Georeferencing
The Geographic Associations of Information

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Laying the Groundwork

Overview of Georeferencing in Information Systems

Georeferencing—relating information to geographic location—is a component of our lives and has been incorporated in our information systems in various ways. We are all familiar with information object types that represent geographic space and features of the Earth’s surface—for example, maps and globes. We use online services that tell us where a named place or address is, how far it is from one place to another, and what route we should take or that has been taken (figure 1.1). In television news, it is no longer a novelty to be shown a “bird’s-eye view” of the location of a story and to be taken on a virtual flight in for a closer view. Newspapers often supplement articles with maps showing the general location and details of the immediate area of the event. Increasingly, our scientific, engineering, governmental, business, and political practices are incorporating geographic information systems (GIS) to hold and analyze georeferenced data, leading to the discovery of geographic distribution patterns that support decision makers and planning (figure 1.2). In general, we are living in an age where technology and information techniques are enriching our understanding of geography and its effect on our lives and the lives of others.

In fact, “whatever occurs, occurs in space and time” (Wegener 2000) and can be visualized, explained, and understood in those terms. The route traveled by a scientific expedition, the path of a hurricane, the recounting of military battles, the individual paths we take through life, and the understanding of complex social and environmental dynamics all involve space and time dimensions. An elegant graphic by Charles Joseph Minard (1781–1870) of Napoléon’s invasion of Russia in 1812–1813 (figure 1.3) illustrates the power of a space-time visualization to convey information. The graphic is described and praised by Edward R. Tufte in The Visual Display of Quantitative Information (1983, 40):
Beginning at the left on the Polish-Russian border near the Niemen River, the thick band shows the size of the army (422,000 men) as it invaded Russia in June 1812. The width of the band indicates the size of the army at each place on the map. In September, the army reached Moscow, which was then sacked and deserted, with 100,000 men. The path of Napoleon's retreat form Moscow is depicted by the darker, lower band, which is linked to a temperature scale and dates at the bottom of the chart. It was a bitterly cold winter, and many froze on the march out of Russia. As the graphic shows, the crossing of the Berezina River was a disaster, and the army finally struggled back into Poland with only 10,000 men remaining. Also shown are the movements of auxiliary troops, as they sought to protect the rear and the flank of the advancing army. . . . It may well be the best statistical graphic ever drawn.

The lowest temperature is roughly −24°C on December 6.

The scope of georeferencing includes the informal means of referring to locations, which we use in ordinary discourse using placenames, and the formal representations based on longitude and latitude coordinates and other spatial referencing systems, which we use in activities such as mapmaking and navigating. Formal rep-
Figure 1.2
Eastern United States population distribution map for 2000 from the U.S. Census Bureau
(Source: http://www.census.gov/geo/www/mapGallery/2kpopden.html.)
Figure 1.3
Graphic by Charles Joseph Minard in 1861, as recreated by John Schneider, showing the routes and the fate of Napoléon’s invasion of Russia in 1812–1813 in geographic and temporal dimensions. (Reprinted with permission from John Schneider, Napoleonic Literature: Losses Suffered by the Grande Armée during the Russian Campaign, http://www.napoleonic-literature.com/1812/1812.htm.)
resentations are geospatial *footprints*—so called because they show on a map of the Earth’s surface a particular spot or area where something is located. These footprints are the basis for mathematical calculations of distance and direction, and for definitions of spatial relationships (e.g., overlap and containment). That is, if we know that one place is located at one spot on Earth and another elsewhere, we can calculate the distance between them and the direction of travel to get from one to the other. We can calculate whether two areas overlap one another—that is, occupy some of the same area—and, if so, whether one is contained within the other. If we have the formal georeferencing of footprints, we can show where places are on a map and how they relate to administrative districts, coastlines, rivers, mountains, or any geographic point of interest. Placenames without geospatial referencing do not allow us to do this.

Most of the georeferencing we encounter daily is in the form of placenames. It has been estimated that at least 70 percent of our text documents contain placename references (MetaCarta Inc. 2005a). Half (49.68 percent) of a set of five million library catalog records (1968–2000) of the University of California contain one or more place-related subject headings or codes (Petras 2004). The pervasiveness of place references in oral histories is very strong; a spokesperson for the Survivors of the Shoah Visual History Foundation reports that all of the testimonies in their archives, which are from survivors of the World War II Holocaust, contain one or more references to the places of importance in their lives, such as where they were born and the ghettos and camps to which they were forcibly transferred (K. Jungblut, personal communication, 2005).

