12 Geovisualization

LEARNING OBJECTIVES

After studying this chapter you will understand:

- How GI systems facilitate visual communication.
- The ways in which good user interfaces can help to resolve spatial queries.
- Some of the ways in which geographic representations may be transformed.
- How 3-D geovisualization and augmented reality can improve our understanding of the world.

This chapter builds on the cartographic design principles set out in Chapter 11 to describe a range of novel ways in which information can be presented visually to the user. Using techniques of geovisualization, geographic information (GI) systems provide a far richer and more flexible medium for portraying attribute distributions than paper mapping. First, through techniques of spatial query, geovisualization allows users to explore, synthesize, present (communicate), and analyze the meaning of a representation (see Chapter 2). Second, it facilitates map transformation using techniques such as cartograms and dasymetric mapping. Third, geovisualization allows the user to interact with the real world from a distance, through interaction with and even immersion in digital environments. Together, these functions provide new insights into geographic data, broaden the user base of GI systems, and have implications for the supply and use of volunteered geographic information (VGI).

12.1 Introduction: Uses, Users, Messages, and Media

Effective decision support through GI systems requires that computer-held representations (as discussed in Chapters 2 and 5) are readily interpretable in the minds of the users who need them to make decisions. Because representations are necessarily partial and selective, they are unlikely to be accepted as objective. Critiques of GI systems (Section 1.5.5) have suggested that even widely available digital maps and virtual Earths (as provided by Google, Apple, and Microsoft) present a "privileged" or "God's-eye" view of the world because the selectivity inherent in representation may be used to reinforce the message or objectives of the interest groups that created them. This issue predates digital GI: it is evident in the early motivations for creating maps to support military operations (Box 11.1), and the subject of geopolitics is rife with examples of the use of mapping to reinforce political propaganda. Today, Web mapping and digital spatial data infrastructures can open up politically sensitive issues and, in the era of VGI, allow them to be openly contested (see Box 12.1).

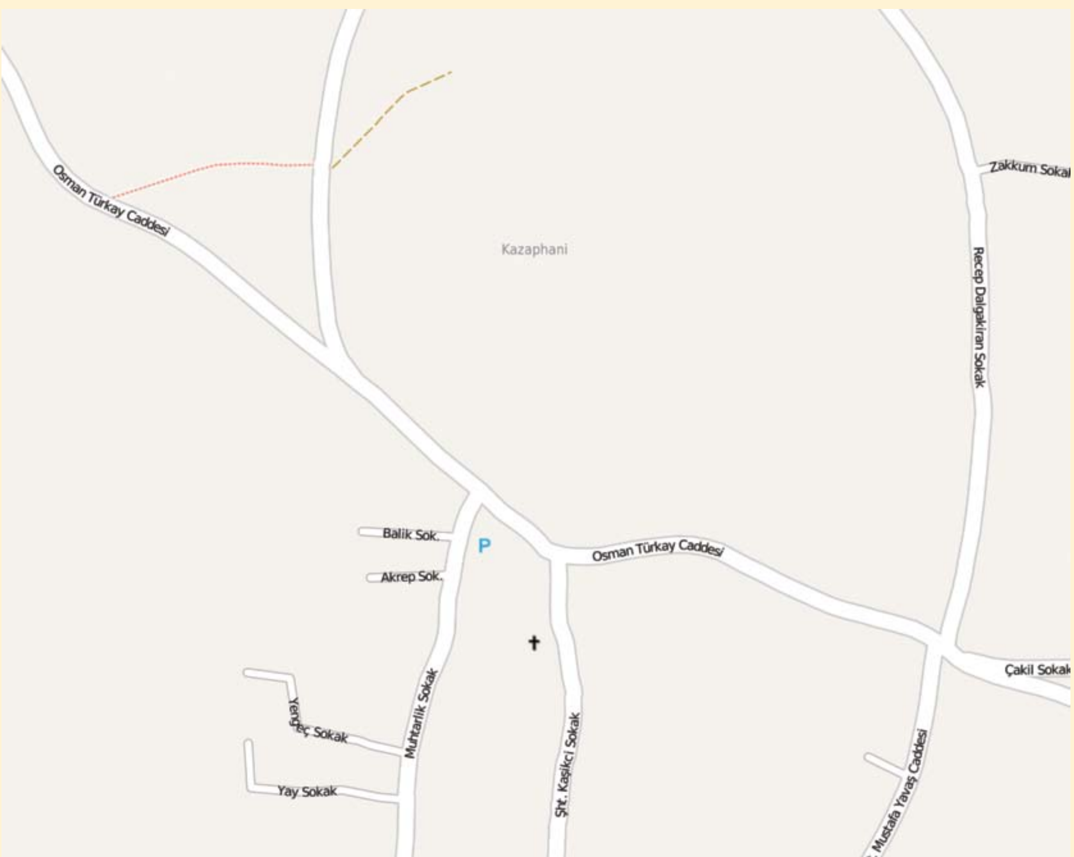
Today's Big Data and other sources are much more numerous, varied, voluminous, frequently updated, and complicated than was the case even a decade ago. Geovisualization techniques offer the prospect of rendering them intelligible to users and avoiding information overload, by weeding out

Applications Box 12.1

The Legacy of Conflict, "Tag Wars," and Cohesive Communities

OpenStreetMap (www.openstreetmap.org and Section 18.6) is an ongoing collaborative volunteered geographic information (VGI) project that is seeking to create a free digital map base of the entire world. Online maps are created using global positional system (GPS) traces that are recorded, uploaded, and annotated by volunteers, along with aerial photography and other free sources. Most volunteers have detailed local knowledge of the areas for which they capture data, and all volunteers are empowered to edit the database as well as add to it, in order to generate coverage and to correct for errors. Local knowledge is, of course, situated in direct experience (Chapter 3), and open-source maps may be heavily contested if, as in the case of Cyprus, received wisdom is heavily conditioned by cultural affiliation.

Cyprus has been divided since 1974, when Turkish forces invaded the north part of the island. The south is the Greek-dominated Republic of Cyprus (which is internationally recognized), and the north is the Turkish Republic of Northern Cyprus (which is not). After 1974, places in the north part of the island were renamed in Turkish, and road signs were made consistent with them. Some volunteers believe that Turkish names should be used, with Greek names relegated to the metadata; this stance is pragmatic not least because OpenStreetMap is used as a navigational aid. Yet other volunteers, mindful perhaps of the island's unhappy recent history and the illegal status of the north, have persisted in replacing Turkish names with their pre-1974 Greek counterparts. The ensuing "tag war", marked by the successive editing of Turkish and Greek names, can be viewed at www.openstreetmap.org/browse/node/276379679/history, and some of the changes to the map are illustrated in Figure 12.1. Geovisualization enables dynamic mapping of the tensions that surround this disputed territory and that underpinned Greek-Cypriot rejection of the United Nations' Annan Plan to reunite the island in 2004.



Source: © OpenStreetMap contributors

Figure 12.1 Greek and Turkish edits to OpenStreetMap in Cyprus.

distracting or extraneous detail. They also make it possible to identify and assess outliers—apparently rogue observations that stand out from an overall pattern or trend—that are not revealed by other Big Data analytics. At the other end of the data volume spectrum, historical GI system applications are concerned with assembling digital shards of evidence that may be scattered across space and time or with providing wider spatial context to painstaking local archive studies. In such cases, geovisualization provides the context and framework for building representations, sometimes around sparse records. In these various instances, geovisualization is different from cartography and map production (see Chapter 11) in that it typically uses interactive computing for data exploration, it entails the creation of multiple (including 3-D) representations of spatial data, or it allows the animated representation of changes over time.

Geovisualization may entail interrogation of multiple representations of large and complex datasets, through a series of interactions that pursue different lines of inquiry, with the objective of developing cumulative findings. Mapping makes it possible to communicate the meaning of a spatial representation of the real world to users. Historically, the paper map was the only available interface between the mapmaker and the user: it was permanent, contained a fixed array of attributes, and was of predetermined and invariant scale. Typically, national mapping agencies would provide metadata (Section 10.2) that demonstrated that the map was fit for the general purpose for which a map was designed, although this did not invariably make it easy for users to ascertain whether it was safe to use for specific applications. Moreover, it was not possible to differentiate between the needs of different users. These attributes severely limit the usefulness of the paper map in today's applications environment, which can entail applications of seemingly unfathomable complexity. Indeed it is often now necessary to visualize data that are very detailed, continuously updated, or have been assembled from diverse sites across the Internet. These developments are reinvigorating the debate over the meaning of maps and the potential of mapping.

Like paper mapping, digital visualization is open to negligent or malevolent use. However, in general terms, geovisualization makes the selective nature of representation more transparent and open to scrutiny. An interactive computer environment makes it easier to evaluate data quality and to present alternative constructions and representations of geographic information.

In technical terms, geovisualization builds on the established tenets of map production and display. It entails the creation and use of visual representations to facilitate thinking, understanding, and knowledge construction about human and physical environments, at geographic scales from the architectural to the global. It is also a research-led field that integrates a wide range of approaches from scientific computing, cartography (Chapter 11), image analysis (Section 8.2.1), information visualization, and exploratory spatial data analysis (ESDA: Chapters 13 and 14). The core motivation for this activity is to develop theories, methods, and tools for visual exploration, analysis, synthesis, and presentation of spatial data.

Geovisualization is used to explore, analyze, synthesize, and present spatial data.

As such, today's geovisualization is much more than conventional map design. It has developed into an applied area of activity that leverages geographic data resources (including Big Data) to meet a very wide range of scientific and social needs. It is also a research field that is developing new visual methods and tools to facilitate better user interaction with such data. In this chapter, we discuss how this is achieved through *query* and *transformation* of geographic data and also user *immersion* within them. Query and transformation are discussed in a substantially different context in Chapters 13 and 14, where they are encountered as types of spatial analysis.

12.2 Geovisualization, Spatial Query, and User Interaction

12.2.1 Overview

Fundamental to effective geovisualization is an understanding of how human cognition shapes the usage of GI systems, how people think about space and time, and how spatial environments might be better represented using computers and digital data. The conventions of map production, presented in Section 11.3, are central to the use of mapping as a decision support tool. Many of these conventions are common to paper and digital mapping, although GI systems allow far greater flexibility and customization of map design. Geovisualization develops and extends these concepts in a number of new and innovative ways in pursuit of the following objectives:

1. *Exploration*: for example, to establish whether and to what extent the general message of a dataset is sensitive to inclusion or exclusion of particular data elements.
2. *Synthesis*: to present the range, complexity, and detail of one or more datasets in ways that can be readily assimilated by users. Good geovisualization

should enable the user to differentiate the "wood from the trees" and may be particularly important in highlighting the time dimension.

3. *Presentation*: to communicate the overall message of a representation in a readily intelligible manner and to enable the user to understand the likely overall quality of the representation.
4. *Analysis:* to provide a medium to support a range of methods and techniques of spatial analysis (see Chapters 13 and 14).

These objectives cut across the full range of different applications tasks and are pursued by users of varying expertise that desire different degrees of interaction with their data.

