Scale and Geographic Inquiry

Nature, Society, and Method

Edited by
Eric Sheppard
and
Robert B. McMaster

Blackwell
Publishing

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Dedication

This book is dedicated to the faculty, staff and students who have participated in, and contributed to the success of, the Geography Department at the University of Minnesota during its first 77 years, and to our daughters Katherine, Keiko, and Kirstin.

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Preface

The papers collected in this volume were originally commissioned as a series of public lectures celebrating the 75th anniversary of the Geography Department at the University of Minnesota during the spring of 2000. The Geography Department at the University of Minnesota is the fifth oldest in the United States, founded in 1925 by Darrell Haug Davis who had recently moved from the University of Michigan. Richard Hartshorne joined in 1924, followed by Ralph Hall Brown and Samuel Dicken, who together established Minnesota's reputation as a center for scholarship in historical, philosophical, and human geography. Hartshorne's *Nature of Geography* (1938), and Brown's *Mirror for Americans* (1941) and *Historical Geography of the United States* (1948) became classics in their fields. Major changes occurred after World War II with the retirement of Davis, the departure of Hartshorne and Dicken, and the death of Brown. Renewal of the department occurred under Jan Broek, and the intellectual leadership of John Borchert and Fred Lukermann, during which time the department expanded its scholarly profile to incorporate physical geography. John Fraser Hart, E. Cotton Mather, Philip W. Porter, Joe Schwartzberg, and Yi Fu Tuan established the department's national reputation as a center for cultural geography while Richard Skaggs and Dwight Brown established the department's biophysical program. Later, during the 1960s and 1970s the department, partially because of its situation in a thriving metropolitan region, developed considerable depth in urban geography with John Borchert and John Adams and other faculty members at the University of Minnesota. The department, now with some 22 faculty members, provides undergraduate and graduate instruction that emphasizes a broad education in human, physical, environmental geography, and geographic information science/systems, stressing both a strong theoretical and a rigorous quantitative and qualitative empirical training in the discipline. Current areas of strength include urban and economic geography, cultural geography, nature–society relations, geographic information science, GIS and society, climate and biogeography, and geographic education.

The topic of the lecture series, "Scale and Geographic Inquiry," was chosen to reflect the department's reputation as a broad-based community of geographers with an abiding interest in the nature of geographic inquiry. Geographic scale has received considerable scholarly attention across the discipline in recent years, making it an ideal focus for examining the range of geographic inquiry. We invited as speakers a mix of geographers representing the breadth of the field, each a leading researcher on questions of geographic scale over the last decade. Each author gave a lecture and an informal seminar with faculty and students, and was asked to provide a chapter for this volume. We also commissioned a chapter on scale in biogeography to balance other contributions in physical geography.

The result is a set of essays by leading researchers that demonstrate the depth and breadth of scholarship on geographic scale, which we hope provides a definitive assessment of the field and a benchmark for further work on geographic scale in and beyond geography. While we began with the idea of categorizing these essays as either human, biophysical, or methods, in fact many defy such categorization. For example, Walsh et al. (Chapter 2) embrace methods and biophysical geography, Goodchild (Chapter 7) discusses cartography and human geography, and Swyngedouw (Chapter 6) applies a human geographic approach to environmental geography. One of the distinguishing features of geography over the last 40 years, emphasized at Minnesota, has been its ability to embrace an exceptionally broad range of epistemologies, methodologies, and topics, eschewing a canonical approach to the discipline. As the chapters that follow demonstrate, this diversity can create tensions between what may appear to be fundamentally different approaches to geographic scale. Yet, as we seek to show in our introductory and concluding essays, the diversity hides considerable overlap. Geography's vitality depends on mutual respect and cross-fertilization between its different proponents, and certainly our understanding of geographic scale can only be enriched by engagement across, and not just within, the different approaches to the topic collected in this volume.