Georeferenced information is everywhere (figure 1.4). Georeferencing is so ubiquitous that it seems that it should be an important component of all of our information systems, from library and museum catalogs to online searching services to data centers to scientific data services. And it is to some degree. Georeferencing is accomplished predominantly through text in today’s information system, where searches to find information about a geographic area must be expressed as a text query—that is, query by placename. Sometimes this works just fine, as in cases where the information has been described with placenames for well-known administrative units. For example, many social statistics are collected by administrative areas (e.g., census tracts) and can be unambiguously retrieved using the names or codes for these administrative areas. But if the need is to find information about a location that could be identified by several placenames (or for an unnamed location such as a location at sea), then the retrieval of relevant information using text is more difficult. It could require some research to find all of the past and present
placenames that exist for the area or its surroundings so that they can be included in the query; then the results have to be reviewed to find the useful results. An example of this situation is attempting to find maps that cover all or part of Los Angeles in an online catalog. The user may find “a map of Los Angeles” by a text search but will probably not find maps of suburbs of Los Angeles such as Long Beach, Hollywood, Beverly Hills, Torrance, Redondo Beach, or Inglewood, which may be equally useful.

An even larger problem is that text searching does not search the whole universe of information about a location. Maps, for example, are traditionally handled by
special units of libraries or mapping agencies and they are accessed through special map indexes, filing systems, and agency contacts. Maps are also not indexed so that they can be found by all of the named features in a particular map; to use the previous example, the map of Los Angeles probably does include Hollywood, Beverly Hills, and so on, but the map cannot be found by using those names through a text search. Data such as remote sensing images and aerial photography is indexed by geospatial location instead of by placename; they cannot be found by the names of places covered by the image. Access to these resources must be directed through information services that are geospatially indexed—for example, GIS interfaces or georeferenced digital libraries such as the Alexandria Digital Library (ADL).

To take full advantage of placename referencing—to be able to map them and see the geographic patterns and associations of information—a translation between the formal and informal representations of geographic location is essential. This highlights the importance of gazetteers: dictionaries of placenames that include geospatial footprints for the named locations. Figure 1.5 illustrates the integration between placenames and associated geospatial information that has been implemented by the U.S. Geological Survey in its Geographic Names Information System (GNIS). The potential of georeferencing services is to extend this type of access to all types of information.

In ways that are ingrained in the information management practices of different communities, we have segmented the information associated with geographic locations by discipline. Much of the geographic data community interprets geographic information as geospatial data representing the Earth’s surface (i.e., data that is formally represented with models of the Earth and coordinate and grid location notations). The advent of GIS technologies to manipulate and capitalize on such data has solidified this view. Within text-oriented communities, librarians have viewed the geographic associations of information as a type of subject heading (e.g., indicating that a document is about a place), an attribute of publication (i.e., place of publication), or a parameter of classification (e.g., the Library of Congress classification of DJK 1-77, which designates “Eastern Europe, History of”), and they have delegated cartographic materials to the care of map librarians in special map collections. Museum curators have represented the collection locations of specimens by descriptive narratives written in the field. Toponymic authorities—units of government with responsibility for establishing official placenames for government purposes—have bridged the gap between text (placenames) and geospatial locations (coordinates that identify the place) to produce freestanding gazetteers that have been seen to be useful but that are often not recognized as a key component
Figure 1.5
Example from the U.S. Geographic Names Information System (GNIS) of links between placenames and associated information about the location based on the coordinates

in information management systems for translation between the data and text domains (figure 1.5). Such integration is, in fact, an idea that has been slow to develop.

The premise of this book is that the users of information systems are best served through unified georeferencing where both placename and geospatial access works across all types of information resources and in all types of information storage and retrieval systems. Users should be able to start with what they know, whether a placename or a geospatial footprint, and create a query to find georeferenced information about a particular location from a variety of library catalogs, data centers,
Panel 1
Georeferencing for Natural History Museum Collections

Museums and herbaria worldwide curate over one billion biological specimens. Every one of these objects is associated with a biological identity and a place of collection. Although there has been much recent effort to digitally capture museum collection data, this task remains largely unfinished, and an even smaller percentage of the total has been digitally geospatially referenced. The natural history collection community would benefit greatly from a federated naming service for geographic names. This is especially true in light of our recent efforts to transform data captured by automated methods from original documents that are capable of directly accessing digital naming services.

Collections often house a vast array of primary archival material associated with biological specimens, including collectors’ logs, original illustrations, bibliographical material, and maps. The collections community is therefore also in the position to contribute to gazetteer development. Access to primary collection information (e.g., collectors’ maps) provides the ability to geospatially reference names that are often not found in existing [digital] naming projects; they may represent variant spellings or features known only in historical contexts.

