3 Defining Cities

> The city in its complete sense, then, is a geographic plexus, an economic organization, an institutional process, a theater of social action, and an aesthetic symbol of collective unity. The city fosters art and is art; the city creates the theater and is the theater.
>
> —Lewis Mumford, "What Is a City?," 58–62

Ever since cities first emerged in ancient Mesopotamia some 5,000 years ago, they have had geographical integrity, meaning that the elements that enable them to function as integrated systems are always in close proximity. In this sense, the earliest cities, until classical times and perhaps even until the first Industrial Revolution, remained compact—limited to interactions based on reasonable walking distances where, for the most part, their populations needed to remain in close touch to function at all. Lewis Mumford, the great 20th-century historian of cities, makes this point in the essay from which we quote here, using the idea of a geographic plexus as his starting point. But he also portrays the city as much more than this. It is a social artifact as much as a geographical one, a theater of ideas where the critical mass of its population feeds upon itself to generate ever-greater diversity and potential for social and economic interaction. Cities, therefore, are not simply spatial systems, but are aspatial or even nonspatial, in that many of their attributes do not explicitly vary across space. Indeed, in the vast majority of writing about the city in documentaries and novels, the geographical dimension is often simply implicit.[1] In works of fact and fiction from Plato to Charles Dickens, from Herodotus to George Orwell, their writings about the city are more about their history and culture than their geography and economy.

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Cities are places where people come together to pool their labor in the quest for greater prosperity and engage in many social pursuits that enrich their lives. They are places where the critical mass engendered by the density of living, as well as the social interactions that increase more than proportionately as more and more people come in contact with one another, generate innovations that drive civilization forward. Cities lie at the root of how new technologies are popularized and disseminated—not invented, necessarily, but developed and spread. In his book *Triumph of the City*, Ed Glaeser celebrates the kind of diversity large cities provide:[2]

> Cities, the dense agglomerations that dot the globe, have been the engines of innovation since Plato and Socrates bickered in the Athenian marketplace. The streets of Florence gave us the Renaissance and the streets of Birmingham gave us the Industrial Revolution. The great prosperity of contemporary London and Bangalore and Tokyo comes from their ability to produce new thinking.

In this book, we need to begin by defining what a city is so that we can map out how cities of different sizes are associated with different functions. As we have seen in the last chapter, there are many more smaller cities than big cities, and thus the notion that "we will all get richer if we live in big cities" requires some unpacking. There is little doubt that although living in big cities does bring social and economic benefits, it also brings many costs and limitations on how we might behave and function. Economies of scale, sometimes called by economists increasing returns to scale, must be set against diseconomies or decreasing returns to scale. In the late 19th century, Alfred Marshall first brought our attention to such agglomeration economies and diseconomies,[3] and as our love affair with ever-bigger cities has gathered pace from the late 20th century onwards, the notion that such economies outweigh the diseconomies has gained considerable currency. However, it is by no means clear that big cities are more preferable places to live and transact business than little cities, and thus it is absolutely essential that we learn how to define a city in appropriate ways so that we can measure these kinds of attributes. Moreover, the attributes in question are far beyond the simple geography or geometry of the city in terms of its physical extent, for they depend on the myriad ways in which we connect with one another. To this end, we need to explore the different ways in which we build connections with one another as we engage in the many aspects of daily life that define how we function in different sizes of city.

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Connectivity and Hierarchy: Entangled Relations

How the elements comprising a city are connected is the all-important anchor to understanding how a city functions. These connections are not just geographical or physical but, as Mumford implies in his definition above, are also social, aesthetic, and cultural. Although the geographical definition of a city is often a good starting point, it has many characteristics that cannot be rooted primarily in geography. In fact, it is very likely that although geography has been one of the most dominant constraining factors on what constitutes a city in the past, the great transition through which we are living may well lead to cities that are not geographically connected at all. To an extent this is already the case. When people like myself spend more of their time away from their adopted city through traveling to meet like-minded colleagues, or when we engage in various transactions through email and other electronic forms of instant access that connect us to more people who are not physically near us, then the city that we inhabit has a very different extent and definition than the physical city to which we are rooted. You can see this kind of global city phenomenon with respect to the way our best universities are setting up branch campuses in world cities where there are the biggest markets for students and the largest thirst for knowledge.

In the past, we have studied cities in terms of their locations, paying much less attention to the interactions between their parts as well as to other cities of varying sizes. Even though we have recognized that traffic and land use in cities are different sides of the same coin, our focus has been much more on locations than interactions. This is changing, and the new science of cities is moving the frontier of how and what we understand cities to be into the domain of interacting systems.[4] Throughout this book, starting here, we will emphasize how important networks are—first, in terms of defining cities, and in later chapters in terms of showing how cities will function in the future as contemporary society becomes ever more digital, virtual, and physically distant but electronically connected.

At the finest scale, it is now well known that there are upper limits to the numbers of people and things to which we might be connected. Robin Dunbar's number is one such limit,[5] based on the notion that there are cognitive constraints on the number of persons one might have a stable relationship with; this number appears to be about 150. Above this figure, it

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is possible to form meaningful relationships, but it is likely that more and more constraints need to be imposed on the nature of the relationships for such levels to persist, and there is now evidence that such limits are affected by many different kinds of communication, particularly electronic. What Dunbar's number also shows is that in the smallest settlements, of up to 100 or so persons, it is very likely that most people all know one another, but as this increases to small towns over 1,000 persons, our ability to link is strongly determined by other factors.

In terms of social networks, it is well known that on average there are about six links from any person anywhere to any other. This is the so-called six degrees of separation. This "small-world" phenomenon was first demonstrated by Stanley Milgram in 1967 for the continental United States, when he posed an experiment essentially asking persons drawn at random to target someone whom they did not know in another part of the country.[6] They were then asked to try and establish contact with that unknown person by communicating with someone they thought might be nearer to the person in question, thus asking that person to pass on the message. This resulted in the conclusion that everyone seemed to be connected to everyone else by an average of six links in their network. It then followed that this number would likely remain invariant for different sizes of network, or at different levels of the geographical hierarchy, hence applying equally well to small and to large cities. There is, of course, some dispute about the generality of these relationships, with some arguing that the small-world phenomenon is a convenient "urban" myth, but it is, at least, a good basis on which to get going with respect to thinking of cities as connected systems.

As cities get larger, the number of potential connections increases as the square of the number of persons living in the city. This number is, of course, an upper limit. As we add more and more networks, and assuming that the networks are largely independent of one another (in that most use one network or another but not more than one at the same time), the number of connections still rises as the square of those who are connected. This is in effect Metcalfe's law,[7] noted in the previous chapter, but in reality, the total number of connections is limited by Dunbar's number, and the structure of those connections is dramatically simplified by the fact that the average degrees of connection or separation are something like six network links.