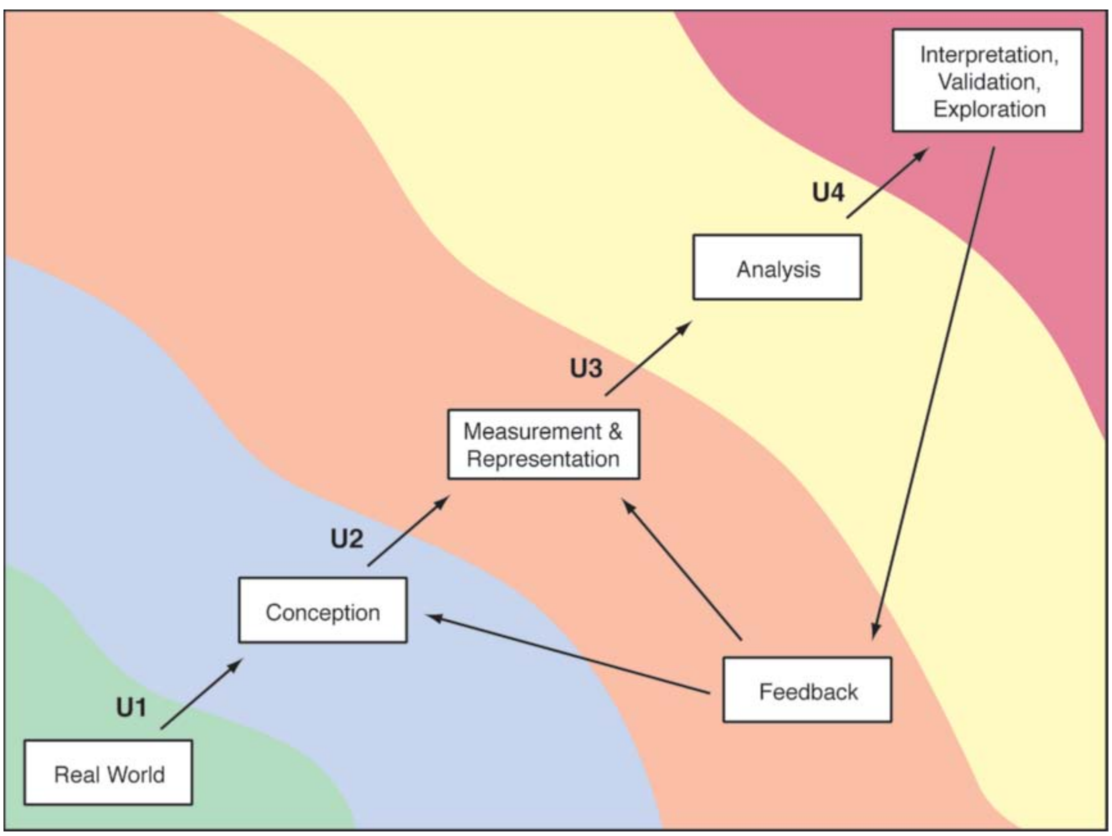
Geovisualization allows users to explore, synthesize, present, and analyze their data more thoroughly.

These motivations may be considered in relation to the conceptual model of uncertainty that was presented in Figure 5.1, which is presented with additions in Figure 12.2. This extended conceptual model encourages us to think of geographic analysis not as an endpoint, but rather as the start of an iterative process of feedbacks and what-if scenario testing. It is thus appropriate to think of geovisualization as imposing a further filter (U4 in Figure 12.2) both on the results of analysis and on the conception and representation of geographic phenomena. The most straightforward way in which reformulation and evaluation of a representation of the real world can take place is through posing *spatial queries* to ask generic spatial and temporal questions such as:

- Where is . . .?
- What is at location . . .?
- What is the spatial relation between . . .?
- What is similar to . . .?
- Where has . . . occurred?
- What has changed since . . .?
- Is there a general spatial pattern, and what are the anomalies?

These questions are articulated through graphical user interfaces (GUIs) that remain based upon windows, icons, menus, and pointers—the so-called

Figure 12.2 Filters U1–U4: conception, measurement, analysis, and visualization. Geographic analysis is not an end point, but rather the start of an iterative process of feedbacks and "what-if?" scenario testing. (See also Figure 5.1)



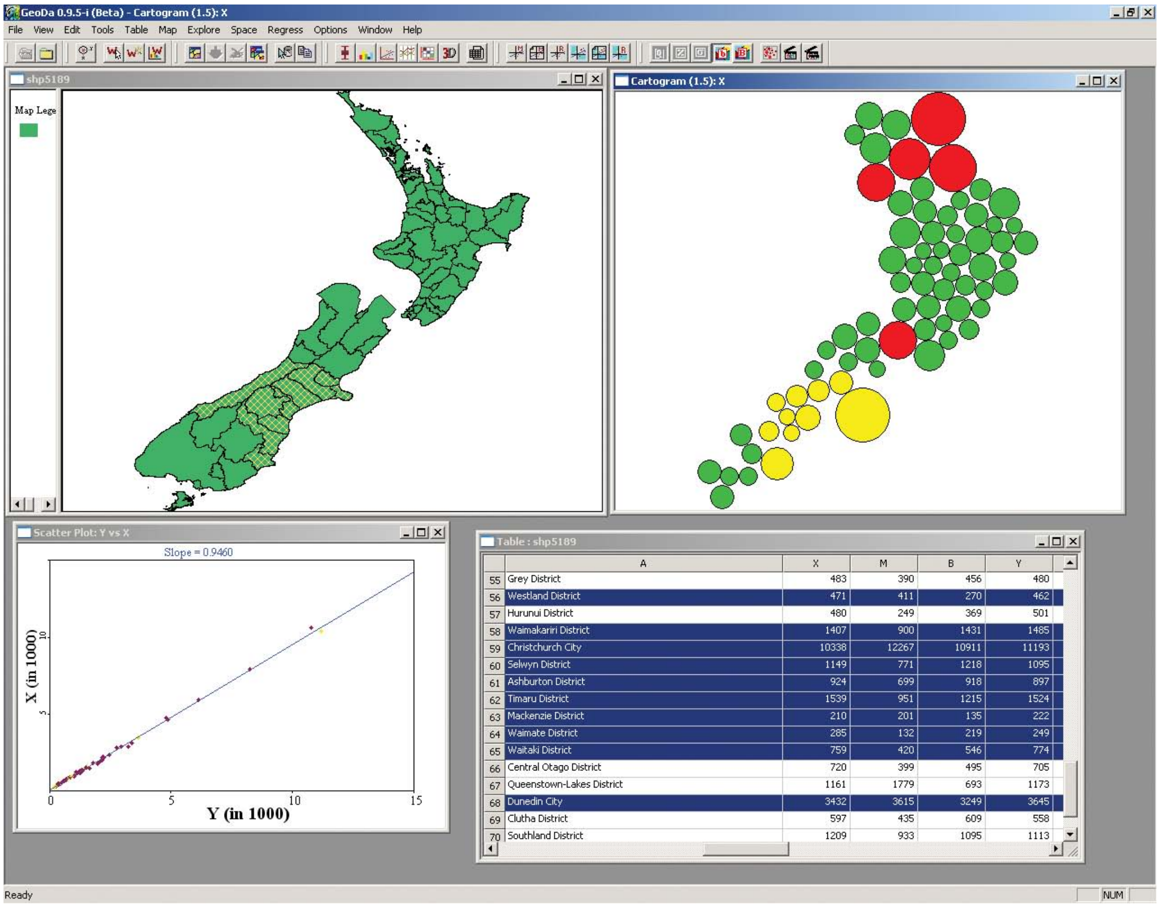


Figure 12.3 Geovisualization using multiple dynamically linked views in the GeoDa software. The data that the user has highlighted in blue in the table are identified in the maps using yellow hatching or coloring, whereas the red circles denote outliers in the analysis. The scatterplot summarizes the relationship between two variables under consideration.

WIMP interface illustrated in Figure 12.3. Although eclipsed by different design principles in computer gaming, the familiar actions of pointing, clicking, and dragging windows and icons remain the most common ways of interrogating a geographic database and summarizing results in map and tabular form. The wide use of multitouch screen and touchpad technology of smartphones and tablets also makes it possible to manipulate data and maps through gestures. Zooming is one such interactive gesture, accomplished by emulating a pinching motion on the screen of the hardware device. High-end GI systems use multiple displays and projections of maps (see Section 4.8) along with aspatial summaries such as bar charts and scatterplots. Together these make it possible to build up a picture of the spatial and other properties of a representation. The user is able to link these representations by "brushing" data in one of the multiple representations and viewing the same observations in the other views. This facilitates learning about a representation in a data-led way.

Spatial querying is performed through pointing, clicking, and dragging windows and icons.

Although most computer interfaces can run software that enables spatial query, the greatest volume of spatial queries is made through smartphones and other handheld devices, many of which use integral GPS receivers or phone networks to render them location aware. These devices have increased the challenges to geovisualization because of the much more restricted screen size. They have also led to a vast range of new spatially enabled applications, mainly for use by nonexpert users.

The implications for geovisualization are profound and far reaching in that a new, larger, and much more diverse user base is seeking to use smartphones to solve an ever wider range of location-specific problems, on the fly and in real time. Figure 12.4 shows the user interface of a locationally aware smartphone used to identify travel options (in terms of travel cost, travel time, and

Image courtesy: Alistair Leak

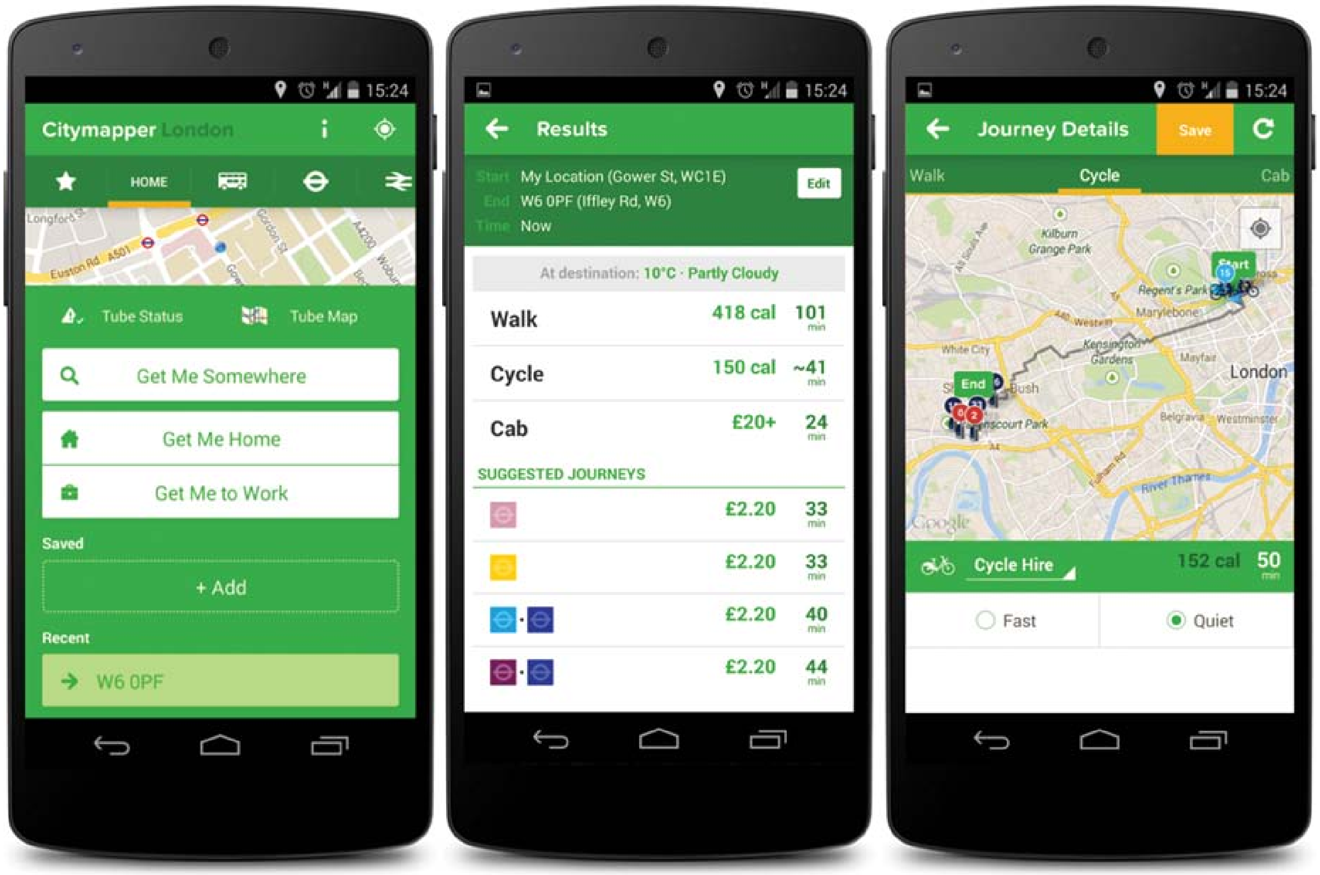


Figure 12.4 The locationally aware Citymapper mobile phone application for London, presenting travel options between two points, taking into account some aspects of travel conditions.

calorific usage) between two locations in London. Such services can also accommodate real-time spatial information feeds such as prevailing weather, current network disruptions, or levels of traffic congestion and may allow users to pose a range of additional spatial queries.

