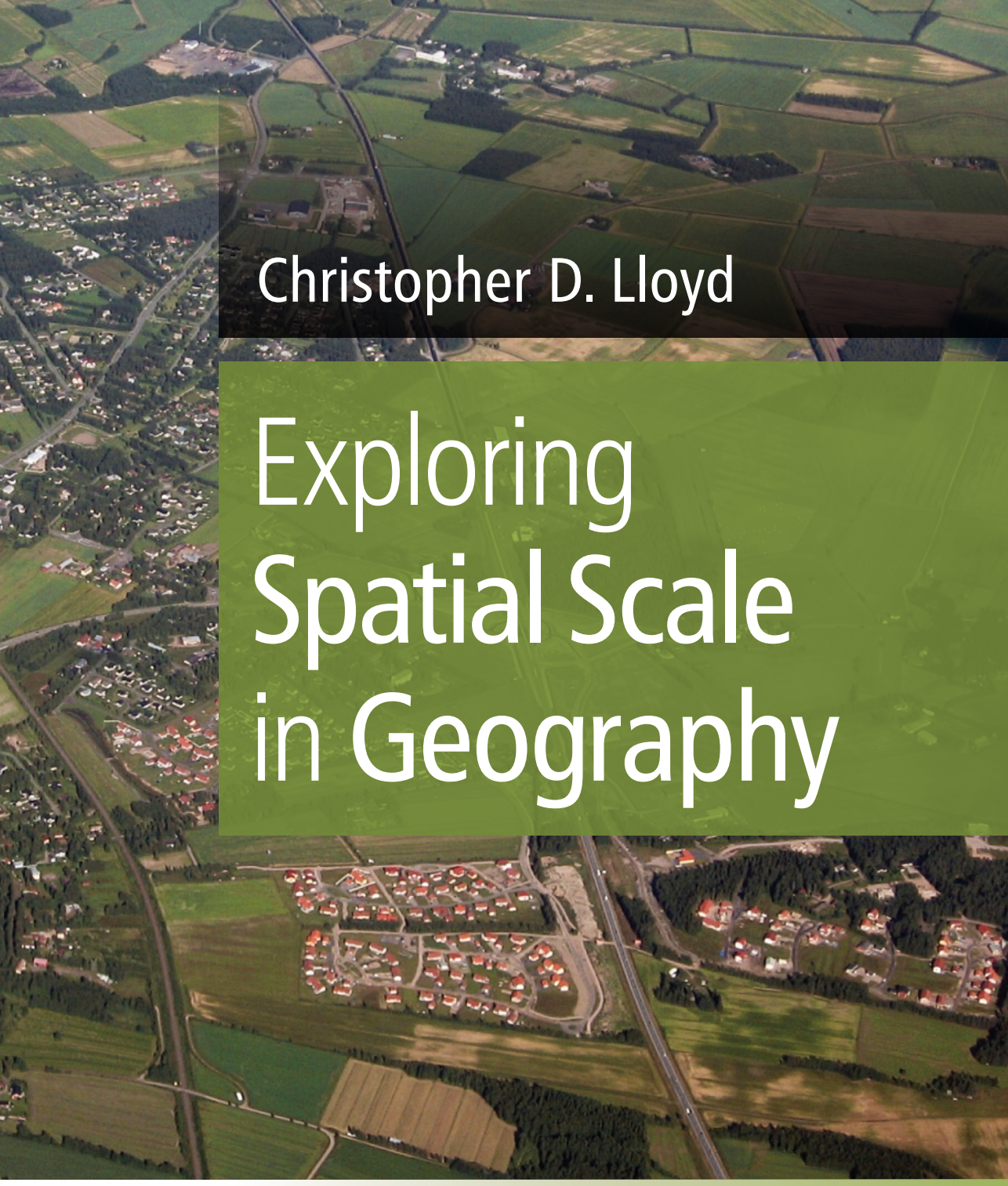

Christopher D. Lloyd

Exploring Spatial Scale in Geography

WILEY Blackwell

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For Philip and Dorothy

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Preface

Spatial scale is central to geography and to all disciplines concerned with the spatial arrangement of properties. Throughout the physical and social sciences and the humanities, the scale over which processes operate are key to interpreting those processes. But, as yet, there are no authored (as opposed to edited) books which are concerned with spatial scale and its measurement. This book was written to provide a focused introduction to the quantitative exploration of spatial scale. The book deals primarily with geography, but scale concerns all those who work with spatial data, and the book draws on multiple examples to illustrate concepts and methods.