What all this implies is that as cities get bigger, there is an inexorable pressure to increase connections to others. This probably manifests itself in the

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kind of tensions associated with urban density, both in terms of the increasing numbers occupying the same space and increasing numbers of relationships. It is the basic argument for increasing returns to scale, and, as we will see a little later, it lies at the heart of the current fascination with scaling and qualitative change as cities get larger. Moreover, in certain cultures and economies, this is a primary thesis: that bigger cities are better in terms of the way they act as incubators and accelerators of technological progress, higher economic rewards, and more sustainable, greener, and healthier living.

Thinking of a city as a constellation of networks, which are in themselves connected by different networks, is the formal model we have in mind when we seek to define the extent of a city. One might consider the relationships formed by an individual citizen in this morass of networks as a hierarchy of sorts, if the links to those to whom that person is connected can be ordered in terms of who knows who. Constructing this morass, however, is more akin to an entangled set of hierarchies that somehow need to be simplified if we are to have any understanding of the structure of cities and who relates to whom. The simplest hierarchy was introduced in the previous chapters as a ranking of cities by their size. However, in this context, such hierarchies were simply different levels, from the largest city at the top down to many smallest cities at the bottom. The levels were not nested within one another, and our discussion of city sizes might thus be seen as a line defining the rank order. Our best definition of hierarchy within the city is easiest to visualize as smaller and smaller geographical units or communities, grouped within each higher and larger geographical level, almost like a set of Russian dolls, but with more than one doll of the same size within a doll of a bigger size. Such hierarchies are strictly ordered groups of objects nested within one another as their size decreases from the entire system down to its smallest elements. This is the familiar tree-like structure that defines our traditional and simplest conception of a hierarchy as a river-like or dendritic network. Whether or not we can simplify the city or system of cities into such ordered structures is very much an open question, because this requires the boundaries between the elements that are nested to be quite distinct—which is far from what we see in actual cities.

To best demonstrate entangled hierarchies, we can grow a city starting with its most basic elements. This is completely consistent with our view, which we emphasized in the first two chapters, that cities evolve from the bottom up. Imagine a hamlet—a couple of households who live

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as neighbors in a place where they pool their labor to create bigger farms, which in turn attract other farmsteads, which grow to form a village. The structure of these local communities develop stronger links when they are adjacent than when they are dispersed, and these structures form the rudiments of the emerging city. To serve the entire settlement, adjacent households group in communities, which offer services particular to their neighborhoods, and as the city grows, ever bigger districts and specialized centers emerge to service the entire system. If we assume the neighborhoods remain strictly separate, then a perfect hierarchy emerges that can be represented as a tree-like graph. In essence, the elements that comprise the hierarchy are all self-contained with respect to their sustainability, and if the tasks that take place to sustain this structure generate an economic surplus, one might imagine the urban structure would operate like a well-oiled machine. This is the model of a resilient system, first articulated in general terms by Herbert Simon in his wonderful paper entitled "The Architecture of Complexity," in which he argued that one needs to build small to create large, in much the same way that small cities begat large. If the small parts have a dense internal structure of connections, but a weaker lower density of interactions between them, the hierarchy that emerges is resilient to breaking down at the level of its most basic parts.[8]

This construction might sound like a machine, but it is not. In fact, what begins to happen to the originally distinct households and communities is that they establish ties in the normal ways, but then change their locations, or they redevelop their land, or they regenerate parts of their neighborhood while also attracting new populations into their own communities. The distinctiveness breaks down as people in one community associate with another and mix together, as much because they were once part of that community but also because social friendships and economic links evolve and change. Our perfect hierarchy is no longer nested, but consists of overlapping levels and linkages, which blur its edges. If the communities are geographically adjacent, they begin to overlap, but there is no reason why this model should be restricted to spatial neighborhoods. The relationships might be purely social, and although everyone exists in geographical space, the geographical dimension can be unimportant to the motivation for developing the network. This blurring of the hierarchy in cities was first articulated by Christopher Alexander in his paper "A City Is Not a Tree," where he argued that a strict, nested hierarchy was too simple a model for the way cities are

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structured and the way they have developed.[9] In fact, Alexander argued that the tree structure of the city hierarchy should be replaced by a more complicated structure, which, borrowing from mathematics, he called a semi-lattice. Alexander's thesis was that much city planning tended to simplify the world into cities composed of hierarchies, but to generate the real diversity that comprised the city—the kind of diversity Jane Jacobs and Ed Glaeser speak about in their celebrations of the richness of city life[10]—overlapping hierarchies are much better descriptors of these structures. We illustrate Alexander's varieties of hierarchy in figure 3.1.

In fact, Alexander's notion of the city as being formally represented as a semi-lattice and not a tree is a way of saying that cities are much more than hierarchies. He only assumed one kind of network, one kind of hierarchy, one kind of semi-lattice, but it is quite clear that the contemporary city is composed of multiple networks, all of which might be represented in simpler form as semi-lattices of overlapping subdivisions and subsystems. Put all these over one another and, if you can imagine them as semi-lattices, considering that there may well be links between different types of network, then entangled structures that are almost impossible to visualize emerge. Later in this chapter, we will introduce the simplest of networks to illustrate how far we have to go in defining distinct, nonoverlapping geographic communities we might take as being the right kind of elements that compose cities. How we map social networks onto economic networks, which in turn have geographic footprints, is the great challenge for a new science of cities that is theoretically consistent with what we know about how cities function economically as well as the ways in which they hold together as social artifacts.

Polis, Metropolis, Megalopolis, …

Although we will explore the actual physical form of cities—their morphology—in the next chapter, here we need to introduce the traditional form of the city from its earliest development. Since prehistory, cities have always been small, limited by how far we can walk in a reasonable time without tiring and still be able to accomplish a day's work. This has meant that cities have rarely been more than about 6 km (3.7 mi) in radius. Where they have grown to hundreds of thousands of people, which appears to have been a tiny number from classical times—Rome in the first century CE, and later Nanjing in China in the seventh and 15th centuries CE—enormous

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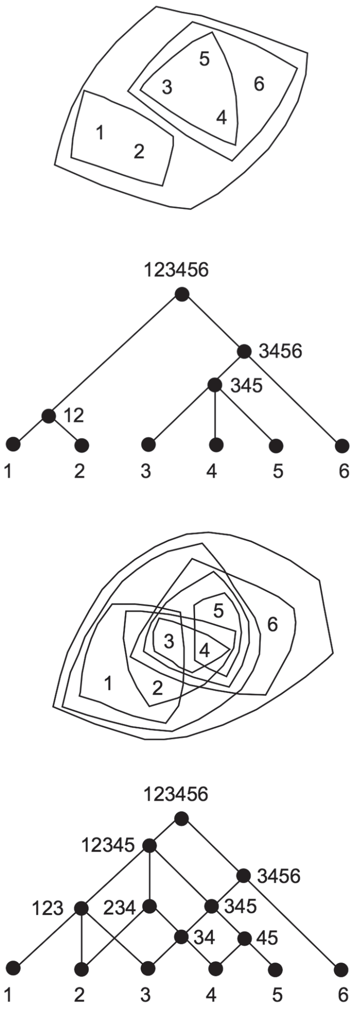

Figure 3.1
Varieties of hierarchy after Alexander (1965).