Introduction: Scale and Geographic Inquiry

Robert B. McMaster and Eric Sheppard

The concept of geographic scale has intrigued scholars from many disciplines for centuries. From science to fiction, authors have struggled with the many meanings and problems in understanding geographic scale. In his novel *Sylvie and Bruno Concluded*, Lewis Carroll (1893) provides a lay example of the importance of scale:

> "That's another thing we've learned from your Nation," said Mein Herr, "map-making. But we've carried it much further than you. What do you consider the largest map that would be really useful?"
>
> "About six inches to the mile."
>
> "Only about six inches!" exclaimed Mein Herr. "We very soon got to six yards to the mile. Then we tried a hundred yards to the mile. And then came the grandest idea of all! We actually made a map of the country on the scale of a mile to the mile!"
>
> "Have you used it much?" I enquired.
>
> "It has never been spread out yet," said Mein Herr: "the farmers objected: they said it would cover the whole country and shut out the sunlight! So we now use the country itself, as its own map, and I assure you it does nearly as well." (Carroll, 1893)

Scale is intrinsic to nearly all geographical inquiry. It has received increasing attention within geography in recent years, with significant differences in the understanding of scale emerging among the subdisciplines. Geography's cognate disciplines, including ecology, meteorology and climatology, geology, economics, sociology, and political science, also have strong interests in the concept of spatial scale. Indeed it is difficult to identify a completely "scaleless" discipline. Whereas quantum physicists deal with scaled relations between quarks, neutrons, and atoms, and medicine and the emerging work in genomics is involved with mapping and scale at the level of genes, astronomers operate at the other extreme, conceptualizing space both in terms of light-year distances and alternative geometries.

Traditionally, geographers thought about scale as predominantly a cartographic concept, where scale associates a map distance of a feature to that feature's distance on the surface of the earth. This representative fraction (RF) has become the standard method for representing this meaning of scale. As discussed below, this definition of scale is mathematical, and remains the focus of the cartographer. Robinson and Petchenik note restrictions on this focus:

> Cartographers are not concerned with mapping at all scales of spatial relation. The arrangement of the components of a molecule of DNA, for example, may obviously be "mapped"; this molecule occupies space on the earth, and such a mapping activity might seem to have a logical counterpart of the mapping of the arrangement of streets within a city. In common usage, however, such sub-microscopic mapping lies outside the activity of the cartographer, as do the scales of architectural and engineering drawing. (Robinson and Petchenik, 1976: 53)

Biophysical geographers rely heavily on mathematics, but are concerned with the ranges of "operational" scales in which processes operate, and often consider scales as nested. A classic example is a river's drainage basin, which can be subdivided into the smaller scale watershed of its tributaries, each of which can be divided again into even smaller scale watersheds of the tributaries' tributaries. "Contemporary human geographers are drawn increasingly to diverse scales of study because of the wide range of subjects they address, and also because of their use of explanatory modes in which sensitivity to scale effects is explicit, modes that themselves imply spatial meaning" (Meyer et al., 1992: 257). If biophysical geographers are concerned with the scale dependence of phenomena and processes, and with finding the principles and laws that operate at different scales, human geographers increasingly view scale more as a social construction than a concept guided by definitive laws. In this view, scale is not an externally given attribute of human processes, nor do particular processes necessarily operate at characteristic scales, making the mathematical modeling of scale problematic. Scales are thus spatially and temporally fluid. Nation states change their scale, such as when the Soviet Union subdivided or Germany reunited. Furthermore, whereas social scientists used to think of nation-states as the predominant scale at which political process govern society, it is now commonly argued that globalization has made supra and subnational scales just as important operational scales for governance.

In short, different concepts of scale are employed in geography's various subdisciplines, making any modern definition difficult. Although much has been written recently on scale in geography, there has been little attempt to integrate across these subdisciplinary perspectives. The purpose of this edited volume is to address this failure, by comparing and contrasting the different approaches within geography. In this introduction we seek to provide a context for the essays that follow by placing them within a comparative discussion of recent and contemporary thinking about scale in cartography and geographic information science, physical, and human geography. Whereas we stress here the differences that have recently emerged in conceptualizations of scale within geography, the concluding chapter of the book will seek common ground. As our concluding chapter suggests, these differences are not as stark as they at first seem, but rather are testimony to the richness of a discipline that embraces the human and natural sciences.