Applications such as these are currently developed for the general market and are not tailored to personal circumstances (e.g., visual acuity), prior experience, decision-making strategies, and basic cognitive abilities. Looking to the future, it is likely that interfaces will be tailored to serve group or individual needs: for example it is possible to envisage that a navigation service offering landmark-based wayfinding instructions might use only particular types of landmarks, or that the number and type of landmarks might be changed according to the user's familiarity with particular physical settings. This area of current research is termed *cognitive engineering*, and in the future it is likely that cognitively engineered applications will be more closely attuned to the user's ability to interpret spatiotemporal information, in order to meet specific user requirements. In practice, the software used to accomplish this may come from a wide variety of proprietary and open sources.

The advent of VGI and Web 2.0 GI systems is increasing the range of sources that may be used to create, serve, and exchange GI; such sources are increasingly being used to devise niche maps for specialist applications. Figure 12.5 illustrates this with regard to the creation of maps for use in orienteering, created using public-domain software and OpenStreetMap data. A closely related application is geocaching, which is an outdoor treasure-hunting game in which participants use a GPS receiver or other navigational techniques to hide and seek caches, or containers, as shown in Figure 12.6.

Cognitive engineering matches device functions to user requirements.

12.2.2 Spatial Query Online and the Geoweb

The spatial query functions illustrated in Figure 12.4 are also central to many Internet GI systems applications, and the different computer and network architectures set out in Chapter 10 can each be used

Figure 12.5 (A) The general-purpose map layer base of OpenStreetMap for Durham, UK; (B) a specialist orienteering map created using the OpenStreetMap base along with the contour data derived from Shuttle Radar Topography Mission data. These sources were integrated using the MapWindow open-source GIS (www.mapwindow.org); and (C) a competitor registering at an orienteering post.

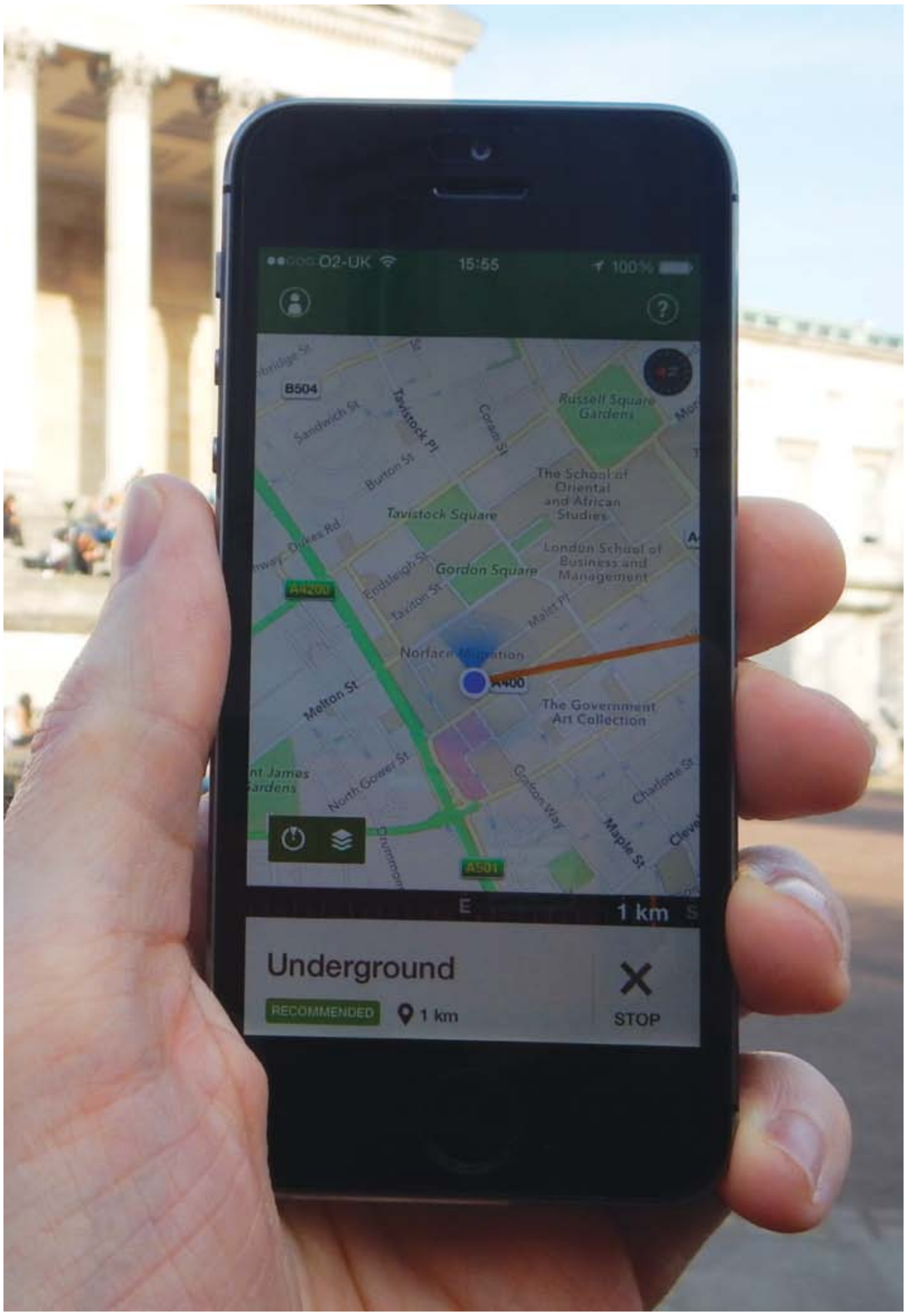


Image courtesy: Alistair Leak

Figure 12.6 Geocaching is a global treasure-hunting game where participants locate containers, called geocaches, hidden outdoors and then share their experiences online.

to query remote datasets. For many users, spatial query is the end objective of a GI systems application, as for example with queries about the taxable value of properties, customer-care applications about service availability, or Internet-site queries about real-time traffic conditions. In other applications, spatial query is a precursor to more advanced spatial analysis. Spatial query may appear routine, but may entail complex operations, particularly when the datasets are continuously updated (refreshed) in real time—as, for example, when optimal traffic routes are updated in the light of traffic conditions or road closures.

The innovation of Web 2.0 has enabled bi-directional collaboration between Web sites (see Section 1.5.1) and has important implications for geovisualization, including the development of consolidator sites that take real-time feeds from third-party applications. Box 12.2 describes one such application, MapBox.

Applications Box 12.2

Interactive Mapping using MapBox

Tilemill (www.mapbox.com/tilemill/) is an open-source software tool that allows users to create interactive maps with pan and zoom functionality. Users can create map tiles that are assembled into a single portable database (MBTiles—www.mapbox.com/developers/mbtiles/) that can either be hosted by Mapbox or on the user's own server.

MBTiles are an adaptation of SQLite, a self-contained, transactional structured query language (SQL) database engine (see Section 9.4). The Mapbox business model is innovative in that it is based upon user subscription for Web mapping hosting services, with all software developed as open-source products.

Applications using this infrastructure include Eric Fischer's maps of Twitter social media data to derive smartphone device usage (www.mapbox.com/labs/twitter-gnip/brands/#5/38.000/-95.000), and of a map separating locals from tourists (www.mapbox.com/labs/twitter-gnip/locals/#5/38.000/-95.000; see also Figure 17.7B). Figure 12.7 presents a MapBox hosted map of the currency of OpenStreetMap data for Rio de Janeiro (www.mapbox.com/osm-data-report/).

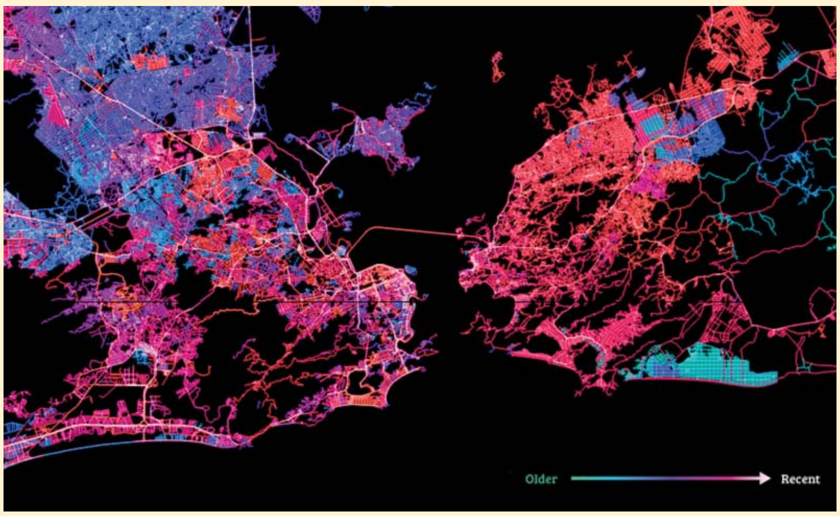


Figure 12.7 A MapBox-hosted map of the currency of OpenStreetMap data for Rio de Janeiro (red colors denote old data, with more recent uploads and amendments in blue).

12.3 Geovisualization and Transformation

12.3.1 Overview

Chapter 11 illustrated circumstances in which it was appropriate to adjust the *classification intervals* of maps, in order to highlight the salient characteristics of spatial distributions. Changing the *scale* at which attributes are measured can help us to represent spatial phenomena, as with the scaling relations that may be used to characterize a fractal coastline (Box 2.7). Other components of a map can be adjusted in order to present or highlight spatial information: for example, the work of computer scientist Ross Maciejewski, illustrated in Box 12.3, illustrates how the linear features of maps can be used in novel ways to depict spatial distributions.

We have previously discussed the inherent uncertainties in representing geographic data (Chapter 5) and some of the consequences of the absence of natural units for most geographic analysis. In addition we have seen (Box 2.5) how representing *count* data using choropleth maps is unwise because areal extent of mapped units is not taken into account. Standard map production and display functions in GI systems allow us to standardize according to numerical base categories, yet large but unimportant (in attribute terms) zones then achieve greater visual dominance than is warranted.

These related problems can be addressed by using geovisualization to transform the shape and extent of areal units. Our use of the term *transformation* here is in the cartographic sense of taking one vector space (the real, or observable, world) and transforming it into another (the geovisualization). We

Biographical Box 12.3

Ross Maciejewski, Computer Scientist

Ross Maciejewski (Figure 12.8) completed his PhD at Purdue University in Computer Engineering in 2009 under the direction of David S. Ebert. His doctoral work in syndromic surveillance and spatial analysis brought him into contact with members of the geography community, notably visual analytics expert Alan MacEachren at Penn State University.

Following the completion of his PhD, Ross served as a visiting faculty member at Purdue as a member of the Department of Homeland Security's Center of Excellence focusing on visual analytics (VACCINE) exploring Coast Guard Search and Rescue Cases, criminal incident reports, and a variety of other spatiotemporal data. His work at Purdue's VACCINE Center was honored by the U.S. Coast Guard with a Meritorious Team Commendation as part of his work on the Port Resilience for Operational/Tactical Enforcement to Combat Terrorism (PROTECT) Team.

In 2011, Ross joined Arizona State University's School of Computing, Informatics, and Decision System Engineering, where he continues to develop visual analytics methods. His bristle maps are an innovative multivariate mapping technique in which geographically locatable statistical measures are assigned color, orientation, and length offsets along a geographical network. The image shown in Figure 12.9 presents statistical estimates of the density of vandalism complaints in Lafayette, Indiana. The linear extent of each bristle from the underlying street network allows the user to gain an impression of the severity of vandalism crimes at that point on the network. Bristle length and color are used to encode an estimate of the number of crimes, whereas orientation and color are used to differentiate between daytime and nighttime occurrences (red for night, blue for day, opposite sides of a street for day/night). This technique provides a neat depiction of the geotemporal pattern of crime in the area.