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resources and political power were required to make a functioning city possible through appropriate regulation and transportation. In fact, even the largest cities remained geographically small until the beginning of the Industrial Revolution because densities for work and living were much higher than in contemporary cities, and there was very little sprawl in the absence of machine power. Rome was only about 14 km^2 (5.4 mi^2) in area, with no more than 1.1 million population; compare this with modern-day Manhattan, which is 85 km^2 (32.8 mi^2) with a population of 1.6 million.

Cities until the 18th century were generally surrounded by walls, traditionally for purposes of defense, but also to impose some political order on societies, most of which had much less developed political and administrative systems than those of today. In fact, city walls were still being built and repaired during the early to mid-19th century before developments in the technology of warfare essentially made such defensive installations obsolete. Too, urban sprawl outside the city walls did not begin until the mid- to late 19th century, first with the arrival of heavy rail and then with the arrival of the tram and omnibus, which were quickly followed by the automobile, subway, and electric rail. During this period, heavy rail also became ever more efficient, thus allowing long-distance commuting. Until the Industrial Revolution, cities tended to be pretty similar in their economic structure, acting largely as service centers for their agricultural hinterlands or as political towns, often with capital city functions of government. Various theories of human geography, such as central place theory, developed by Walter Christaller,[11] provide explanations of how strict and less-strict distinct and overlapping hierarchies of dependent services by city size relate to this preindustrial landscape.

Insofar as scholars reflected on different kinds of town prior to the 19th century, it was the Greeks who articulated the city as a manmade artifact in describing its political and economic structure. In particular, the idea of the city, loosely called the “polis,” was used as a template for establishing various philosophies and rules of law that determined how the Greek city-state was to be governed. In many respects, the polis was small in population, little more than 10,000 persons (including citizens and slaves), and its idealized structure was designed so that an army of some 1,000 soldiers could defend the city. In fact, many cities in the ancient world had much the same structure of functions—an acropolis, usually a fortified central point designed for religious and defensive retreat; an agora, or marketplace;

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a coliseum; a gymnasium; a stadium, and so on. We do not know very much about cities that did not have the same well-defined structure as the Greek polis or the Roman castra (fortified camp), but it is likely that many cities in the past were essentially high-density slums with relatively little structure whose actual form and function have been lost in the mists of time. Many cities in this world were built and rebuilt over and over again using mud brick, and what we know very largely from archeological evidence is that excavation on a fairly dramatic scale would be required for a reasonably accurate picture of their form and structure to be revealed.

In the late 19th century, two scholars, Patrick Geddes and Max Weber, began to articulate a classification of cities that pertained to their forms and functions with respect to size and scale.[12] Weber made the key distinction between consumer and producer cities, with the former pertaining very largely to cities dominated by service provision as well as a political focus, while the latter pertained to the industrial city and cities before the Industrial Revolution dominated by trade. In fact, Weber's contribution was largely sociological, and his definition of the city tended to look back to the kinds of growth patterns that dominated the size and distribution of cities in the first and earliest stage of the Industrial Revolution.

Geddes's concern, however, was with the growth of cities and their evolution. He coined the term "conurbation" to identify systems of cities that had begun to fuse together: in today's parlance, these are polycentric forms of city that we will picture in the next chapter, when we unpack the way form follows function. In some respects, industrialized society—certainly in western Europe, and particularly Britain—was built on top of an earlier nonindustrial agricultural base, with an original distribution of market towns serving their agricultural hinterlands. In this sense, the new industrialization led to a fusing of the ancient and modern, and new industries that drew on an earlier distribution of services provided a natural backcloth for cities to fuse together as they grew. Conurbations, therefore, were not formed by urban sprawl which came much later.

In fact, Geddes defined a conurbation as something a little more than simply a fusion of originally freestanding towns and cities. He wrote: "Some name for these city regions, these town aggregates, is wanted. Constellations we cannot call them; conglomerations is, alas, nearer the mark at present, but it might sound unappreciative; what of 'Conurbations?' That perhaps may serve as the necessary word, as an expression of this new form

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of population-grouping, which is already, as it were sub-consciously, developing new forms of social grouping." This was particularly perceptive of Geddes, for throughout his century and into our own, the massive and dramatic growth and fusion of settlements into one another—which are conurbations—has become the dominant pattern. In fact, Geddes went much further in his speculation of city forms. He resurrected the old word "heptarchy"—the original seven kingdoms of England—to refer to conurbations joining together, as indeed they have done in Britain during the 20th century. He thence coined the term "world city" for these city regions, a term that has massive resonance in terms of the way cities are now being connected using new information technologies.[13]

Geddes also introduced the term "megalopolis," which he implied is a fusion of fusions—cities as much connected by sprawl as by their aggregation at the metropolitan scale. His arguments about the growth of cities did much to anticipate the study of urbanization and the growth of world cities during the past century, but his was a less than completely optimistic view of urban growth, which he considered to be largely out of control. It was left to Lewis Mumford, however, his one-time disciple, to really lay out this classification of an urban future, which was even gloomier than Geddes originally anticipated. By the middle of the 20th century, Mumford was arguing that urban sprawl, which had led to megalopolitan regions such as the northeast seaboard of the United States, was running into an economic and social decline whose form and function would accelerate apocalyptic collapse. Much of this is elaborated in his book *The Culture of Cities*, which contains his own views about the future of technics and civilization. Jacobs violently disagreed with his somewhat dark view, saying this particular book "was largely a morbid and biased catalogue of ills."[14] But the term megalopolis has been used by several others, such as Jean Gottmann, whose study of the northeast seaboard is a considerably more optimistic vision of this urban future.[15] This is also the case with Constantinos Doxiadis's view of the urban future: he speculated that the world's population will reach 50 billion by the end of this century and that the future will be composed of a worldwide city, which he called an "ecumenopolis."[16]

Doxiadis is one of the few scholars to define a complete progression of city types by size, which is worth listing, for it serves to give some substance to our verbal vision of how cities change as they grow. His continuum of populations is: *anthropos*, 1 person; *room*, 2; *house*, 5; *hamlet*, 40; *village*,

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250; *neighborhood*, 1,500; *small polis* (town), 10,000; *polis* (large town/city), 75,000; *small metropolis*, 500,000; *metropolis*, 4 million; *small megalopolis*, 25 million; *megalopolis*, 150 million; *small eperopolis*, 750 million; *eperopolis*, 7,500 million; and, lastly, *ecumenopolis*, 50,000 million—the entire population of the earth, as predicted back in 1976. It is instructive to note that when Doxiadis speculated about the future of cities nearly 50 years ago, the general view was one of dramatic population growth, which many then considered to be unsustainable, echoing the Malthusian predictions for the mid-20th century described in the previous chapter.