The book focuses on the exploration of spatial scale, which can be defined as the size or extent of a process, phenomenon or investigation. A key concern of the book is to consider ways of characterising the degree to which a particular property, such as precipitation amount or the percentage of people over the age of 65, varies over space and in different directions. Some properties may be similar over small areas but very different across larger areas, while others may change very gradually over a large area – thus, the scale of spatial variation relates to the distances over which similar values tend, on average, to occur. Such information is important to describe a spatial property, but it is often also necessary to assess the relationship between the scale of spatial measurement and the scale of variation of the characteristics of interest. In addition, this kind of information is essential for ascertaining if an existing dataset, or a planned sampling framework, is appropriate for a particular application.

Spatial scale is a central concept in both physical and social sciences. In geomorphological contexts, for example, a particular landform may vary markedly over small areas whereas another landform may have similar properties over quite large areas. In this case, the first landform varies at a fine spatial scale while the second varies at only a coarse spatial scale. In social geography, a population may be strongly spatially concentrated by one characteristic (e.g. proportion of social housing at a neighbourhood scale within a city) but quite dispersed with respect to another (e.g. car ownership across the whole city). In short, the properties vary at different spatial scales. The term

spatial dependence, which is the subject of a large part of the book, refers to the tendency for neighbouring observations (e.g. elevations or population values) to have similar values. Spatial dependence is likely to vary at different spatial scales. For many properties, spatial dependence is more marked at small distances than it is at large distances, and spatial scales of variation can be summarised by measures of spatial dependence. Whether the concern is with, for example, residential segregation or airborne pollution, the scale of spatial dependence is crucial.

The book illustrates key concepts through presentation of several real-world case studies. As such, in many respects this book could be considered as a research monograph which draws together the results of work addressing diverse issues such as the geography of population concentrations, transfer of population counts from areas to surfaces and prediction of data values at locations where there is no sample. Some of the material which introduces methods overlaps, in part, with that provided in a previous book of mine (*Local Models for Spatial Analysis*), but the focus of the two books is fundamentally different. Both deal with spatial scale in some sense (the previous book deals with local models, and what we define as 'local' is a function of spatial scale), but in the present book the aim is to consider spatial scale generally and how it can be explored.

Guidance is given on the principles and practice of exploring spatial scale, with reference made to appropriate software packages. Particular topics include definitions of spatial scale, spatial dependence, fractals, Fourier transforms, wavelets, areal interpolation and geostatistics, as well as discussions about the exploration of spatial scale in a wide variety of applications areas. The book synthesises ideas and applications that I have worked on over the last decade and more, and I hope that these combine clearly enough to show effectively why scale is central to spatial data analysis and how it can be explored.

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Various people provided support in the writing of this book. Pierre Goovaerts is thanked for making available a copy of the Biomedware SpaceStat software and for his advice on its use. Gemma Catney and Myles Gould provided helpful comments on parts of the text. Phaedon Kyriakidis conducted an extremely insightful review and made many suggestions for improvements to the manuscript – he is sincerely thanked for his efforts. Any errors or omissions which remain are entirely the fault of the author.

About the Companion Website

This book is accompanied by a companion website:

www.wiley.com/go/lloyd/spatialscale

The website includes:

- Additional training resources
- Powerpoints of all figures from the book for downloading
- PDFs of all tables from the book for downloading

1
Introduction

1.1 The purpose of the book

Scale is at the heart of geography and other spatial sciences such as hydrography and cartography. Whether the concern is with geomorphological processes, population movements or meteorology, a consideration of spatial scale is vital. Mike Goodchild has suggested that 'scale is perhaps the most important topic of geographical information science' (Goodchild, 2001, p. 10). However, the concept of scale has multiple meanings, both between and within academic disciplines, and popular ideas about what it means are perhaps no less diverse. Section 2.1 provides definitions of scale which link to cartography (e.g. we talk of 'map scale') and to the characteristics of spatial data. As well as considering some definitions of spatial scale, the book describes some approaches for its characterisation. In addition, the book addresses topics like the effect of different levels of aggregation on statistical analyses and approaches to transferring data values for one set of zones to another set of zones or to a surface. Section 2.1 provides some definitions of scale, but, in the present book, the key focus is on scale as the size or extent of a process.