Cartographic Scale

Initial thinking on scale paralleled developments in mapmaking. A deterministic method of calculating scale was derived from the idea of the map as a general measurement/storage device (rather than seeing a map as a mechanism to depict some specific distribution – such as the thematic map). As the "science" of cartography emerged in eighteenth-century France with the development of modern geodesy and the creation of the first state-sponsored national map – the Carte de Cassini – the problem of measurement consumed the cartographic community. Large-scale topographic mapping required that the precise relationship between the map and earth be known. It was during this time that formalized state-sponsored cartographic scales were sanctioned, first by the French and then in other European countries. The Carte de Cassini, finished in 1789 on 180 sheets, was published at a representative fraction (RF) of 1:86,400 (and the RF value has now become the standard method for representing scale on maps). An RF value of 1:24,000 indicates that one distance unit on the map represents 24,000 units on the surface of the earth. It is a simple and very functional way to represent scale: the relationship is "unitless," in that any distance measure may be inserted (feet, meters, miles), and also intuitive. However, a serious problem is that any enlargement or reduction of the original map makes the RF value wrong – since it alters the map units without adjusting the earth units. The cartographic graphical scale (the scale bar seen on many maps) is a more reliable representation of scale because it is reduced or enlarged along with the accompanying map. Cartographers have identified three major methods for representing scale on maps: the representative fraction, the graphical scale, and the verbal statement (e.g., one inch equals one mile). All these concepts of scale in cartography, and geographic information science (GISc), are mathematical, with the "representative fraction" being the standard measure.

An interesting development in the cartographic representation of scale is the idea that, within a virtual environment, *there is no scale*. The argument is made in the geographic information science community that many computer databases are "scaleless" in that the traditional concept of scale is not meaningful for electronic data (Goodchild, this volume). Of course, one cannot ignore the fact that most of these databases were acquired from paper maps with an established scale and thus a certain intrinsic "fitness for use." An excellent example of this may be found with the United States Bureau of the Census TIGER (Topologically Integrated Geographically Referenced) files. Much of the geographical detail was geocoded from existing 1:100,000 US Geological Survey maps and thus a "fitness for use" is in "in the vicinity" of 1:100,000. A user would be unwise to map these data at either 1:50,000 or 1:500,000, because the level of geographical detail that was captured in the geocoding process is appropriate at this 1:100,000 scale. Yet the digital data themselves – the strings of *x-y* coordinate pairs stored as binary digits – have no real scale.

While topographical mapping normally occurs at a large cartographic scale (e.g., 1:24,000), much of the thematic, or special purpose, mapping starting in mid- to late-nineteenth-century Europe has been at intermediate or small scales (e.g., 1:500,000). This terminology of large and small is a major source of confusion in the understanding of cartographic scale. Mathematically, a fraction of 1:24,000 is larger than that of 1:500,000, meaning that a detailed map (say, of a village) has a smaller cartographic scale than a map of the world.

Geographers think of scale in the opposite way, however. Human geographers, for example, think about small-scale neighborhood problems and large-scale national problems, meaning that large scale refers to a large area; and small scale to a small area. The scales used by human geographers range from the human body to the globe:

- human body;
- household;
- neighborhood;
- city;
- metropolitan area;
- province/state;
- nation-state;
- continent;
- globe (all adjectives, or all verbs).

These scales have generally been thought of as nested, although the true relationships among scales are often more complicated than this. For example, the Twin Cities metropolitan area is not nested within the state of Minnesota, but stretches into Wisconsin.

A related range of spatial scales, designed for environmental health policy and research, was proposed by Sexton et al. (2002). This includes:

- personal exposure;
- city block / factory;
- city;
- state;
- country / continent;
- earth.

Operational scale

Operational scale refers to the logical scale at which a geographical process takes place (Lam, this volume). For example, the spatial mismatch theory in human geography – i.e., that American inner city residents have lost access to employment as firms moved to the suburbs – operates by definition at the metropolitan scale. In the US, the city scale is too small for examining this theory (because suburbs typically are separate municipalities), whereas the nation-state scale is too large. In the biophysical realm, stream turbulence is studied at the "reach" scale, not for the entire stream or drainage basin. Most biophysical processes operate at particular spatial and temporal scales (see Phillips, this volume), and plenty of examples can also be found in human geography. Gentrification is typically localized to small areas of the inner city, and foreign direct investment occurs at the international scale. Yet the social construction of scale means that there are many other examples where there is no characteristic operational scale (see Smith, this volume).