Speaking of the prospects of geovisualization, Ross says: "This is an exciting time for students to get involved in spatial data analysis. Currently, new technology is allowing us to collect spatial data at unprecedented rates, and students can learn how to mine these data for information that can in turn help us to shape our world. There are great opportunities to develop visual analytics for business intelligence, urban planning, and operational research that exploit the ever growing volume of spatial data that is becoming available in real time."

Ross's own research applications in geographic visualization and visual analytics focus on public health, social media use, criminal incident reporting, and dietary analysis. He is a regular participant in research competitions concerned with visual analytics. You can check out the current work of the Visual Analytics and Data Exploration Research Lab at vader.lab.asu.edu.

Courtesy: Ross Maciejewski

Figure 12.8 Ross Maciejewski, computer scientist.

Courtesy: Ross Maciejewski

Figure 12.9 Bristle map of vandalism complaints in Lafayette, Indiana.

Table 12.1 Some examples of coordinate and cartographic transformations of spatial phenomena of different dimensionality. (Based on D. Martin. 1996. *Geographic Information Systems: Socioeconomic Applications* (2nd ed.). London: Routledge: 65)

Dimension	0	1	2	3
Conception of spatial phenomenon	Population distribution	Coastline	Agricultural field	Land surface
Coordinate transformation of real world arising in GI systems representation/measurement				
Measurement	Imposed areal aggregation	Sequence of digitized points	Digitized polygon boundary	Arrangement of spot heights
Cartographic transformation to aid interpretation of representation				
Visualization	Cartogram or dasymetric map	Generalized line	Integral/natural area	Digital elevation model

consider cartographic transformation here, rather than in Chapter 11 because this is likely to be the outcome of an interactive series of map transformations.

GI systems provide a flexible medium for the cartographic transformation of maps.

Some examples of the ways in which real-world phenomena of different dimensions (Box 2.2) may or may not be transformed are shown in Table 12.1. These illustrate how the representation filter of Figure 12.2 may have the effect of transforming some objects, such as population distributions, but not others, such as agricultural fields. Further transformation may occur in order to present the information to the user in the most intelligible and parsimonious way. Thus, cartographic transformation through the U3 filter in Figure 12.2 may result from the imposition of artificial units, such as census tracts for population, or selective abstraction of data, as in the generalization of cartographic lines (Section 3.8). The standard conventions of map production and display are not always sufficient to make the user aware of the transformations that have taken place between conception and measurement—as in choropleth mapping, for example, where mapped attributes are presented using the proportions of the zones to which they pertain.

Geovisualization techniques make it possible to manipulate the shape and form of mapped boundaries using GI systems, and in many circumstances it may be appropriate to do so. Indeed, where a standard mapping projection obscures the message of the attribute distribution, map transformation becomes necessary. There is nothing untoward in doing so. One of the messages of Chapter 4 was that all conventional mapping of geographically extensive areas entails transformation, in order to represent the curved surface of the Earth on a flat screen or a sheet of paper. Similarly, in Section 2.8, we described how generalization procedures may be applied to line data in order to maintain their structure and character in small-scale maps. There is nothing sacrosanct about popular or conventional representations of the world, although the widely used transformations and projections do confer advantages in terms of wide user recognition and hence interpretability.

12.3.2 Cartograms

Cartograms are maps that lack planimetric correctness and distort area or distance in the interests of some specific objective. The usual objective is to reveal patterns that might not be readily apparent from a conventional map or, more generally, to promote legibility. Thus, the integrity of the spatial object, in terms of areal extent, location, contiguity, geometry, or topology, is made subservient to an emphasis on attribute values or particular aspects of spatial relations. One of the best-known cartograms (strictly speaking a *linear cartogram*) is the London Underground map, devised in 1933 by Harry Beck to fulfill the specific purpose of helping travelers to navigate across the network. The central-area cartogram that is widely used today is a descendant of Beck's 1933 map and provides a widely recognized representation of connectivity in London, using conventions that are well suited to the attributes of spacing, configuration, scale, and linkage of the London Underground system. The attributes of public transit systems differ between cities, as do the cultural conventions of transit users, and thus it is unsurprising that cartograms pertaining to transit systems elsewhere in the world appear quite different.

Cartograms are map transformations that distort area or distance in the interests of some specific objective.

A central tenet of Chapter 2 was that all representations are necessarily selective abstractions of reality.

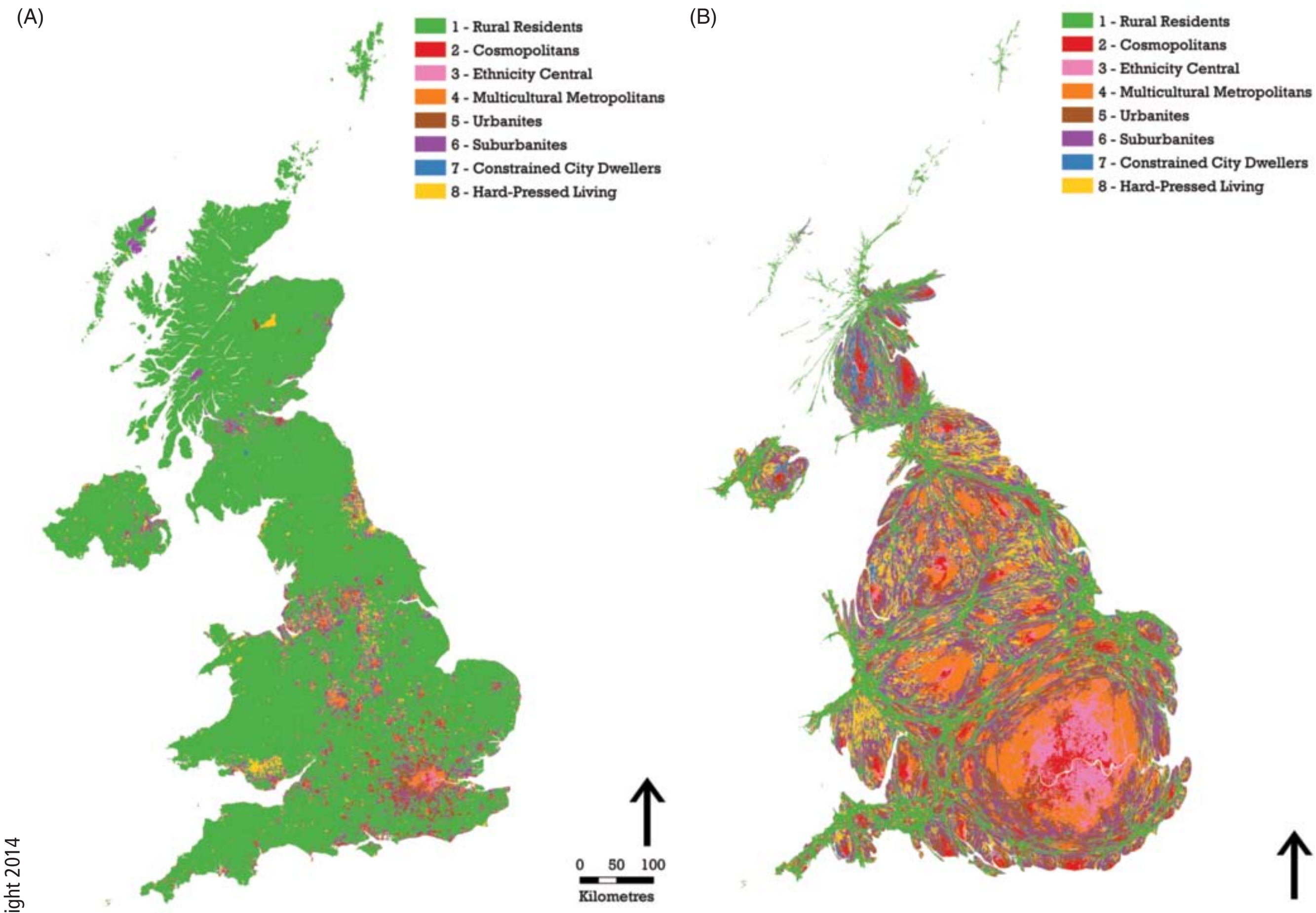


Figure 12.10 The 2011 Output Area Classification of the UK shown using (A) a standard transverse Mercator projection and (B) an approximate area cartogram.

Cartograms depict transformed, hence artificial, realities, using particular exaggerations that are deliberately chosen. Figure 12.10A presents a transverse Mercator map of a *geodemographic classification* based upon the 2011 UK Census, in which colors are used to denote the lifestyle characteristics of neighborhoods. The most rural group, "Rural Residents," occupy the least densely settled parts of the country and so visually dominate the map, whereas the geographies of the other seven Super Groups are far less clear. Figure 12.10B presents an approximate area cartogram of the same data, in which the area of each census zone is made proportional to its population size, and the areas are stretched in order to maintain contiguity wherever possible. This makes the densely populated areas of London and the other major urban conurbations appear much larger, whereas sparsely populated areas, particularly in North Wales and Scotland, are diminished in extent. Every individual in the population is thus accorded approximately equal weight in Figure 12.10B. The overall shape and compass orientation of the country are kept roughly correct—although the real-world pattern of zone shape, contiguity, and topology is to some extent compromised. When attributes are mapped, the variations within cities are revealed, whereas the variations in the countryside are reduced in size so as not to dominate the image and divert the eye from the circumstances of the majority of the population. Cartograms like these have been widely used by Danny Dorling (Box 11.5) to depict the considerable diversity in social structure and wealth that occurs in many densely populated city areas.

Although cartograms usually require human judgment and design, automated routines (such as that in ArcGIS used to produce Figure 12.10B) are also available. Throughout this book, one of the recurrent themes has been the value of GI systems as a medium for data sharing, and this is most easily achieved if pooled data share common coordinate systems, or can be reprojected for comparison. Yet this convenience, as well as wide recognition of the mapped data, sometimes needs to be evaluated against the value of cartometric transformations that accommodate the way that humans think about or experience space, as with the measurement of distance as travel time or travel cost. As such, the visual transformations inherent in cartograms can provide improved means of envisioning spatial structure, and geovisualization offers an interactive and dynamic medium for experimentation with different transformations.

12.3.3 Remodeling Spatial Distributions as Dasymetric Maps

The cartogram offers a radical means of transforming space and hence achieving spatial balance, but sacrifices the familiar spatial framework valued by most users. It forces the user to make a stark choice between assigning each mapped element equal weight and being able to relate spatial objects to real locations on the Earth's surface. The interactive environment of geovisualization and scalable cached datasets provides a means by which the data-integrative power of GI systems can be used to remodel spatial distributions and hence assign spatial attributes to meaningful, recognizable spatial objects. One example of the way in which ancillary sources of information may be used to improve representation of a spatial distribution is known as *dasymetric mapping*. Here, the intersection of two datasets is used to suggest more precise estimates of a spatial distribution.

Figure 12.11A presents a census tract geography for which small-area population totals are known, whereas Figure 12.11B shows the spatial distribution of built structures in an urban area (which might be obtained from a cadaster or very-fine-resolution satellite imagery, for example). A reasonable assumption (in the absence of evidence of mixed land use or very different residential structures such as high-rise apartments and widely spaced bungalows) is that all the built structures house resident populations at uniform density. Figure 12.11C shows how this assumption, plus an overlay of the areal extent of built structures, allows population figures to be allocated to smaller areas than census tracts and allows calculation of indicators of residential density. The practical usefulness of dasymetric mapping is illustrated in Figure 12.12.

Figure 12.12 shows the location of an elongated census block in the City of Bristol, UK, which is characterized by both a high unemployment *rate* (Figure 12.12A) and a low absolute *incidence* of unemployment (Figure 12.12B). The resolution to this seeming paradox is that the tract houses few people, an unusually large proportion of whom are unemployed (see Section 5.4.3 for discussion of related issues of ecological fallacy). However, this hypothesis alone would not help us much in deciding whether or not the zone (or part of it) should be included in an inner-city workfare program, for example. Use of GI systems to overlay fine-resolution aerial photography (Figure 12.12C) reveals the tract to be largely empty of population apart from a small extension to a large housing estate. It would thus appear sensible to assign this zone the same policy status as the zone to its west.