At the heart of this book is the idea that we must work with abstractions (models) of geographical phenomena which we seek to summarise or generalise in some way so as to make them intelligible or interpretable. The characteristics of these phenomena are likely to vary geographically, and their characteristics at one spatial scale may be quite different to those at another. If we are dealing with multiple phenomena in combination then potential problems are magnified, as each phenomenon may have very different spatial characteristics and may operate at different spatial scales. Accounting for the nature of a model and the inherent spatial variation in some property or properties is not straightforward, and it is on this problem that the book is focused.

Exploring Spatial Scale in Geography, First Edition. Christopher D. Lloyd.

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Geographical information systems (GISystems) constitute a powerful means to manage and analyse multi-scale data. In this context, the term multi-scale refers to data with different levels of spatial aggregation (e.g. different pixel sizes) or different levels of generalisation (e.g. the level of spatial detail in representing linear features). In addition, GISystems provide tools which can be used to rescale the data – to change from a representation at one spatial scale to a representation at another (Atkinson and Tate 2000). This book seeks to consider how scale can be defined and explored in geographical information (GI) science contexts.

To capture or use geographical data it is essential to have information about the spatial scales of the processes which are of interest. *Characterising* spatial scale is important in its own right, but it is also necessary to quantify the relationship between the sampling framework and the spatial scale of a process. In short, is the data framework sufficient or excessive for a given application? Geomorphologists characterising landforms are directly concerned with the spatial scale of variation of those landforms. In addition, the spatial scales of processes operating on those landforms are of interest. Social geographers seek to understand the ways in which human populations are distributed. In some societies, subgroups of the population tend to cluster, either by choice or by force – for example, those with a similar social class are more likely to live in close proximity to one another than those in markedly different social classes. Such clustering may be evident over small areas (at a fine spatial scale) or over quite large areas (a coarse spatial scale). Any analysis of spatial data is dependent on the measurement scale (the support; see Section 2.1) and coverage of the data; thus, characterising the spatial scale of variation and how this relates to the measurement scale should be a fundamental part of any application of such data. Here, the spatial scale of variation can be taken to refer to distances over which similar values tend to occur on average.

This book offers alternative definitions of spatial scale, presents some approaches for exploring spatial scale and makes use of a wide variety of case studies in the physical and the social sciences to demonstrate key concepts. Spatial scale with respect to a physical process is often expressed in terms of distances (and perhaps directions) between observations. Alternative representations are possible. One example concerns the concept of neighbourhood whereby the size of the neighbourhood as conceived of by an individual may differ between urban and rural areas, and it thus may be possible to consider spatial scale as a function of population density rather than simply distance. The book explores such alternative representations through detailed case studies.

The book has a practical focus – the core concern is with real-world problems and potential solutions to these problems. Therefore, links are made to appropriate software environments, with an associated website providing access to guidance material which outlines how particular problems can be

approached using popular GISystems and spatial data analysis software. The book consists of three strands. The first is conceptual – some definitions of spatial scale are outlined and debates about the meaning and value of concepts of spatial scale are considered. The second strand outlines methods for the exploration of spatial scale including standard measures of spatial autocorrelation, fractals, wavelets, multilevel models, methods for areal interpolation and geostatistical measures, and the methods are illustrated with examples. The third and final strand demonstrates the application of these concepts and methods to real-world case studies. Chapters 3–9 follow this structure and thus each presents concepts, methods and example applications. Use is made of multiple examples drawn from physical and social geography, and these diverse cases help to illustrate why scale should not be ignored in any analysis of spatial data.