Urban Clusters as Cities

The message in the last chapter, however, was that by the end of this century we will all be living in cities of one form or another. Doxiadis's notion that this would be an *ecumenopolis*, one physical entity or superorganism that connects everyone physically, is one vision of this future. Burdett and Sudjic,[17] following in Doxiadis's tradition, call this *The Endless City* in their book of the same name. Brenner and Schmid[18] broaden this image to one of *planetary urbanization*, embracing a much more differentiated "cityness" in which urbanization is largely defined by global connectivity. Although such a connected entity is unlikely (for obvious physical reasons pertaining to the impossibility of building everywhere), the idea that cities are merging into one another, creating forms that are bigger than anything we have considered possible hitherto, increases our need for clear and unambiguous definitions of where cities begin and end in the many dimensions they embody. The largest city in the JRC database used in the last chapter reveals that this is the megalopolis that covers the Pearl River delta in southeastern China, where continuous urban development links the cities of Hong Kong and Guangzhou, embracing Macao, Zuhai, Dongguan, and many other towns within this urban constellation.

This urban cluster now contains some 46 million people. Go back 30 years, and this entity barely existed, its cities then comprising no more than 12 million. If you took the Kowloon Canton Railway from Hung Hom in Hong Kong-Kowloon, it would take about 40 minutes to reach the border with China, but from thereon, the railway ran through a different world of paddy fields and villages until, three hours later, it reached Guangzhou, which was a city of bicycles. Now you can take the metro from Hong Kong to Lo Wu on

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the border and transfer to one of the many high-speed “bullet” trains that crisscross the delta. These trains and all the related infrastructure that has been ploughed into this largest urban agglomeration the world has yet seen is continually increasing the accessibility of every part to every other. The fastest trains take 40 minutes to reach Guangzhou, which is now an entirely modern metropolis whose growth shows little sign of slowing down.

The emergent megalopolis plotted from the JRC data is shown in figure 3.2, where is it eminently clear how difficult it is to partition this agglomeration into distinct clusters which form a clear hierarchy. We have argued that defining cities involves more than merely using geometry and geography to determine where the city begins and ends, and this is entirely consistent with the sentiments of Jacobs, Mumford and Glaeser alluded to earlier. In fact, if you look closely at figure 3.2, it is well nigh impossible to separate individual cities from one another as quasi-independent clusters on the basis of comparing their densities with the rural hinterland. Moreover, although this massive urban entity is connected physically, it is clear from any casual knowledge of how people function in this region that its

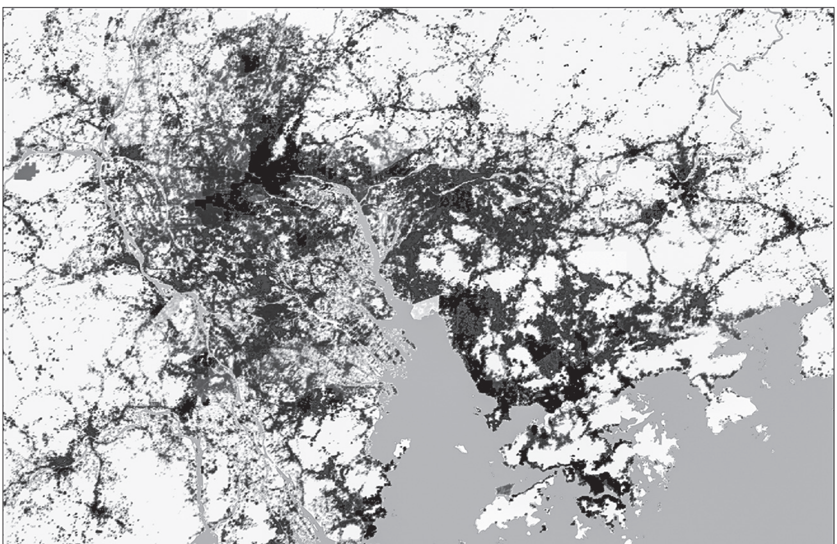

Figure 3.2
Clusters comprising the largest urban agglomeration.

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component parts are individual cities that need to be considered separately for many purposes. Physical connection does not necessarily mean that all those components that connect up with one another form part of the same entity, for it necessary to disentangle function from form. Arguably, if all the pieces making up figure 3.2 were connected by substantial physical flows, illustrating the interdependence of economic activity in various locations, there might be a case for thinking of the entire entity as a single city. Or, if this were not the case, but the flows were electronic, then there is some sense in which the entire agglomeration might be treated as one mass. But the definition of individual and distinct urban clusters is more complex, and we need to be very clear about the rules for breaking up the urban mass into its component parts—cities, if you like—that make sense for purposes of measuring their various attributes.

There are three key criteria that arise time and again in defining cities. The first is density, as measured by the numbers of persons per hectare (or acre), as for example illustrated in figure 3.2. The second is some measure of interaction or dependence of any one area on another, meaning the strength of the links between aggregate populations or individuals over the whole geographical space. These interactions are usually measured in terms of material flows, such as people making the journey to work; commodity flows between different industrial areas; and even migration movements within the residential sector. As we will elaborate in the chapters that follow, electronic linkages and flows are of utmost importance in broadening our definition of cities away from the purely geographical. In fact, in this chapter, although our definition will seek to use interactions based on material and people flows, these will, in essence, be geographically grounded. The third criterion relates to geographical proximity or contiguity. The units that make up the city—whether they be individuals, households, neighborhoods, or districts—must in some sense be close to one another, notwithstanding all the potential generalizations of these definitions to nonspatial linkages and flows we will broach in later chapters.