Dasymetric mapping uses the intersection of two datasets (or layers in the same dataset) to obtain more precise estimates of a spatial distribution.

Dasymetric mapping and related techniques present a window on reality that looks more convincing than conventional choropleth mapping. However, it is important to remain aware that the visualization of reality is only as good as the assumptions that are used to create it. The information about population concentration used in Figure 12.12, for example, is defined only on the basis of common sense and is likely to be error prone (some built forms may be offices and shops, for example), and this will inevitably result in inaccurate visual

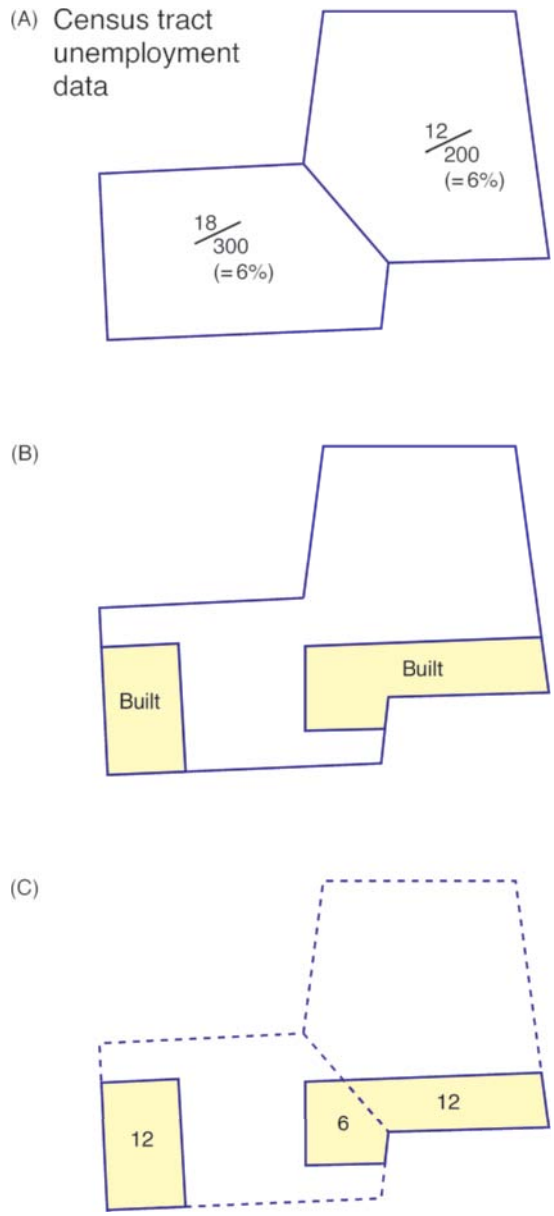
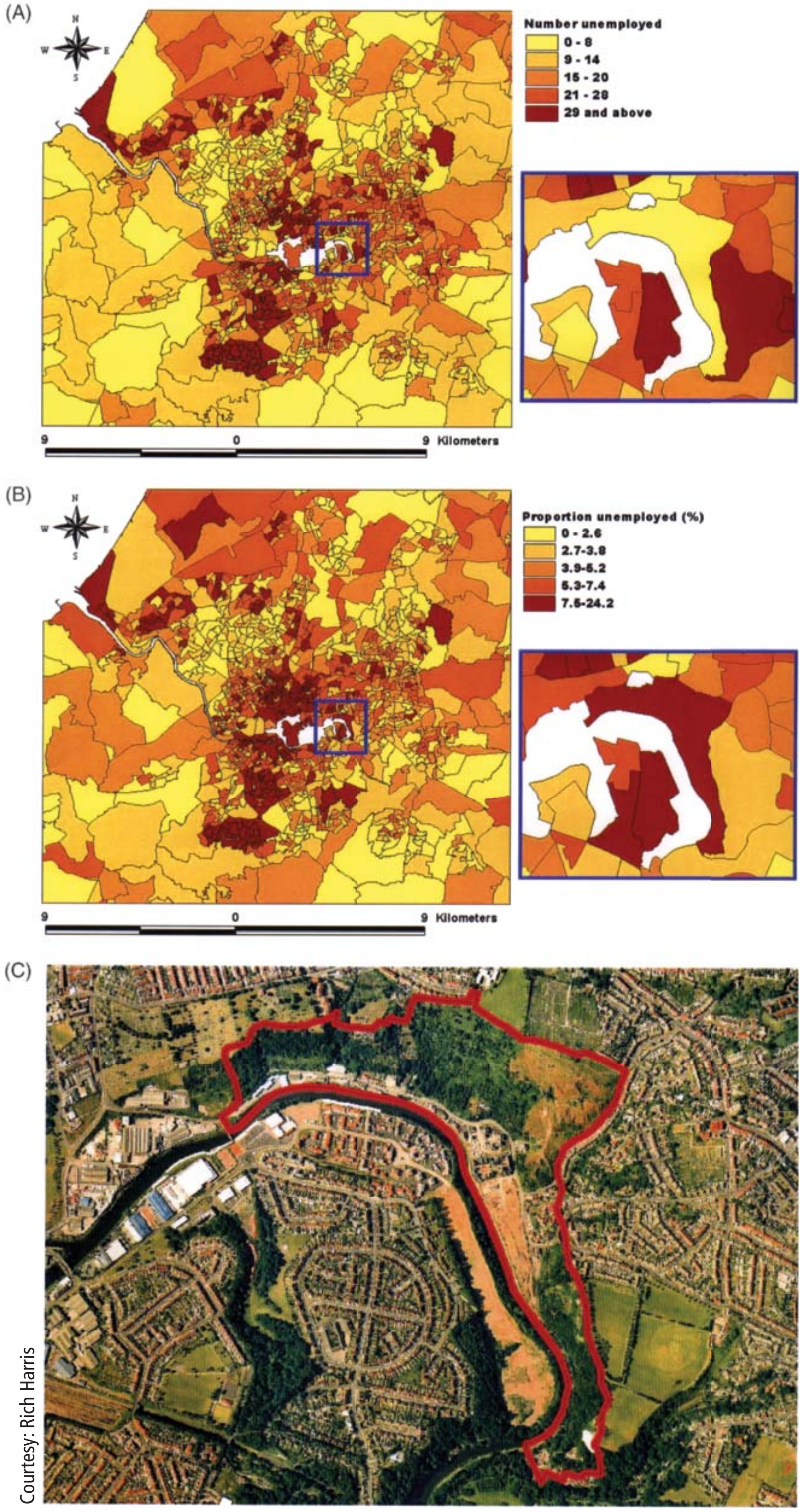


Figure 12.11 Modeling a spatial distribution in an urban area using dasymetric mapping: (A) zonal distribution of census population; (B) distribution of built structures; and (C) overlay of (A) and (B) to obtain a more contained measure of population distribution.



Courtesy: Rich Harris

Figure 12.12 Dasymetric mapping in practice, in Bristol, UK: (A) numbers employed viewed using lowest available census geography (block); (B) proportions unemployed using the same geography; and (C) orthorectified aerial photograph of part of the area of interest.

representation (see also Figure 12.20 below). Inference of land use from land cover, in particular, is an uncertain and error-prone process (see Section 5.3.2), and there is a developing literature on best practice for the classification of land use employing land cover information and classifying different (e.g., domestic versus nondomestic) land uses.

12.4 Participation, Interaction, Augmentation, and Dynamic Representation

12.4.1 Public Participation and Participatory GI systems (PPGIS)

Geovisualization can be used to facilitate the active involvement of many different groups in the discussion and management of change through planning, and may act as a bulwark against officialdom or big business. Good human–computer interaction is key to this process, and the use of geovisualization to foster public participation in (the use of) GI systems is often termed PPGIS. (The same acronym is also used to denote "Participatory GI Systems.") The focus of PPGIS is on how people perceive, manipulate, and interact with representations of the real world as manifested in GI systems (see Box 12.4). Its other concerns include the way people evaluate options through multicriteria decision making (Section 15.4), and the social issues of how GI systems usage remains concentrated within networks of established interests (Section 1.5.5). A related theme is the use of GI systems to create multiple representations—capturing and maintaining the different perspectives of stakeholders rather than framing debate in the terms of a single prevailing authoritative view.

Applications Box 12.4

User Interaction by Indigenous Tribespeople

The Extreme Citizen Science (ExCiteS) group is an interdisciplinary initiative, based at University College London that brings together expertise in anthropology, computer science, and geography, among other disciplines. The group is involved in several participatory mapping projects with indigenous forest communities, most of which are nonliterate, have never used information and communications technology (ICT) devices, and have little or no experience with reading maps, let alone creating them. Allowing these people to engage in spatial data collection and map making therefore requires the development of bespoke software as well as communication and training protocols.

One ExCiteS project, set in the African Republic of the Congo (also known as Congo-Brazzaville), aims to engage indigenous people in monitoring the ecological and social impacts of rainforest logging, using a smartphone application. Initial design work focused upon the task of measurement and representation (Figure 12.13),

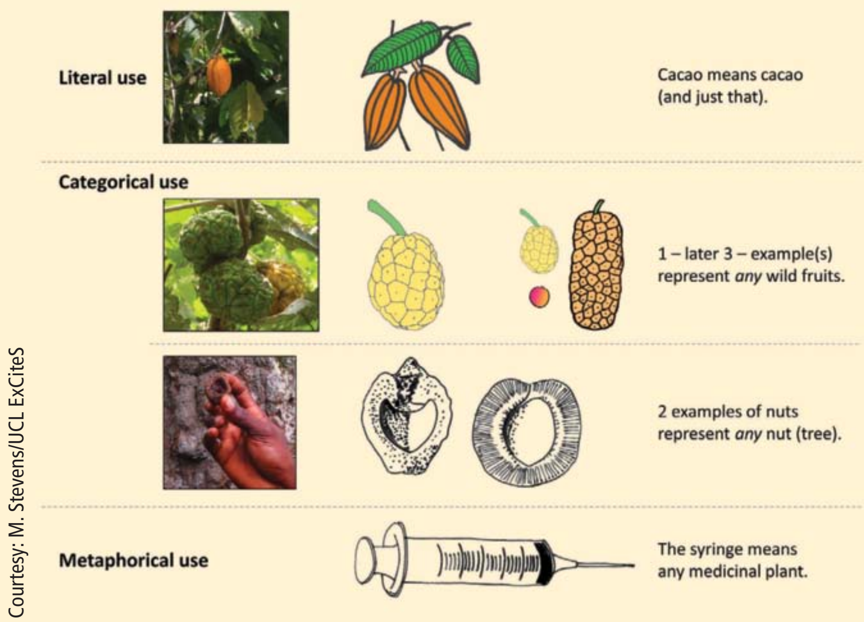


Figure 12.13 User interface design principles for native Congolese tribespeople.

using pictorial icons to represent literal objects (e.g., cacao trees), categories of objects (e.g., examples of the category of native fruits), and metaphors (e.g., the syringe as a metaphor for medicinal plants). Other design work devised a user interface that allows for easy navigation between object classes (arranged in decision trees) and for linking instances to geographic locations and augmenting them with appropriate media (e.g., photography and voice recording).

Fieldwork was used to familiarize users with the devices and their interfaces (Figure 12.14A) so that they might be used to link attributes to locations throughout the study area (Figure 12.14B). Users were asked to comment on interface and icon designs, and their feedback was used to iteratively improve the software. As a result of this participatory design exercise it was possible to establish a set of icons that is well understood by the participants and that represent attributes of the environment that they considered relevant.

Check out this and related projects at the ExCiteS website (www.ucl.ac.uk/excites).

(A) (B)

Images courtesy: J. Lewis/UCL ExCiteS

Figure 12.14 (A) Preparatory work for (B) linkage of attributes to locations in the Congolese study area.

Geovisualization has a range of uses in PPGIS, including

- Making the growing complexity of land-use planning, resource use, and community development intelligible to communities and different government departments.
- Radically transforming the planning profession through use of new tools for community design and decision making.
- Unlocking the potential of the many Open Data (Section 17.4) sources that are becoming available at the local level.
- Helping communities shift land-use decisions from regulatory processes to performance-based strategies, and making the community decision-making process more proactive and less reactive.
- Improving community education about local environmental and social issues.
- Improving the feed of information between public and government in emergency planning and management.