1.1.1 What this book adds

There are many introductions to methods for the analysis of spatial scale or for taking spatial scale into account in the analysis of geographical data (many such sources are cited in this book, with further reading sections at the end of each Chapter). The added value of this book is that it brings together a wide range of ideas and methods which relate to the exploration of scale in geography. The book takes a systematic approach to the explanation of key concepts followed by introductions to key methods which are then illustrated through case studies. Many of the case studies are based on research which has appeared in journal articles, and although each case study is intended to be self-contained, interested readers can follow up the relevant references if they require more details about the data or specific aspects of the methods or interpretations. No equivalent stand-alone introduction to the analysis of spatial scale currently exists, and it is hoped that the book will fill a gap in the spatial analysis literature and act as a first port of call for those with an interest in spatial scale and spatial data analysis.

1.1.2 Scales of analysis and alternative definitions

As noted by Goodchild (2011), the surface of the Earth is infinitely complex and it would be possible in principle to map the surface of the Earth to a submillimetre (and possibly molecular) level. But, in practice, we are obliged to sample the spatial properties we are interested in to make the handling and analysis of data representing them manageable. Spatial data sources are extensive in terms of both the features and properties they represent and the geographical areas they cover. The level of detail represented by these data sets is highly variable. As an example, images acquired through satellite remote sensing are available for multiple spatial (and spectral) resolutions. As such,

users of these data may encounter multi-scale representations, and for one region, there may be available several remotely sensed images that have different spatial resolutions (Lloyd 2011). In most cases, users of such data have little choice about the scale of measurement, and it is therefore necessary to develop ways to work with data at a range of spatial scales (Goodchild and Quattrochi 1997). Characterisation of spatial scale is also important where a new sample is being collected – by quantifying the dominant scales of spatial variation in a property it is possible to ascertain an appropriate sampling strategy.

Scale is a complex topic with numerous definitions encompassed within diverse conceptual frameworks. This complexity has been tackled by researchers in many disciplines. Spatial scale has been the subject of several previous books. Herod (2010) provides a wide ranging introduction to the concept and meaning of scale, within social theory. Several edited books focus on the topic from a GIScience perspective – these include Quattrochi and Goodchild (1997), Tate and Atkinson (2001) and Sheppard and McMaster (2004). A short introduction to scale in geography is given by Montello (2001). While the focus in this book is on geography, and on GIScience in particular, there is much related work in other disciplines including ecology (see, for example, the books edited by Peterson and Parker 1998 and Gardner et al. 2001 and the classic text by Legendre and Legendre 2012) and spatial epidemiology (the book by Lawson 2006 has a lot of material on statistical analysis and spatial scale in this context).

In human geography, there is a general recognition that scale is socially constructed (Smith 1984, Marston 2005). But debates about the forces involved in its constructions are ongoing (Sayre 2005). Some scholars perceive scale as a consequence of social behaviour at a range of different levels which may include, amongst others, the household, neighbourhood, state and nation. In this conceptualisation, scale is seen to emerge from social dynamics from multiple scales such as household micro-politics through to international economic regimes (Ruddell and Wentz 2009). Marston (2005) reviews a diverse literature which deals with the construction of scale, while Herod (2010) provides a review of concepts and related research. These themes are outside the scope of this book, which has as its focus GIScience generally and spatial data analysis specifically.

1.2 Key objectives

This book is intended to cover a range of key conceptual and methodological issues in the exploration of spatial scale, with a particular focus on geography. The key objectives of the book are to (i) enhance understanding of why considering spatial scale is important and (ii) describe and illustrate methods which can be used to address scale-related problems. Case studies,

summarised below, are provided to show the applicability of the concepts and methods discussed across the physical and social sciences.