Spatial resolution

The terms "geographical scale" and "spatial resolution" are often conflated with one another in geography. Whereas the common definition of spatial scale deals with the geographical "extent" of a study area, spatial resolution details the granularity of the data. In nearly all geographic inquiry, it is necessary not only to select the geographical area – or scale – but also the resolution of the data to be analyzed. This is most easily explained with remote sensing data. The study of land-use/land-cover at a particular spatial scale, perhaps the Twin Cities metropolitan region, can involve different spatial resolutions of data. Possibilities include Landsat multispectral scanning imagery (79 m resolution), Thematic Mapper Imagery (30 m resolution), or SPOT imagery (10 m resolution). Each different resolution, or "grain," will likely result in a different empirical result. Similarly, census data can be analyzed at a variety of resolutions (McMaster, Leitner, and Sheppard, 1997, provide an example of how much difference this makes in analyses of environmental equity). These include county, Minor Civil Division (MCD), tract, block group, and block resolutions, and increasingly even a parcel or address level – raising many concerns about privacy. In nearly all of geographic inquiry, one must not only select the geographical area – the scale – but also the resolution of the data to be analyzed. The granularity relates to what is known as the Modifiable Areal Unit Problem (MAUP), discussed below.

Goodchild and Quattrochi (1997) discuss the relationship between scale and resolution. "Geographic scale," they assert:

> is important because it defines the limits to our observations of the earth. All earth observations must have a small linear dimension, defined as the limiting spatial resolution, the size of the smallest observable object, the pixel size, the grain of the photographic emulsion, or some similarly defined parameter. Observation must also have a large linear dimension, defining the geographic extent of the study, project, or data collection effort. There are many ways of defining both parameters, and this is one of the factors contributing to the richness of the scale issue. (Goodchild and Quattrochi, 1997: 2)

This statement relates to our own argument, where nearly all studies require a grain or resolution – the small linear dimension – and a geographic extent – or large linear dimension.

Modifiable Areal Unit Problem (MAUP)

Not surprisingly, geographers (and others) have discovered that the resolution, or grain, of the analysis can affect geographic inquiry. An analysis of poverty at the census block level, of course, will likely yield different results than at the block-group, tract, or MCD (Minor Civil Division) levels. Likewise a land-use/land-cover analysis using 10 m resolution data will likely lead to a different classification than that using remote sensing imagery at a 30 m resolution. Furthermore, as discussed later, even for a particular resolution different spatial units (e.g., different ways of grouping blocks into block groups) can result in remarkably different empirical findings (Openshaw and Taylor, 1979). Although this “discovery” seems rather intuitive, it implies that the geographic analyst faces great problems in identifying which resolution is best, or even optimal. Walsh et al. (this volume) address this very issue, and there is a growing literature on MAUP, and its effect on various types of geographical analyses.

Cartographic generalization

Cartographers have worked for centuries on determining the appropriate amount of information to include on maps of different scales. The amount of information possible at a scale of, for instance, 1:24,000, is different than the information possible at 1:500,000. The filtering of information at one scale to create a map at a smaller scale is known as cartographic generalization. For example, Hudson (1992) identifies the effect of scale on what can be depicted in a map of 5 by 7 inches:

- a house at a scale of 1:100;
- a city block at a scale of 1:1,000;
- an urban neighborhood at a scale of 1:10,000;
- a small city at a scale of 1:100,000;
- a large metropolitan area at a scale of 1:1,000,000;
- several states at a scale of 1:10,000,000;
- most of a hemisphere at a scale of 1:100,000,000;
- the entire world with plenty of room to spare at a scale of 1:1,000,000,000.

Hudson (1992: 282) explains, “These examples, ranging from largest ($1{:}10^2$) to smallest ($1{:}10^9$) scale, span eight orders of magnitude and, as a practical matter, cover the spectrum of scales at which geographers are likely to use maps.”

These differences pose the problem known as cartographic generalization: How should information on a map be simplified, or filtered, when it is redrawn at a smaller cartographic scale? The European cartographic community became aware of the generalization problem in the early part of the twentieth century. In a 1908 *Bulletin* of the American Geographical Society, the German cartographer, Max Eckert, wrote:

> In generalizing lies the difficulty of scientific map-making, for it no longer allows the cartographer to rely merely on objective facts, but requires him *(sic)* to interpret them subjectively. To be sure the selection of the subject matter is controlled by considerations regarding its suitability and value, but the

> manner in which this material is to be rendered graphically depends on personal and subjective feeling. But the latter must not predominate: the dictates of science will prevent any erratic flight of imagination and impart to the map a fundamentally objective character in spite of all subjective impulses. It is in this respect that maps are distinguished from fine products of art. Generalized maps and, in fact, all abstract maps should, therefore, be products of art clarified by science. (Eckert, 1908: 347)