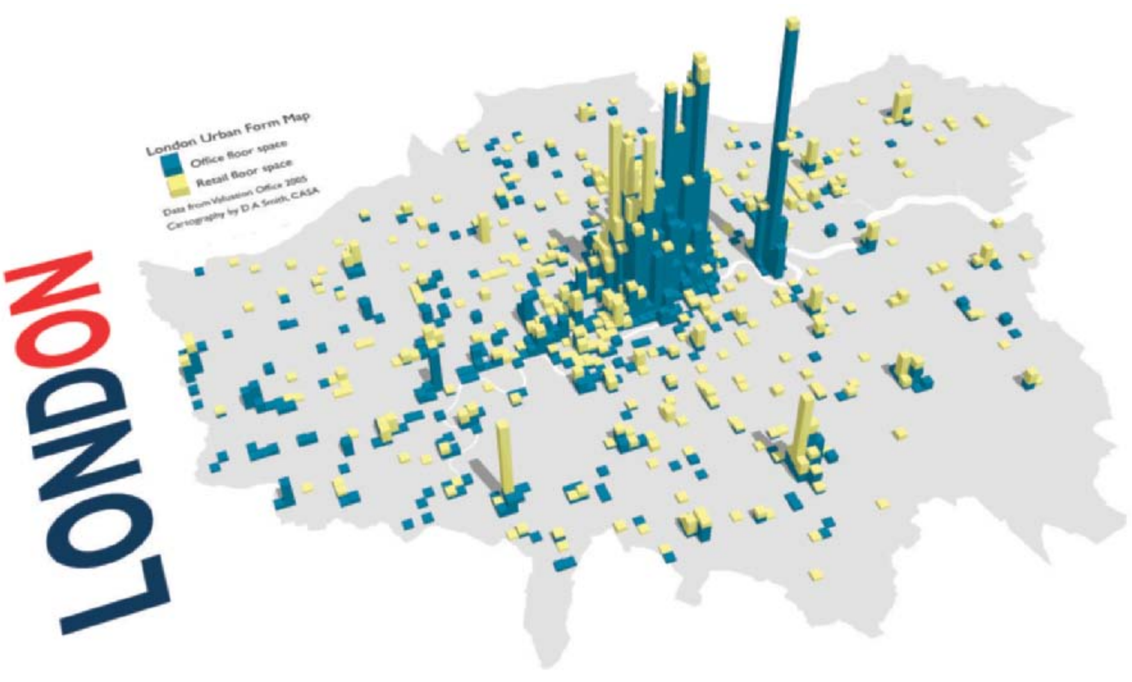
In each of these applications, geovisualization has a strong cognitive component. Users need to feel equipped and empowered to interrogate representations in order to reveal otherwise-hidden information. This requires dynamic and interactive *software* environments and the *people* skills that are key to extracting meaning from a representation. Geovisualization allows people to use software to manipulate and represent data in multiple ways, in order to create what-if scenarios or to pose questions that prompt the discovery of useful relations or patterns. This is a core remit of PPGIS, where the geovisualization environment is used to support a process of knowledge construction and acquisition that is guided by the user's knowledge of the application. PPGIS research entails usability evaluations of structured tasks, using a mixture of computer-based usability evaluation techniques and traditional qualitative research methods, in order to identify cognitive activities and user problems associated with GI systems applications.

12.4.2 User Interaction and Representation in 2.5-D and 3-D

As indicated in Section 11.3.2, extruded 2.5-D representations may be used to reveal aspects of data that are not readily observeable in two dimensions. This is illustrated in Figure 12.15. The map shows London's strongly monocentric structure and the heavy specialization in office facilities both in the historic City of London and London's Docklands. The use of the extruded 2.5-D representation highlights urban density and areas of mixed land use, which are relevant to issues of sustainability and local travel. Metropolitan centers such as Croydon (south of the city) are dwarfed by the main center, suggesting they are struggling to compete. Another trend is the emergence of monofunctional and car-dependent "edge city" developments around Heathrow Airport.

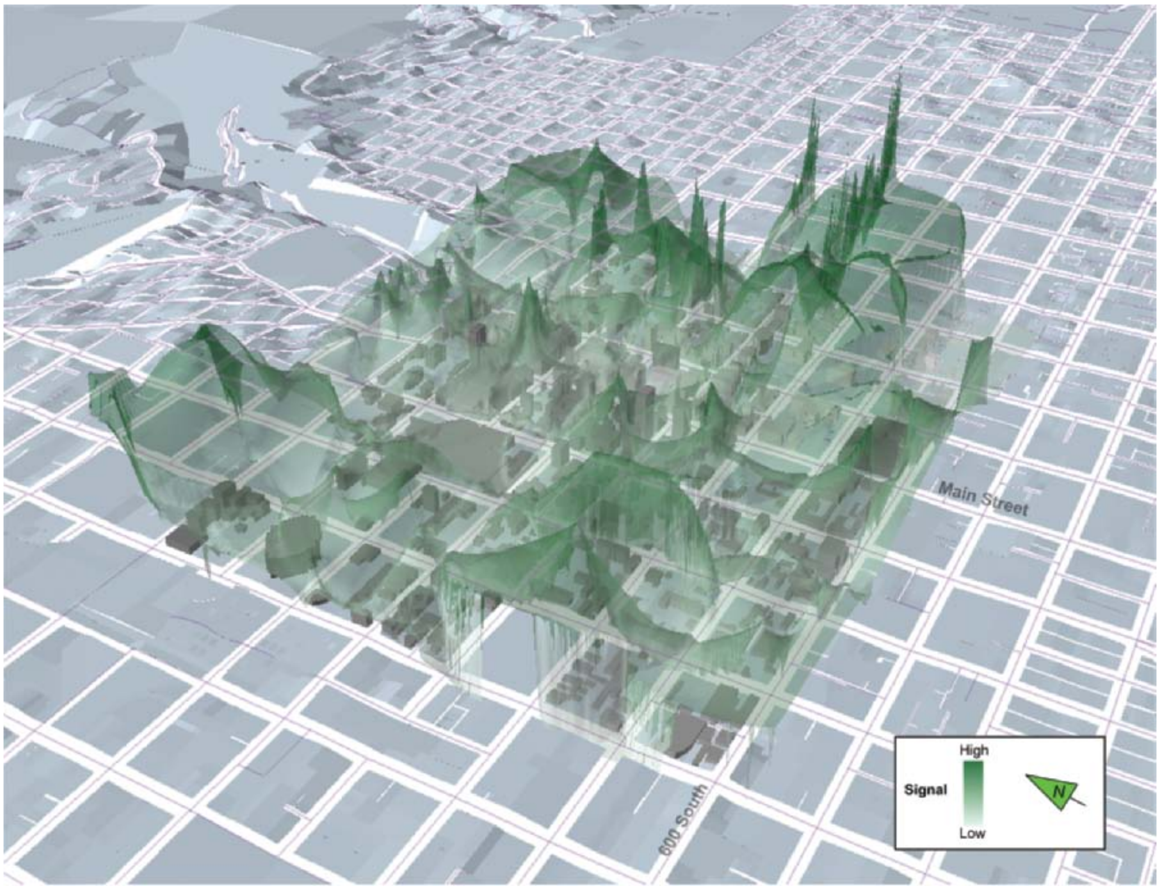
The third dimension can also be used to represent built form, and in recent years, online 3-D models have become available for geographically extensive parts of many cities throughout the world. The virtual globe offerings from Microsoft and Google have arisen following the wide availability of very-fine-resolution height data from airborne instruments, such as Light Detection and Ranging (LiDAR; see Section 8.2.2.2). Augmentation of these models is increasingly straightforward, given the wide availability of free software such as Google Sketchup that enables even the nonspecialist to create 3-D representations of individual buildings and site layouts or to allow users to walk through the interiors of buildings. These representations provide the general user with valuable context to augment online two-dimensional maps and street views, and they have been used for general applications as diverse as city marketing and online social networking. Research applications can benefit from general comparisons with 3-D built form, as with geographer Paul Torrens's work relating the built form of the city to its WiFi geography (Figure 12.16). "Off-the-shelf" 3-D representations can provide very useful contextual information, although it is important to check the provenance of the data that were used to create them, especially if the motivation for their creation was more directly aligned with the generation of advertising revenues than provision of spatial data infrastructure (Section 18.6). Detailed 3-D city models have been used to contextualize the effects of general processes (in the ways suggested in Section 1.3), as for example with modeling the concentration and circulation of pollutants in cities (Figure 12.17).

In many respects, such applications crystallize both what is most exciting and what is most frustrating about GI science. They are typically assembled from diverse sources by stakeholders in local and central government, in utilities, in transportation, and



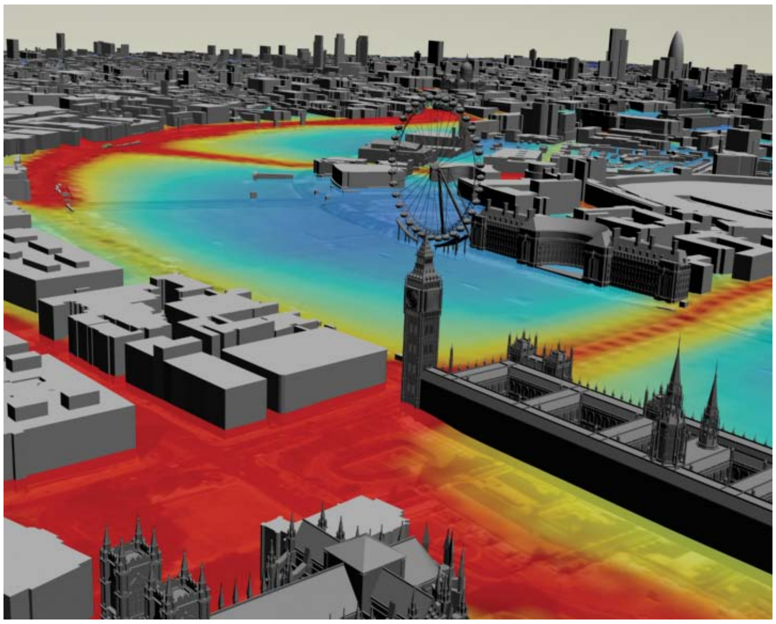
Courtesy: Duncan Smith: data © Valuation Office Agency 2005

Figure 12.15 A 3-D representation of office and retail land use in London. The height of the bars identifies density of office and retail floorspace on 500-meter grid squares.



Courtesy: Paul Torrens

Figure 12.16 A dense network of WiFi infrastructure viewed above the built environment of Salt Lake City, Utah. The pattern of WiFi transmissions suggests no centralized spatial organization, yet does mirror urban built form. WiFi activity is most prominent in the city's traditional commercial core, yet also reaches out to interstitial and peripheral parts of the city. (Areal extent of the WiFi cloud on the ground is ~ 3 km^2: "high" and "low" refers to the strength of WiFi signals, measured in decibels relative to 1 mW.)



Courtesy: Steve Evans: Ordnance Survey data © Crown Copyright; NOx data courtesy of Environmental Research Group, Kings College London and the Greater London Authority

Figure 12.17 Visualizing nitrogen oxide (NOx) pollution in the Virtual London model. This pollutant, often nicknamed "urban smog," is largely derived from vehicle emissions: red identifies higher levels, whereas blue represents lower levels.

increasingly from members of the public. The very detailed yet disparate nature of data holdings suitable for inclusion in 3-D models makes networked GI systems the ideal medium for assembling and integrating data and for communicating and sharing the results. Yet it is crucial to ensure that each of the data sources used is suitable for the task, particularly if multiscale process models are to be applied to them.