1.3 Case studies and examples

This book is, in some respects, case study driven. It presents results from published research, as well as research which was conducted specifically for the book. Chapter 2 uses several examples based on Ordnance Survey© maps, two sets of Census data for Northern Ireland, data on road distances between places in England and Wales and the medieval Gough Map of Britain. The following chapters present case studies using data on population counts (Chapters 3 and 8), religion (Chapters 3 and 4), limiting long-term illness (Chapter 5), mortality (Chapter 9) and a set of socio-economic and demographic variables for (parts of) Northern Ireland (Chapters 3, 4 and 5); precipitation amounts in Scotland (Chapter 4) and in the United Kingdom as a whole (Chapter 9); digital elevation data for (parts of) Britain (Chapters 4, 6 and 9); redwoods, Japanese pine and myrtles point patterns (Chapter 4); the coastline of Britain (Chapter 6); Landsat imagery for an area in Turkey (Chapter 7); data on pore space in rock thin sections (Chapter 7); a digital orthophoto quadrangle of Washington DC (Chapter 7) and population counts for areas in England (Chapter 8). The diversity of these case studies will hopefully help to demonstrate the applicability of the concepts and methods considered across geography and allied disciplines.

1.4 Why is spatial scale important?

In simple terms, if we seek to describe or understand a process and that process behaves in different ways at different spatial scales, then it becomes necessary to have some understanding of this variation. There are numerous examples of why spatial scale is important in exploring physical processes. As an example, erosion of the Earth's surface is a function of multiple processes which operate over many spatial scales (Cantón et al. 2011). Geographers often want to know how a variable is distributed – that is, where are values large or where do small values tend to cluster? Changes in these properties over time may also be of interest. As an example from human geography, is a given population group becoming more dispersed or more clustered? Over what scale is the dispersal or concentration taking place? What size are the areas over which a given group tends to concentrate? Reardon et al. (2008) discuss related issues in the context of residential segregation. Notions of neighbourhoods, although not defined by distance alone, are explicitly linked to spatial scale. Kearns and Parkinson (2001) define three scales of neighbourhoods which relate to home area, locality (linked to planning, service provision and the housing market)

and urban district or region (with connections to employment, leisure interests and social networks).

Uncertainty in GI is, in part, a function of spatial scale (Zhang and Goodchild 2002) and so confidence in results depends on knowledge of how a property is structured spatially. Features on maps are generalised (João 1998) and this generalisation (loss of spatial detail) is linked directly to spatial scale, as information loss relates to the spatial scale of the map. Measures of spatial variation can be used to relate spatial scale to information content. If we know how a property varies in space, then it is possible to ascertain an optimal sampling framework or to consider how an existing sample meets our needs. Increasingly, users of spatial data have access to multiple data sources representing features on the surface of the Earth (and elsewhere) at a wide range of spatial scales. A consequence of these developments is that interest in spatial variation, and how it relates to spatial scale, has increased (Unwin and Unwin 1998).

This book makes extensive use of case studies, as well as references to examples in the literature. These studies address a wide range of topics including residential segregation in human populations, factors which explain illness, the roughness of a terrain and spatial variation in precipitation amounts.

1.5 Structure of the book

The next chapter expands on some of the themes discussed in this chapter. In particular, the focus is on definitions of scale in spatial data analysis. Chapter 3 deals with the modifiable areal unit problem and the ecological fallacy – these topics are relevant for any data set with measurements made over an area, rather than at a point. Chapter 4 develops the discussion of spatial autocorrelation and spatial dependence and presents some approaches to characterising spatial scale. In Chapter 5, spatial relationships and scale are the concern. Chapter 6 introduces fractal analysis. Chapter 7 introduces and illustrates the application of Fourier analysis and wavelet transforms. Chapter 8 describes some methods for areal interpolation. Chapter 9 builds on the previous chapter and presents a framework for using information on the spatial scale of variation in the interpolation process. Finally, Chapter 10 summarises some key issues raised in the book.

1.6 Further reading

The books edited by Tate and Atkinson (2001) and Sheppard and McMaster (2004) provide introductions to some key concepts as well as a range of chapters dealing with particular issues in the characterisation and understanding of spatial scale. Throughout the book, reference is made to subject-specific

material and case studies which expand on the material covered in the text. This book is necessarily selective and, inevitably, coverage of all topics is not equal. Consideration of some themes which readers may like to see included may be absent. In these cases, the suggested further reading, as well as sources cited in the main body of text, should provide a starting point.

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