There is quite widespread agreement about this threefold focus on defining cities with respect to densities, interactions, and contiguity or proximity (though size and political organization are also important features). Several analysts argue that, for an area to belong to a city, it must have a population density of at least 14 persons per hectare, which is 1,400 persons per square kilometer (or 540 persons per square mile). In fact, Cottineau and her colleagues[19] argue that this is a little on the low side, suggesting nearer

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2,000 persons per square kilometer (or 772 persons per square mile) is a better threshold. But much depends on culture, tradition, and the level of modernity of a place. In terms of interaction, it is commuting fields that are usually used to define a city, in that any place that has more than 20 percent of its working population traveling to work outside its residential area should be considered for inclusion in a city's area. Regarding the third criterion, contiguity, places that are within a distance threshold of some 2 km (1.25 mi) are often considered to be part of a city if—and this is a very strict rule—the place in question meets the other two criteria simultaneously. Cottineau and her colleagues then propose a simple algorithm for generating cities that meet these criteria, beginning by identifying areas or cores with the highest densities, then relaxing this to consider places that have slightly less density, are adjacent, and meet a minimum commuting threshold. If there are places that are not contiguous geographically, then the distance threshold is invoked, serving to fill in "holes" that have appeared in the fabric being generated so far. The density threshold is then further relaxed and the algorithm begins again, gradually growing the cities that have emerged until they reach the minimum density threshold of 2,000 persons per square kilometer (or 772 persons per square mile), the 20 percent commuting threshold, and all the requirements for contiguity.

There are many variants on this kind of procedure, but most follow this general form. Two related criteria—a minimum size of unit for a city and whether the derived place has any administrative integrity—are often used to structure the process, either at its start or at any point in the construction of the city area. In the United States, the Census Bureau assumes a minimum size of 10,000 persons for a micropolitan area and 50,000 for a metropolitan statistical area, while the State Council in China uses a similar definition in their designation of cities in the Peoples' Republic. The JRC data, however, is not based on a functional threshold, such as commuting, since it is initially defined from remotely sensed land cover interpretations of what is urban and rural. This is much more akin to using density as the arbiter of what constitutes a city, in contrast to the Organisation for Economic Co-operation and Development (OECD) data set, which defines what have been called functional urban regions using commuting thresholds of 15 percent.[20] As we explore in the next chapter, form and function are quite closely tied together with respect to these various definitions, although there can be substantial differences when tempered by political and administrative boundary definitions.

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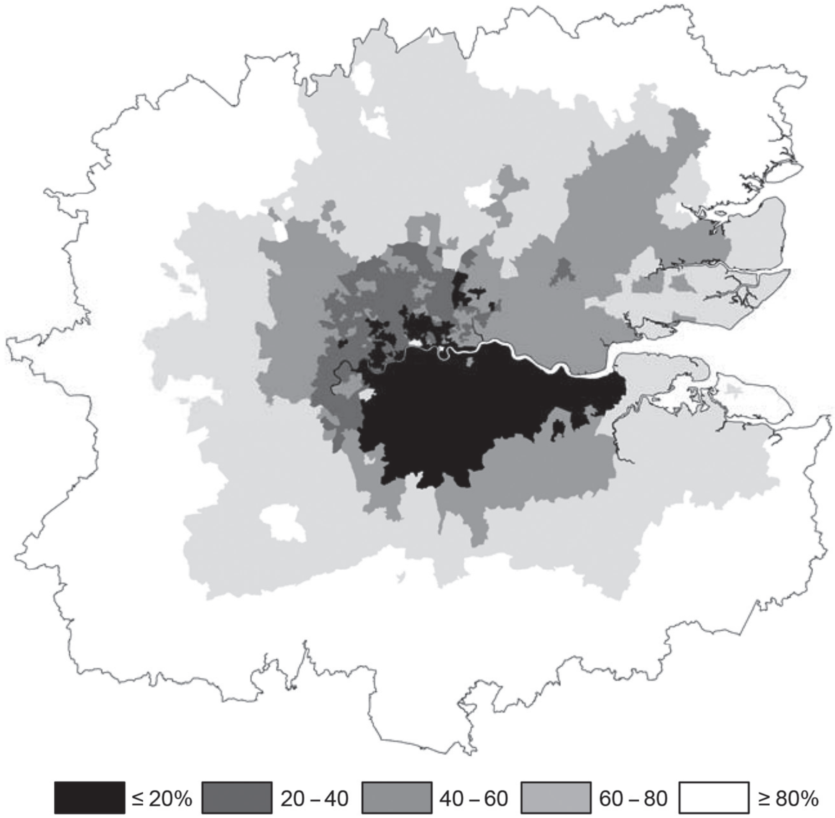

Figure 3.3
Defining greater London at different commuting thresholds.

To give some idea of the multiple boundaries that might define a large city, we will illustrate the impact of varying these criteria for defining London. Starting with a zone at the center of its central business district—in The City at St. Paul's Cathedral—we then add an adjacent zone, one that is contiguous to the zone(s) already comprising the growing mass so that the maximum amount of interaction is contained within the mass. As we add more zones, the proportion of interaction within the city rises—we are capturing more at each stage of the aggregation, and this implies we are covering more and more activity related to the city. To pursue this process, we need a much larger bounded region, and for this we take London and its outer metropolitan area. Once we have added all the zones into this growing aggregate, we cover the

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entire activity of the system. From this point, we can draw boundaries, as in figure 3.3, for 20 percent, 40 percent, 60 percent, and 80 percent of activity captured, thus embodying our two criteria of commuting thresholds and adjacency. In figure 3.3, we do not use the density criteria, but this is easy to implement as an additional filter. In the sections that follow, we will explore how to define cities in a relatively simple manner to generate cities of different sizes, enabling us to examine qualitative change in structure relative to size.

Extracting Cities from the Urban Hierarchy

Prior to the first Industrial Revolution, the iconic symbol marking the city was the pinnacle of its religious and political power: in classical times, this was the acropolis, and by medieval times in Europe, it was the cathedral. But by the third decade of the 20th century with the invention of electricity and the steel frame, the iconic image had changed to that of the skyscraper. We will say much more about skyscrapers in chapter 6, but suffice it to say that the great transition is bringing another, more abstract image of the city in its wake—the network. No longer is the city about location: it is about interaction, about networks, about how we communicate and serve the built and natural environments in terms of the resource flows that sustain the organism. It is no accident that in the last 20 years, the theory of networks has grown dramatically within science and social science. Network science is fast becoming the underpinning representation for complex systems such as cities and, in a wider context, for the economy itself.[21]

In defining cities, we can think of them as being clusters within a much wider network of city systems. Networks are graphs that are composed of nodes and links—where the nodes represent locations that interact in some manner with each other across the links. Sometimes nodes and links are called vertices and arcs, sometimes hubs and spokes, and there are yet other diverse terminologies; but all convey the notion that networks are receptacles for transmitting and receiving flows and messages. In fact, the network is a good enough representation to implement the most basic elements of city definition that we introduced above. First, nodes define locations where activity takes place—where we live, work, entertain, study, and so on—and this, in turn, defines the density of any place. The more nodes within a fixed space, the greater the density, and any casual observation of a city

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reveals that as one moves toward its traditional center, the density of nodes usually increases. Second, the links mark the channels of communication between activities, or nodes—which might be physical or electronic routes fixed in space or varying in the ether, as, for example, in wireless connectivity. These links also define the volume of flows, and might be associated with a weighted graph where the actual flow, distance, travel time, cost, and so on define the way such links are measured. Third, links anchor the city in its geometry and geography, whether they be physical or ethereal; in this regard, this method of definition relates to various thresholds that serve to tie the nodes together through different degrees of clustering. This, of course, is the essence of defining the density and physical extent of the city.