By the 1970s, cartographers were hard at work attempting to "discover" a theory of map generalization, and had identified a set of fundamental elements, including selection, simplification, classification, and symbolization (Robinson, Sale, and Morrison, 1978). Selection, often considered a prior step to generalization, involves identifying which classes of features to retain. For instance, does one retain or eliminate water bodies, transportation networks, and/or vegetation on the generalized map? Simplification involves determining the important characteristics of the data, the retention and possible exaggeration of these characteristics, and the elimination of unwanted detail. Classification is identified as the ordering or scaling and grouping of data, while symbolization defines the process of graphically-encoding these scaled/grouped characteristics (McMaster and Shea, 1992).

Unfortunately, a process (generalization) that was reasonably well-understood for paper maps, and even codified in certain instances by agencies such as the United States Geological Survey, has become a classical "ill-defined" problem in the digital domain. The problem is how to identify the appropriate "techniques," or computer algorithms, to accomplish what had been for many centuries a manual process (for further detail, see McMaster and Shea, 1992; Buttenfield and McMaster, 1991). Figure Intro.1 depicts original and generalized versions of the census tracts for Hennepin County, Minnesota. The generalized version represents a simplification, where coordinate pairs that were deemed "redundant" (superfluous) for representing the shape of the line have been eliminated.

Scale in Biophysical Geography

Biophysical geographers, like earth scientists more generally, seek to account for the spatial dynamics of complex ecological, meteorological, climatic, and geomorphic systems. As the essays in this book illustrate, biophysical geography differs from the earth sciences in giving more attention to human–environment relations. Yet they share a concern for constructing general explanations, rooted in positivist or realist philosophies, and for integrating temporal and geographic scale (Rhoads and Thorn, 1996; Richards, Brooks,

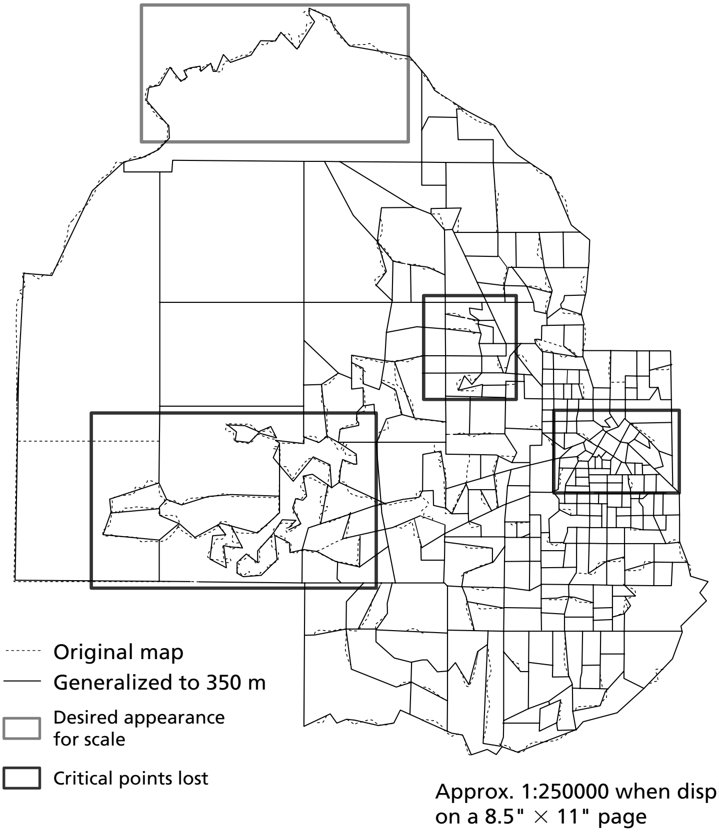

Figure Intro. 1 *Effects of uniform generalization: Douglas–Peucker Algorithm.*

Clifford, Harris, and Lane, 1997; Phillips, 1999). Jonathan Phillips (1997: 99) argues that research on scale in the earth sciences addresses four kinds of issues:

- *identifying and measuring* the range of spatial and temporal scales, and the *characteristic* (operational) *scale* of particular processes;
- *reconciling* the scales of processes with those of observation and measurement;
- issues of *dimensionality and similarity* – addressing ranges of scales across which relationships are constant, or where straightforward rules for down- or up-scaling can be derived;
- operational problems of *scale linkage* – carrying out cross-scale analysis, in situations where relationships vary across scales (*multiscale analysis*, Wilbanks, 2001).