It is important to consider the development of fine-scale city models in the context of the seamless scale-free mapping and street-view systems that allow users to view raster and vector information, including features such as buildings, trees, and automobiles, alongside synthetic and photorealistic global and local displays. In global visualization systems, datasets are projected onto a global TIN-based data structure (see Section 7.2.3.4). Rapid interactive rotation and panning of the globe is enabled by caching data in an efficient in-memory data structure. Multiple levels of detail, implemented as nested TINs and reduced-resolution datasets, allow fast zooming in and out. When the observer is close to the surface of the globe, these systems allow the display angle to be tilted to provide a perspective view of the Earth's surface. The user is able to roam smoothly over large volumes of global geographic information. This enables a better understanding of the distribution and abundance of globally distributed phenomena (e.g., ocean currents, atmospheric temperatures, and shipping lanes), as well as detailed examination of local features in the natural and built environment (e.g., optimum location of cell phone towers, or the impact of tree felling on the viewscape of tourist areas).

12.4.3 Handheld Computing and Augmented Reality

Immersion of desk- and studio-based users in 3-D virtual reality (see also Section 10.3.1 for a discussion of virtual and augmented reality) presents one way of promoting better remote interaction with the real world, using high-power computing and very-high-bandwidth computer networks. The same digital infrastructure is also being used to foster improved and more direct interaction with the real world by the development of a range of handheld, in-vehicle, and wearable computer devices. These are discussed, along with some of the geovisualization conventions they entail, in Sections 6.6 and 10.3. Figure 12.18 illustrates how semi-immersive systems are used in field computing, taking the example of a geography field course in the UK Lake District.

Figure 12.18A illustrates how students previously visualized past landscapes, by aligning a computer-generated viewshed with the real world. This approach exemplifies many of the shortcomings of traditional mapping: perfect alignment is possible from only a single point on the landscape, only a single prerendered coverage can be viewed, and there is no way of interrogating the database that was used to create the augmented representation. Use of the equipment shown in Figure 12.18B enables the user to establish the locations and directions of viewpoints, and loaded images are automatically displayed as the user approaches any of the numbered points. The handheld device makes it possible to annotate the view and to display a range of surface and subsurface characteristics (Figure 12.18C). As discussed in Section 10.3, the current generation of augmented-reality devices remains unable to render viewsheds on the fly, for reasons of computer and bandwidth capacity. Nonetheless, progress continues to be made in this direction, for example, through the integration of digital compasses into mobile devices.

Still other media and software are used to immerse users in the artificial worlds of *virtual reality*. Although not mainstream GI system applications, such tools can be used to help users better understand geographic real-world patterns and processes. The advent of immersive and semi-immersive systems has important implications for participation by a broad user base because they allow

- Users to access virtual environments and select different views of phenomena.
- Incremental changes in these perspectives to permit real-time *fly-throughs*.
- Repositioning or rearrangement of the objects that make up virtual scenes.
- Users to be represented graphically as *avatars*—digital representations of themselves.
- Engagement with avatars connected at different remote locations, in a networked virtual world.
- The development, using avatars, of new kinds of representation and modeling.
- The linkage of networked virtual worlds with *virtual reality* (VR) systems.

The developments that have fostered the emergence of 3-D visualization in GI systems have also encouraged the development of online virtual worlds (e.g., Second Life: www.secondlife.com) in which online users (represented as avatars) engage, interact, and collaborate in a peer-to-peer Web 2.0 environment.

There exists the prospect of infusing the collaborative environment of Second Life and other online spaces into virtual Earth applications (see Section 10.3.1) and creating an occupied Digital Earth. It is also likely that the kinds of advanced models discussed in Chapter 15 (e.g., agent-based models: Section 15.2) will also be assimilated into these virtual worlds in the near future.

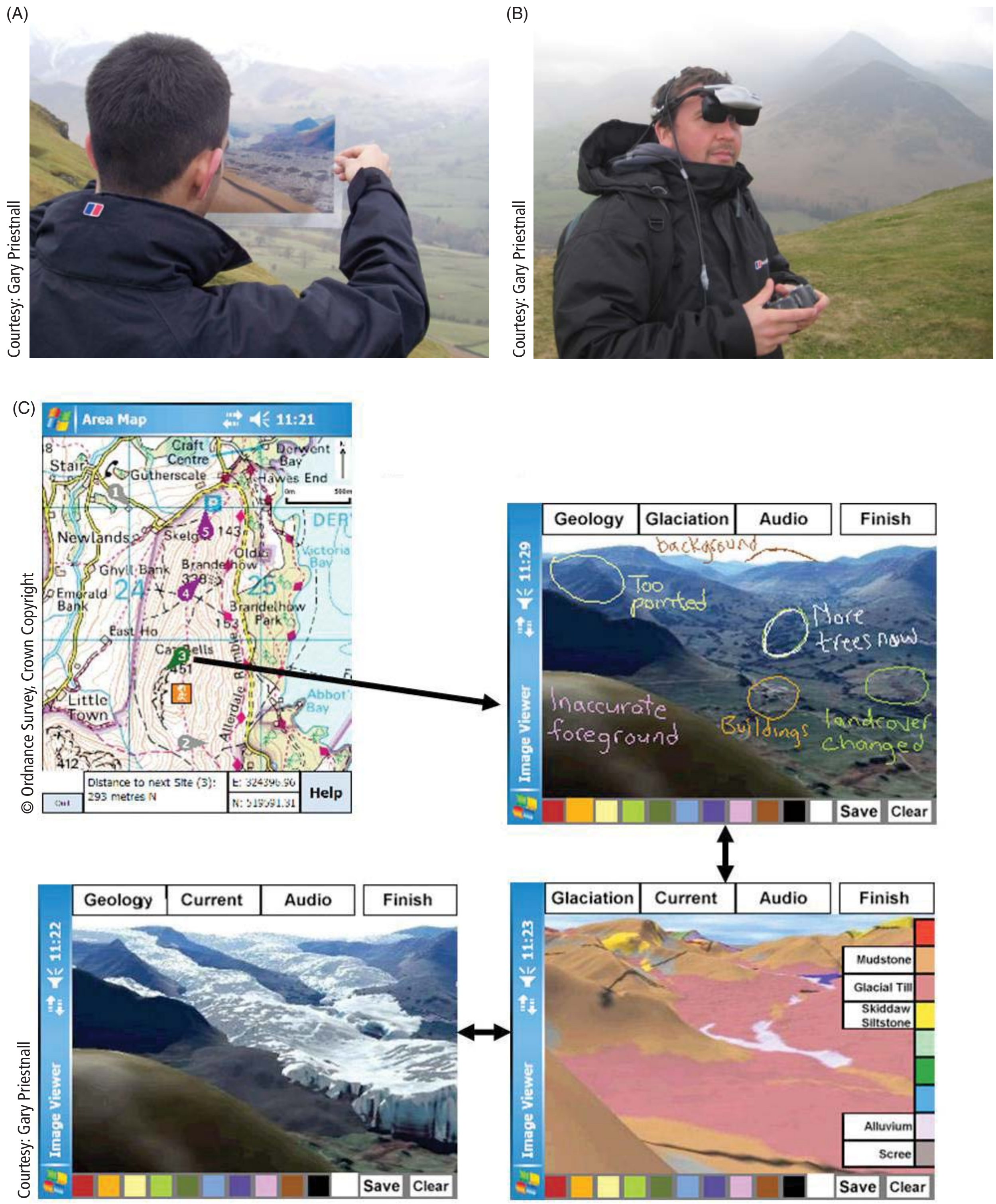


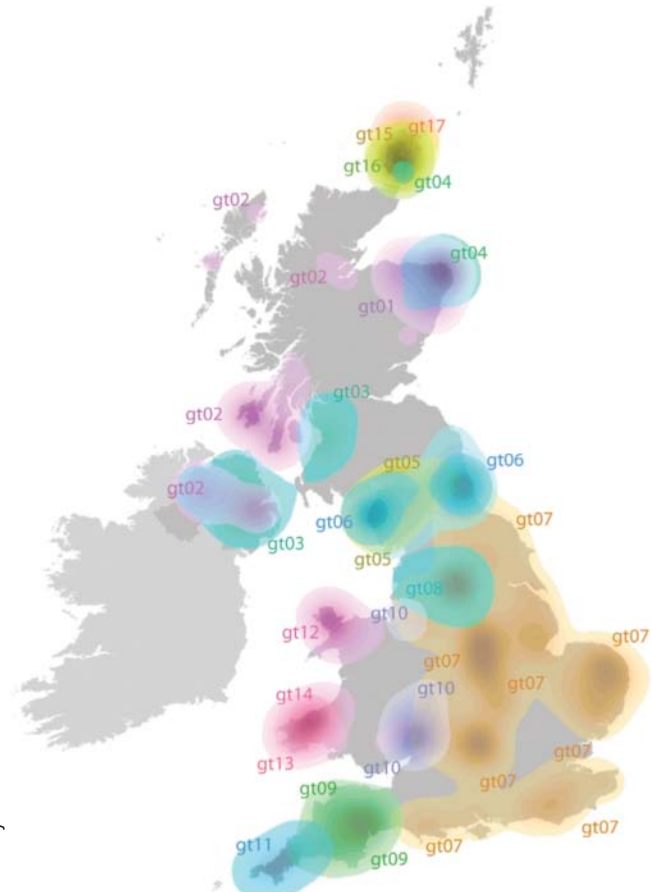
Figure 12.18 (A) Aligning a viewshed transparency to augment a view of the landscape; (B) use of computer devices to achieve the same effect for (C) a number of field sites and different surface characteristics, with the facility to annotate landscape views.

12.4.4 Visualizing Geotemporal Dynamics

Early GI systems were poorly adapted to representing temporal change, although improvements in computer processing power and software enhancements now make animation of representations routine and fairly straightforward. The wider use of geocomputational methods is also increasing the scope for reducing Big Data to mappable phenomena, using a range of visual techniques. It is not possible to summarize the wide range of work in this short overview, and we focus instead upon three instances of mapping geographic phenomena that become apparent at temporal scales ranging from the intergenerational to the diurnal.

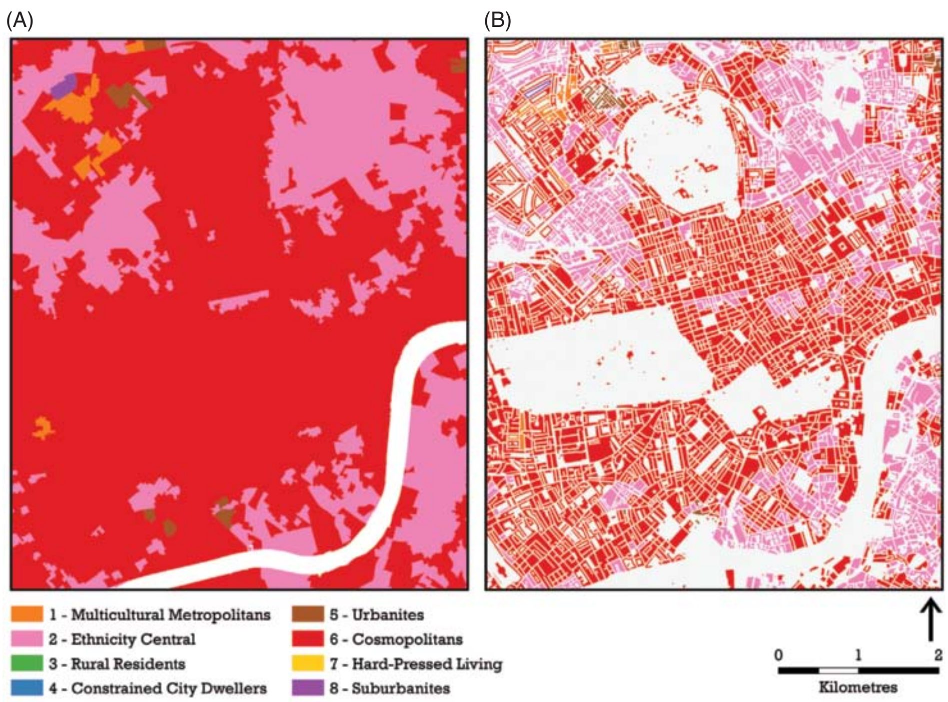
The first (Figure 12.19) comes from the work of geographer Jens Kandt, who has mapped some of the data from Walter Bodmer's (Box 1.4) "People of the British Isles" project. The project took genetic samples from carefully selected individuals whose families had remained in the same localities in the UK for at least three generations. Clustering the important markers on the human genome is a significant Big Data project, and Figure 12.19 presents one of Kandt's attempts to develop a "genetic map" of the long-settled residents of the UK, using distance decay from sample locations. The message of this map is that it is still possible to trace the effects of successive waves of invaders of the British Isles upon contemporary population structure.