We will begin with the simplest of all networks, the one we all have direct experience of, and that is the street network. Flows on this network are people walking or cycling or contained in vehicular traffic, and all these relate to a mixture of activities taking place at different speeds. Other networks complement these physical movements at greater scales, namely railway networks and airline networks (which are not constrained by the same physical limits). To illustrate cities and the hierarchy of places of different densities and sizes, we will take the simplest street network and show how cities can be extracted from this. This network is usually available for most countries from various national mapping agencies or from crowd-sourced versions, the most popular and widespread of which is Open Street Map.[22] In Great Britain, the most detailed network is from the Ordnance Survey. In its latest release, the survey defines some 3.5 million nodes, which are street intersections, and some 8.4 million links, which are street segments of rarely less than about 100 meters (about 100 yards) in length. A measure of the network over the whole country (England, Wales, and Scotland) can be defined by simply dividing the number of links by the number of nodes. This gives an average of 2.4 links per node, showing that this is quite a low-density network overall, notwithstanding that within it strong clusters of cities stand out.

We can define these clusters by proceeding analytically from the entire network down, splitting off the biggest clusters first and eventually ending up with cities of different sizes based on the relevant clusters. Or we can proceed the other way around, building the densest clusters first and moving up the hierarchy synthetically until we have exhausted the entire network. The precise details do not need to bother us, and there are many variants of this kind of percolation analysis that lead to slightly different realizations.

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What we first do, no matter whether we start top-down or bottom-up, is to rank the links between the nodes with respect to their weight (flow), which in the example we show here is their physical distance. We then start with the smallest distance or the largest, adding nodes to form clusters from the bottom or taking them away to reveal clusters from the top. From the bottom up, we first identify the two nodes connected by the smallest distance and group these. At this first stage, we may find that we assemble chains of distances if all we do is join nodes that meet this threshold. If we find at any stage that three nodes get linked for a certain distance threshold, we then have to decide if all three have to be linked within the threshold to form the elements of a tripartite cluster (as long as we consider this to be an important requirement). In fact, given the nature of the spaces that we are working with, then sooner or later simply due to the structure of Euclidean distances, nodes that form cities will all get joined. All such methods are percolation-based, and the analogy with how we make our coffee is not lost on us in this context. A graphic of this procedure is illustrated in figure 3.4, which shows the various steps necessary to produce clusters, and this implies a method of reiterating these steps to gradually develop the entire hierarchy.

It is much easier to illustrate this method pictorially by starting with the entire graph and then decomposing it, taking the biggest distance threshold first and then relaxing the threshold, thus capturing the hierarchy of clusters that remain after each stage of thresholding. In figure 3.4, we show how we can extract a very simple hierarchy and a cluster of cities by starting at the top and gradually relaxing the distance threshold until we can go no further. What is important about this example is the fact that we can generate a very large number of clusters as we proceed. Often in a large network, there are simply too many to identify, and of course they are decomposing into ever-smaller clusters as we proceed down the hierarchy. As we are searching here for distinct cities, we do not want overlapping clusters, although the method could easily be modified to produce lattice-like hierarchies, such as that suggested by Christopher Alexander and illustrated in figure 3.1. In a world of cities where they are fusing with the urban landscape, thus becoming polycentric, it may well be necessary to consider overlapping clusters if there is ambiguity as to which node belongs to which cluster. But once again, it depends on the criteria that are used in a city's definition. So much in this world of cities is based on what we perceive as being the most intuitive way of proceeding to definitions that suit our particular purposes, and

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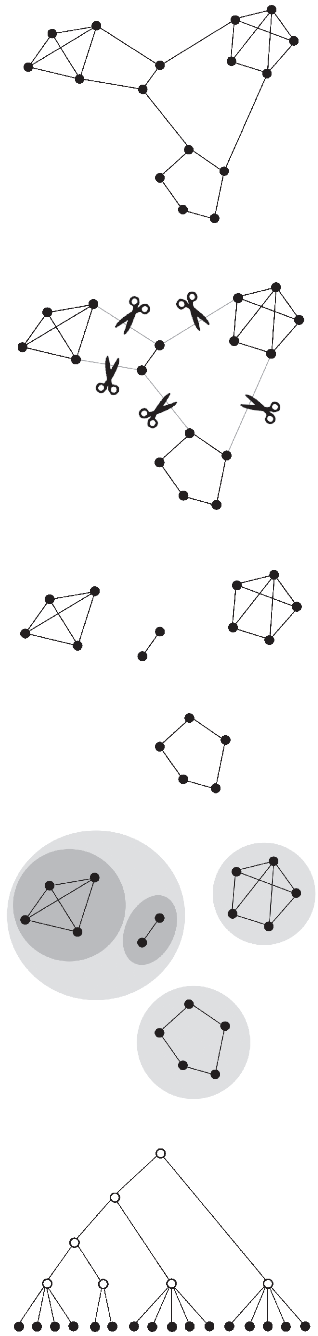

Figure 3.4
Defining urban clusters using percolation theory.

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this in turn will vary greatly dependent on context. There are many different ways of constructing hierarchies, which we report elsewhere.[23]

We can best illustrate the method using the street network data set for Great Britain. When we start with the complete graph and proceed with our percolation from the top down, we first identify all those clusters that are more than 5 kilometers (about 3 miles) distant from one another, and at these large distance thresholds all the islands (mainly off the coast of Scotland) are separated from the mainland. As we continue to relax this threshold, first the major national divisions stand out as connected clusters—the giant cluster that is urban Scotland separates first, then the hilly areas separate from one another, and eventually the country divides into the southeast of England and the now-de-industrialized heartland of the north and west. Scotland becomes separate because it was a separate national entity until some 500 years ago, but it is clear that in passing, the different regional subdivisions reveal many political and economic characteristics that pertain to the history of industrial Britain over the last 200 years. The deindustrialized areas around the major cities starkly contrast with pockets of rural wealth and poverty, the richer southeast of the country, and London. Eventually the threshold falls to 100 meters (about 100 yards), and this is almost too low to define the cities. But cities do stand out quite nicely around the 250 meter (about 275 yard) threshold. A clear picture of the hierarchy and three pictures of the key subdivisions showing the 12 largest clusters at these three threshold levels is provided in figure 3.5 (a) and (b), respectively.