This list indicates the importance of keeping in mind a multiplicity of temporal and spatial scales. Biophysical phenomena vary from highly localized and very fast processes, such as stream eddies of air turbulence, to very large-scale long-term process like climate change. This can pose significant challenges for mapping (Ziegler et al., this volume), and analyzing (Phillips, this volume) biophysical processes. As Bauer, Veblen, and Winkler (1999: 681) note, developing explanations at these very different temporal and spatial scales poses distinct methodological and philosophical problems: "A fundamental question to be addressed in this regard is whether there is an irreducible incommensurability to nature when viewed and described at different scale levels.... Does this imply that there may exist different levels of understanding, each with its own complexities and fundamental laws?" They continue:

> At the smallest scales, scientists have tended to favor concisely expressed, deterministic relations that invoke force balances or conservation principles (of mass, momentum, vorticity, entropy, or energy). At intermediate scales, much of the mathematical formality is retained, but some of the deterministic physics or chemistry are replaced by parameterizations that invoke constitutive coefficients or various other coefficients of bulk behavior...At the largest scales, descriptions of system behavior often assume probabilistic properties or an idiographic and historical character, although exceptions exist (e.g., General Circulation Models). (Bauer, Veblen and Winkler, 1999: 682)

In trying to simplify cross-scale analysis, physical geographers turn to hierarchy theory (see Easterling and Polsky, Phillips, and Walsh et al., this volume).

Hierarchy theory

In trying to make sense of this complexity, biophysical geographers often turn to hierarchy theory – an idea pioneered in ecology (Levin, 1992). According to hierarchy theory, nature subdivides itself into a hierarchical system with both a vertical structure of levels, and a horizontal structure of "holons" (Figure Into.2a). Holon derives from the Greek for whole (*holos*) and part (*on*), conveying the idea that subsystems at any level act as wholes with respect to lower levels of the hierarchy, but are parts of units at higher levels. By definition, interactions are significantly stronger both within holons than between holons at a particular level, and within a level rather that across the "surfaces" separating levels. Furthermore, each level can be distinguished from others by its time and space scale: Processes at lower

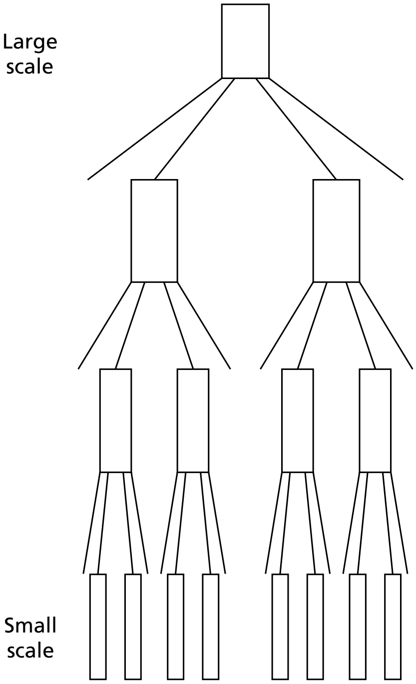

Figure Intro. 2a *Hierarchy theory: the arrangements of scales and spatial units.*

levels occur both more rapidly and across smaller spatial scales than those at higher levels.

Hierarchy theory has several implications for scale and geographic inquiry in biophysical geography. First, natural phenomena can be separated according to distinctive time and space scales (Figure Intro.2b). Second, it follows from this that different processes can indeed be expected to have characteristic spatiotemporal scales at which they operate – the previously mentioned "operational scale." Third, this implies that multiscalar analysis can be dramatically simplified (indeed Wu, 1999, argues that without hierarchy theory little simplification is possible). In particular, when analyzing any particular level the processes operating at the next higher scale can be regarded as constraints. They are so much slower, and show so little spatial variation at the scale of analysis, that they can be treated as constants. Processes operating at the next lower scale are conceptualized as driving change at the scale of interest, but run so much more quickly that they can be regarded as having reached an equilibrium state. This means that they can be approximated as fixed initial conditions for the purposes of modeling change at the scale being studied. Wu concludes that hierarchy theory