought about ant colonies—on the scale of the superorganism itself.

The decision-making of an ant exists on a minute-by-minute scale: counting foragers, following pheromone gradients. The sum of all those isolated decisions creates the far longer lifetime of the colony, but the ants themselves are utterly ignorant of that macrolevel. Human behavior works at two comparable scales: our day-to-day survival, which involves assessments of the next thirty or forty years at best; and the millennial scale of cities and other economic ecosystems. Driving a car has short-term and long-term consequences. The short term influences whether we make it to soccer practice on time; the long term alters the shape of the city itself. We interact directly with, take account of—and would seem to control—the former. We are woefully unaware of the latter. Our decisions to shop at a local boutique or move from one neighborhood to another or even leave the city altogether are all made on the scale of the human lifetime—and usually a much shorter time frame than that. Those decisions we make consciously, but they also contribute to a macrodevelopment that we have almost no way of comprehending, despite our advanced forebrains. And that macrodevelopment belongs to the organism of the city itself, which grows and evolves and learns over a thousand-year cycle, as dozens of human generations come and go.

Viewed at that speed—the millennium’s time-lapse footage—our individual volition doesn’t seem all that different from that of Gordon’s harvester ants, each of whom only lives to see a small fraction of the colony’s fifteen-year existence. Those of us who walk the sidewalks of today’s cities remain as ignorant of the long-term view, the thousand-year scale of the metropolis, as the ants are of the colony’s life. Perceived at that scale, the success of the urban superorganism might well be the single most momentous global event of the past few centuries: until the modern era less than 3 percent of the world’s population lived in communities of more than five thousand people; today, half the planet lives in urban environments. Just as the social insects deserve to be seen as some of the planet’s most successful organisms, so too should the superorganism of the city; not necessarily because cities are more humane or civilized places, but because they have done such a good job of replicating themselves, drawing in migrant populations from around the world, and encouraging—for the most part—higher birth rates and longer life spans within their confines. You can debate the merits of the transformation, but the fact is that human life on earth now unfolds in cities more often than not. Quantitatively, we are a species of city dwellers now.

Why has the city superorganism triumphed over other social forms? As in the case of the social insects, there are a number of
factors, but a crucial one is that cities, like ant colonies, possess a kind of emergent intelligence: an ability to store and retrieve information, to recognize and respond to patterns in human behavior. We contribute to that emergent intelligence, but it is almost impossible for us to perceive that contribution, because our lives unfold on the wrong scale. The next chapter is an attempt to see our way around that blind spot.

In the final decades of the twelfth century, the Societas Mercatorum, the organization of merchants that had presided over the commercial culture of Florence for nearly a hundred years, began to break apart into splinter groups: guilds with names like the Arte di Por Santa Maria and the Arte di Calimala, structured around specific trades—blacksmiths, moneylenders, wine merchants. A few guilds incorporated diverse groups under one umbrella. One such guild, the Arte di Por Santa Maria, included both silk weavers and goldsmiths.

The creation of the guild system, by all accounts, proved to be a reorganization that literally changed the world. Historians like to talk up the aesthetic accomplishments of the Renaissance, but the guild system pioneered in Florence had as much of an impact on Western civilization as anything dreamed up by da Vinci or Brunelleschi. The gold florin, the local coin minted by the Floren-