The hierarchy is not as easy to interpret as one might think. As separate clusters at any level of threshold are defined, these clusters can split off from clusters already formed, and such clusters may well decompose successively—not to reveal cities, but to reveal smaller and smaller clusters that eventually fragment into hamlets and villages, missing the city stage entirely. At some point we have to decide where to end the thresholding, but if we continue it until we get the smallest segments, we then need to perform one further stage in using this model of percolation to define cities: define the thresholds that are relevant to particular cities of different sizes, noting that if one picks a threshold with a city of one size, this city might further break into quasi-separate neighborhoods as we continue the decomposition. In essence, we need to use independent criteria to decide when a city is a city. If we look again at the hierarchy in figure 3.5, we see that the nodes at each level are in fact clusters of nodes, their size

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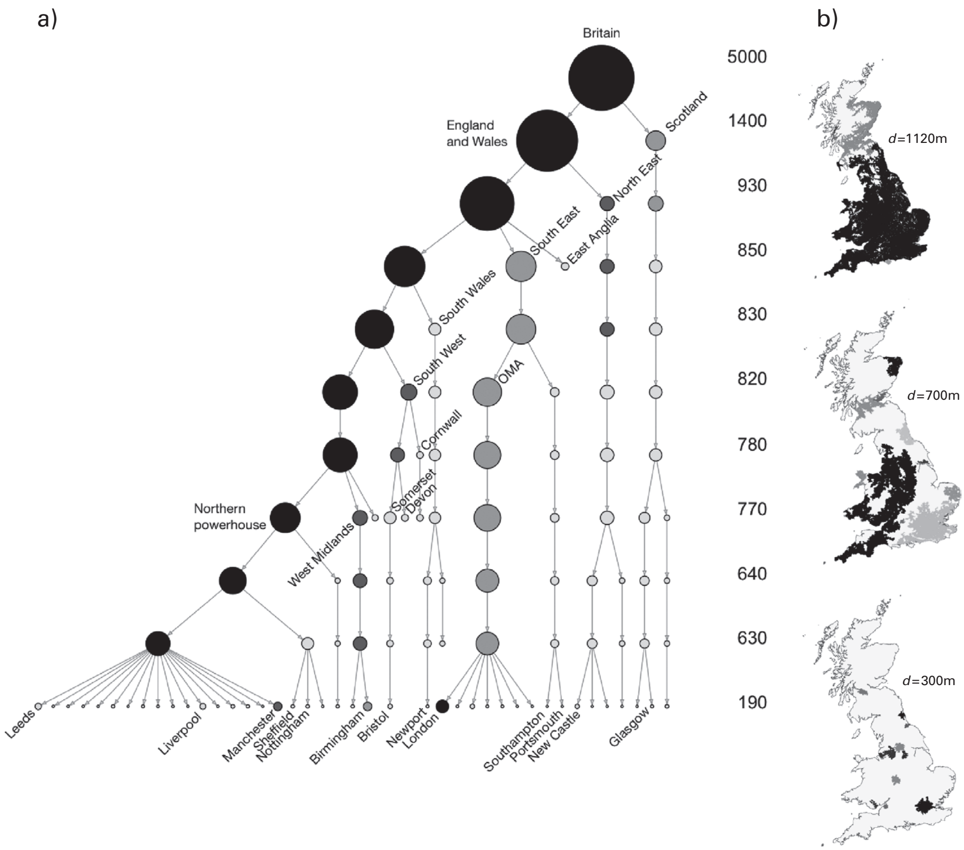

Figure 3.5

The clusters defining Great Britain from its street network: (a) the national-regional and city hierarchy; (b) sample clusters at selected levels of the hierarchy.

being proportional to the number of street intersections contained in the remaining set of connected clusters. These get progressively smaller as the threshold reduces to the succession of distances needed to support clusters at that level of threshold. Arcaute and her colleagues have presented a detailed picture of how the method can be developed and generalized.[24]

There is one last point we need to make before inquiring into what this method of definition might say about clusters within cities. This relates to political and cultural, and to some extent historical, factors. In the last couple of years, the momentum for independence in Scotland has reached an all-time high, and although the vote in 2014 for Scottish Independence

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went against the Scottish nationalists, the vote a year later in 2015 changed the political map of Scotland beyond recognition in favor of the nationalists.[25] The vote in 2016 for leaving the European Community (Brexit, so-called) again pit Scotland against the northern heartlands of England as well as peripheral areas of the country, who all voted to leave the European Union. Scotland and the cities voted to stay. The key issue in this debate is that the kind of clusters we generate as we decompose the hierarchy are persuasively suggestive of this changing political and economic landscape, with the cities standing out as distinct enclaves of cosmopolitanism and internationalism in a sea of anti-EU sentiment. The core cities appear to be enlightened in terms of the global economy, while the de-industrialized urban swathe around the core cities—who incidentally have clearly missed out on all the benefits that have accrued to ever-bigger cities this last 30 or more years—are manifestly anti-global. This is an important signpost to the future, and we will return to it implicitly in later chapters, particularly chapter 8 where we come to grips with what these city definitions tell us about the future urban world and the ways it might be segregated.

Of course, our clusters do not stop being formed or being dissolved when we reach what we consider the correct city size. If we are building clusters from the bottom up, it is the smallest components of the city that are detected first. To be recognizable and meaningful, these smallest clusters are likely to be neighborhoods, and there is a long tradition of thinking about cities as having neighborhoods—which are cohesive and impart a sense of community, while also reflecting ethnic as well as income and social class differences. Indeed, it was Jane Jacobs[26] who argued that well-functioning cities are composed of diverse neighborhoods that are not segregated by artificial barriers like streets, while at the same time are characterized by multiple land uses. The notion of partitioning cities into discrete neighborhoods was also demolished by Christopher Alexander,[27] who argued that such distinct hierarchies are entirely artificial and, even if imposed by planners, would eventually morph into much more diverse and messy kinds of structures—that is, overlapping neighborhoods, illustrated quite effectively by figure 3.1.

Again, we will comment at greater length on this in later chapters, for much segregation is generated from forces that are undesirable, such as ghettoization. Indeed, one of the classic demonstrations of how such divisions can emerge was the subject of some highly insightful work by Thomas Schelling,[28] who showed that from simple and somewhat mild preferences