The dynamics of change in the built environment of cities is captured in socioeconomic classifications of social structure, which are often updated and mapped every ten years when the results of censuses or other major population surveys are released. Figure 12.20A shows part of London for one such classification, the 2011 UK Output Area Classification, depicted as a choropleth map. Such representations make it possible to depict the kaleidoscope of change between censuses, within the constraint of the administrative geographies for



Courtesy: Jens Kandt

Figure 12.19 A "genetic map" of part of the British Isles. The map uses kernel density estimation to impute values around the biological samples used to create Figure 1.13B.



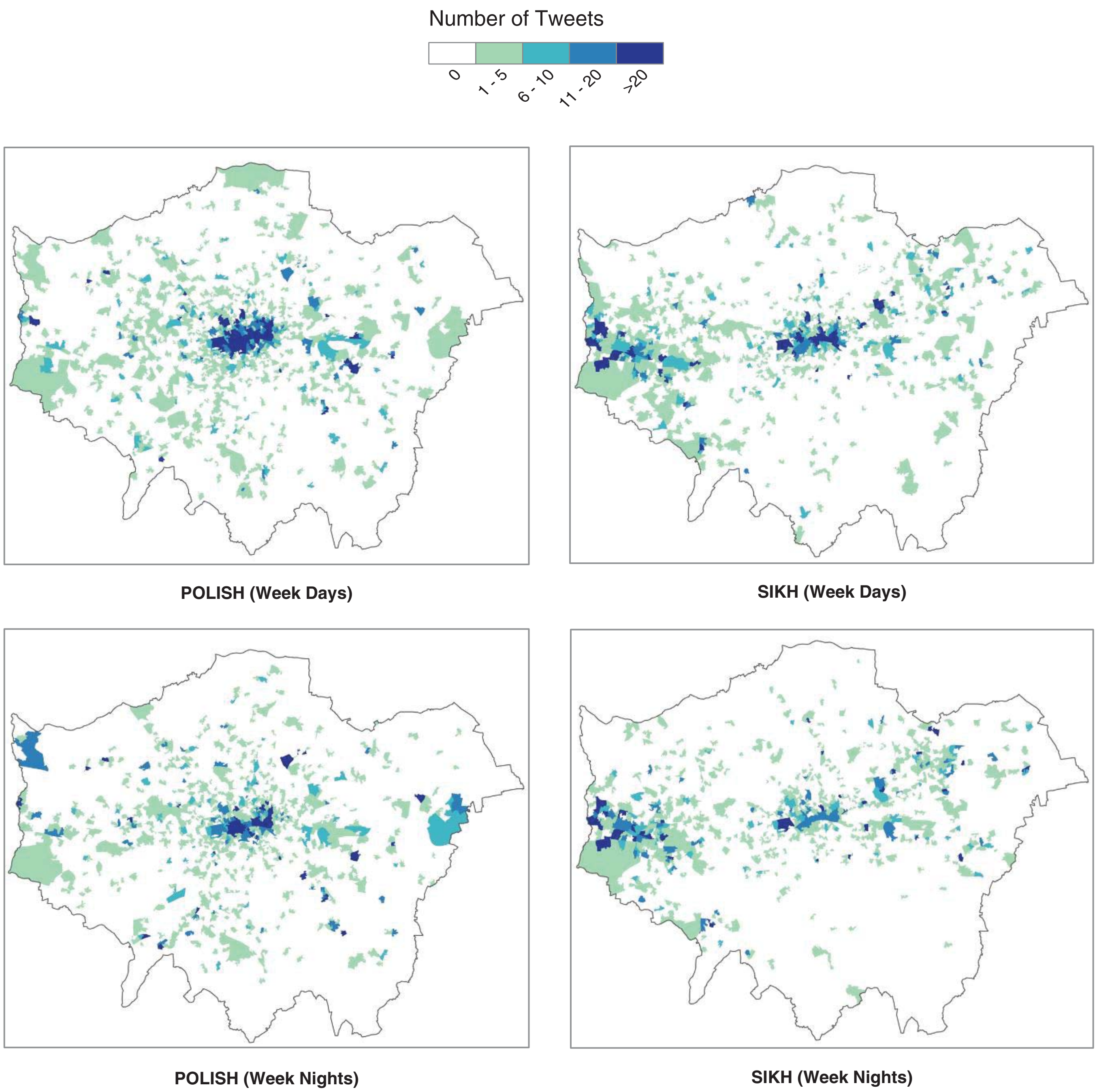
Courtesy: Chris Gale; contains National Statistics and Ordnance Survey (GB) data © Crown copyright and database right 2014

Figure 12.20 Two representations of the 2011 Output Area Classification for the UK in Central London: (A) a standard choropleth map based upon Census Output Area geography and (B) using building footprints from Ordnance Survey (GB) Open Data.

which census and other data are released. Geographer Chris Gale has remodeled this distribution as a kind of dasymetric map (Section 12.3.3), which gives a better impression of changes in residential structure with respect to the built environment. Figure 12.20B uses Open Data made available through Great Britain's Ordnance Survey, and provides a means of mapping socioeconomic distributions that are not visually dominated by large vacant areas such as parks, although this Open Data source does not yet make it possible to discriminate between residential and other land uses.

At the other end of the temporal spectrum, Figure 12.21 presents computer scientist Muhammad Adnan's analysis of geotagged Tweets, selected for different times of day and segmented according to the ethnic and linguistic group of their originator. Such mapping makes it possible to map the flows of different groups within London according to time of day, week, or season. A related map of

Figure 12.21 Geotemporal snapshots of the pattern of Twitter usage in Greater London by individuals classified as being of Polish or Sikh origin.



Courtesy: Muhammad Adnan

Courtesy: Antonio Lima, map tiles by Stamen Design, map data © OpenStreetMap contributors

Figure 12.22 The use of mobile telephone data to characterize daily movement patterns. Hue is used to identify time of day for each individual and travel mode.

activity patterns is provided in Figure 12.22. Here, computer scientists Antonio Lima and Mirco Musolesi have mapped the movements of three mobile phone users over time, using circles of different colors and hues. Hue is used to identify time of day, allowing the user to visualize the correlation between these movement patterns and any synchronization. Such visualizations may be used in attempts to predict future locations or activity patterns of the users.

12.5 Consolidation

Geovisualization can make a powerful contribution to decision making and can be used to simulate changes to reality. Yet, although it may be governed by scientific principles, the limitations of human cognition mean that user interpretation inevitably presents a further selective filter on the reality that is being represented. Mapping is about seeing the detail as well as the big picture, yet the wealth of detail that is available from today's Big Data can sometimes create information overload and threaten to overwhelm the message of the map. Geovisualization seeks to foster effective user interaction and participation in the use of GI systems as decision support tools.

At its worst, greater sophistication of display may simply confer information overload to the user; or it may oversimplify and fail to communicate the inherent uncertainty in the spatial data that are being represented. But at its best, geovisualization empowers users to make informed and balanced assessments of geographic representations and thence to create better descriptions, explanations, predictions, and understanding. These benefits need not accrue only to specialists: geovisualization and PPGIS extend the community of engaged users and encourage it to visualize geography, to exchange spatially literate views, and to participate in effective decision making. Yet although the media and software may be changing at breathtaking pace, the old adage that "seeing is believing" only holds if visualization and user interaction are founded upon representations that are fit for purpose.

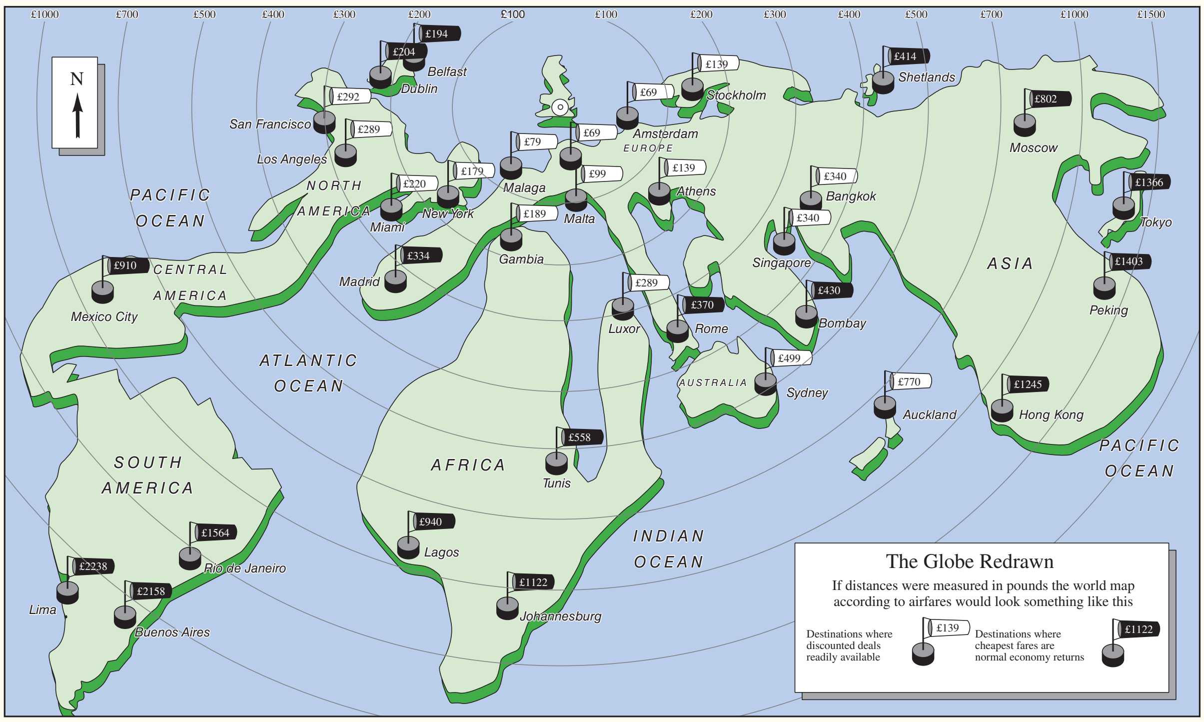
Questions for Further Study

1. Figure 12.23 is a cartogram redrawn from a newspaper feature on the costs of air travel from London in 1992. Using current advertisements in the press and on the Internet, create a similar cartogram of travel costs, in local currency, from the nearest international air hub to your place of study.

2. How can Web-based multimedia GI systems be used to improve community participation in decision making?

3. Produce two (computer-generated) maps of the Israeli West Bank security fence barrier to illustrate opposing views of its effects. For example, the first might illustrate how it helps to preserve an Israeli "Lebensraum," whereas the second might emphasize its negative effects on Palestinian communities. In a separate short annotative commentary, describe the structure and character of the fence at a range of spatial scales.

4. Review the common *sources* of uncertainty in geographic representation and the ways in which they can be *manifested* through geovisualization.



Source: redrawn from newspaper article by Frank Barrett in *The Independent* on 9 February 1992, page 6

Figure 12.23 The globe redrawn in terms of 1992 travel costs from London.

Further Reading

Dorling, D. 2012. *The Visualization of Spatial Social Structure*. Chichester, UK: John Wiley & Sons.

Dykes, J., MacEachren, A. M., and Kraak, M.-J. (eds.) 2005. *Exploring Geovisualization*. London: Elsevier Science.

Haklay, M. (ed.) 2010. *Interacting with Geospatial Technologies*. Chichester, UK: John Wiley & Sons.

Kraak, M. J. and Ormeling, F. J. 2011. *Cartography visualization of spatial data* (3rd ed.). New York: Guilford Press.

Tufte, E. R. 2001. *The Visual Display of Quantitative Information* (2nd ed.). Cheshire, CT: Graphics Press.