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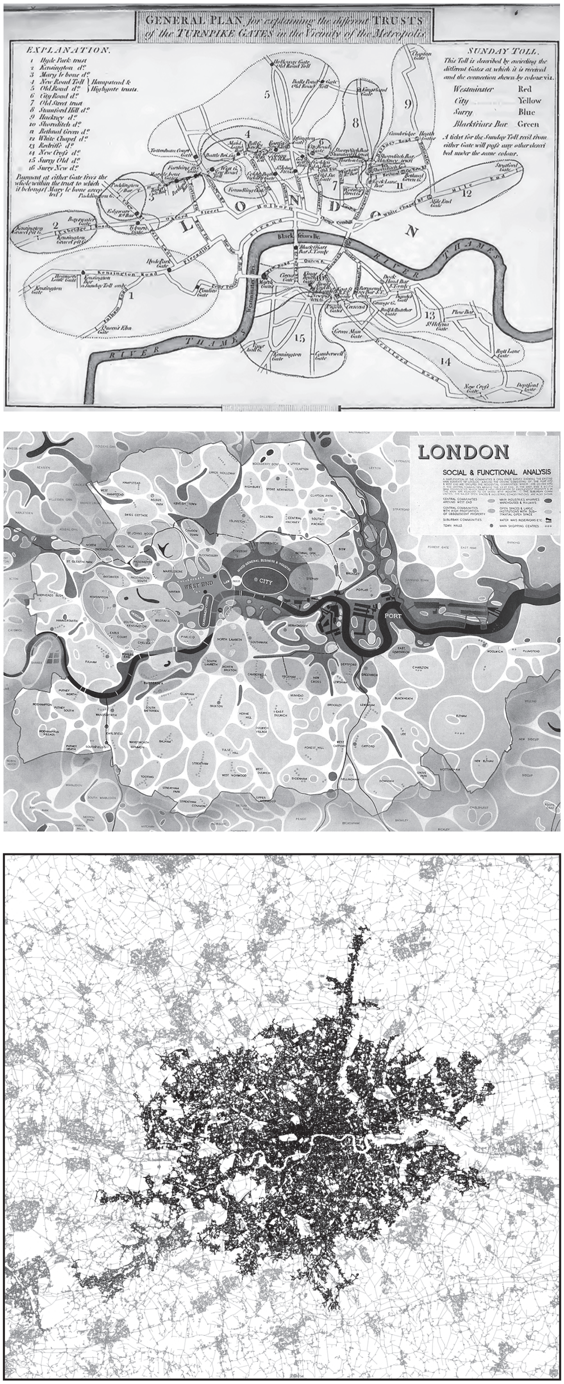

Figure 3.6
Defining neighborhoods from the bottom up: (a) Cary's map of turnpike districts in London (1790); (b) neighborhoods in Abercrombie's Greater London Plan (1945); (c) the top 12 clusters in London from bottom-up percolation.

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for being a part of a neighborhood that was more similar to one's own preferences, such diversity could soon unravel once even one person began to move. Here we will conclude by illustrating that cities can be defined as distinct and separate neighborhoods using percolation, which compare to many idealizations often used for master planning. In figure 3.6, we show Cary's (1790) map of turnpike districts in London, which are a type of geographical neighborhood,[29] alongside Abercrombie's famous map of neighborhoods in London from his *Plan for Greater London*.[30] These neighborhoods do not overlap. Next to this we show clusters built using bottom-up percolation to a particular threshold level. In each case, these neighborhoods are quite distinct. More realistic pictures, of course, which reflect the messiness of the world in terms of overlapping neighborhoods are harder to interpret, despite being more realistic regarding the blurred nature of city definitions. But, for the moment, all we have done here is show that density, distance, and contiguity represent the key forces defining cities as geographical objects.

The Central Paradox of the Modern Metropolis

Several scholars and commentators on the urban condition have drawn attention to a seeming paradox: as information technologies have enabled us to spread ourselves out and communicate globally, big cities have become more polarized. In some senses, their cores are denser, but their suburbs are more spread out. Ed Glaeser[31] refers to this as the "paradox of the modern metropolis," saying, "proximity has become ever more valuable as the cost of connecting across long distances has fallen." This "death of distance" is much more than it appears, for it is a massive stretching, a transformation that enables us to live and work anywhere, but to interact with like-minded people in pursuit of the same goals at central cores in the global urban landscape that is quickly being created, as we described earlier in this chapter.[32] In the previous chapter, we also noted that the very biggest cities were increasing in size as a proportion of the top 500, 1,000, or even 10,000 biggest cities, while the distribution of cities of all sizes was tending to flatten. It is as if all cities are becoming more competitive, whatever their size, while the biggest cities are capturing an increasing share of the world's population. The paradox between needing ever more face-to-face contact in the biggest cities and the fact that we can now communicate so easily globally is something that will dominate the urban future, as form

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becomes more detached from function and as the complexity of how we define a city as a distinct geographic object becomes ever more problematic. We will thus use Glaeser's paradox as our second generic principle to distinguish cities of the pre-industrial age from those that are fast emerging in the post-industrial, in which the roles of geometry and time are likely to be considerably more convoluted than anything we can observe in the urban past.

At this stage, before launching into a description of how form is becoming detached from function, which will occupy our concerns in the next chapter, we should say a little about how cities are exploding physically while at the same time becoming global in terms of function. There is a tendency to think that because of information technology, all the glue and cement that ties people together to accomplish joint actions in the same places is melting—that the world of the electronic cottage where we no longer interact very much physically with one another is upon us. But a little reflection on how much time we spend in our lives with our physical neighbors provides some sobering reflections. As children, our world is very small in scale, and for most of us, we really have to reach adulthood to begin to appreciate just how large the world actually is. The number of people we interact with grows from the family unit to the classroom to the club and neighborhood for the first 20 years of our lives, and the intense interactions that take place in these small physical worlds have a dominant effect on our sense of place. After we reach adulthood, these early experiences weigh less heavily as we travel more and interact within a wider world. But as a proportion of our life experiences, the importance of place continues throughout our lives. It may become less significant, but it is a powerful lever in ensuring that we retain our sense of place, making it probable that location will continue to figure in a world which is largely composed of interactions, many of them nonphysical: a speculation, of course, but one that needs to be borne in mind as we discuss our future cities.

In this chapter, we have sketched just how hard it is to define the city as a distinct physical artifact. Although we have only noted casually, in passing, that cities are multidimensional—making it virtually impossible to collapse all their variety into a single definition—we still need to do this, for it is the only way to make comparisons about cities of different sizes with different densities and growth rates. This is a book about the future, and as our ideology about how cities grow and evolve is from the bottom up (with top-down

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design being relatively modest in cities' overall evolution), a generic prediction would be that such design will itself evolve during this century. Good design should be able to begin to construct modest plans that no longer have the rigid definitions of neighborhoods, districts, and entire cities—all separate from one another—that our building in the past has assumed. The plans for ideal cities produced from classical times onward, which strictly separate functions in areal terms—just as the Abercrombie[33] (1945) plan for London did, just as Le Corbusier[34] (1929) did for his City of Tomorrow and Frank Lloyd Wright[35] (1945) did for his Broadacre City—should be a thing of the past. If we have learned anything this last century about city design and construction, it is that uniformity imposed on the future city is futile and misguided: cities evolve spontaneously through the actions of individuals adapting to the wider context and to each other. Whether this is what indeed will occur is hard to say, but to broach this question more directly, we need to explore in much more detail the form and function of existing and future cities. To this, we will turn in the next chapter.

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