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museums, archives, directories, and web-based resources. Place-based research should not be hampered by the lack of unifying georeferencing practices to bridge across different domains of information resources.

Using geospatial footprints to gather information of all types together based on their relevance to a location on the Earth’s surface is a powerful query capability and one that overcomes many query difficulties, such as choosing the right place-names to specify a region and working in a multilingual environment. In addition, the ability to visualize the placement of items retrieved from a collection as they are distributed across a geographic landscape instantly conveys information about their relevance to the region of interest that is hidden otherwise.

Within the field of information retrieval, the limitations of text searching are well known. In particular, Don Swanson’s (1988, 96) research revealed that “literatures of different scientific specialties tend to develop independently of one another, but the connectedness inherent in the physical world suggests that there are many fertile, unintended logical connections between these distinct literatures.” He found by searching the medical literature by hand, for example, an undiscovered relationship between fish oil and Raynaud’s Syndrome—undiscovered
because the nutritional effects of fish oil were discussed in one community and the causes of Raynaud’s Syndrome in another and the literatures of the two communities were noninteractive; they seldom, if ever, cited one another (Swanson 1986). In similar situations that are associated with geographic locations, geospatial information retrieval has the potential of doing the same thing: bringing together information from multiple points of view and different communities of practice and research that otherwise operate in separate, noninteractive domains with different terminologies.

Despite this potential, the uptake of geospatial description and access in digital libraries and other information systems outside of GIS has been slow. There are several reasons for this that this book addresses. One reason is that geospatial referencing is perceived as the domain of GIS software rather than as an integral part of general information storage and retrieval software. Another is that geospatial materials (e.g., maps, remote sensing images) are perceived as the responsibility of map libraries and geospatial data centers. Given this perception that geospatial referencing and geospatial resources are “someone else’s problem,” many who could apply georeferencing practices in new ways find themselves ill prepared to integrate geospatial technologies and resources into their systems (e.g., in digital libraries, museum informatics, and online search services).

This book explains the potential of the integration of informal and formal means of georeferencing for information storage, retrieval, and visualization—for all cases where the geographic distribution of information and objects is of interest and where either placename or geospatial referencing is encountered. The application of georeferencing extends to almost all fields of academic and applied study, including the arts and humanities; social, physical, and life sciences; medicine; government administration; petroleum and mineral exploration; message understanding (text analysis); historical and genealogical research; and the documentation of personal histories. The approach of the book is to cover the fundamental concepts, terminology, and standards for georeferencing technologies, with the aim of educating those who would profit from integrating new georeferencing practices into their information systems and services. This includes library professionals, library software vendors, digital library designers, and managers of museum informatics, indexing and abstracting services, and online information services. From a GIS perspective, this book is about putting more emphasis on integrating formal and informal means of georeferencing and working toward a time when place-based resources of all kinds are shared easily among GIS services and services outside the specialized software environments of GIS applications.
A Little History

The term *distributed geolibrary* was advanced by a National Research Council workshop convened by its Mapping Science Committee in June 1998:

A distributed geolibrary is a vision for the future. It would permit users to quickly and easily obtain all existing information available about a place that is relevant to a... *geographically defined need*... relevant to a wide range of problems, including natural disasters, emergencies, community planning, and environmental quality. A geolibrary is a digital library filled with geoinformation—information associated with a distinct area or footprint on the Earth’s surface—and for which the primary search mechanism is *place*....

It is currently easier to find information about a named individual, an agency, or a field of scientific knowledge than about a place on the Earth’s surface. (National Research Council Mapping Science Committee 1999, 1, 13)

The grand vision of the geolibrary was that it would not only enable place-based searching for and evaluation of useful information across distributed resources but that it would facilitate the retrieval, integration, manipulation, and analysis of that information. The analysis environment envisioned was a GIS environment, with mechanisms in the geolibrary architecture for capturing the knowledge resulting from such work (e.g., models, visualizations, reports, and statistics) and making it available to others. The broader construct of a *cyberinfrastructure* has expanded the scope of *digital libraries* in the last few years; the conclusions of this workshop apply equally well to the broader scope.

The Distributed Geolibraries workshop was held to generate ideas for the expansion of the vision and scope of the U.S. National Spatial Data Infrastructure (NSDI), which was established in 1994 by a presidential executive order as a means of "assembling" U.S. geospatial data from federal, state, local, and private-sector sources, as well as encouraging the reuse of data and a reduction in duplicative efforts to collect and archive geospatial data. A geospatial data clearinghouse was established to implement this directive and is administered by the Federal Geographic Data Committee (FGDC), which is part of the U.S. Geological Survey (USGS). As of January 2005, the Clearinghouse has 371 registered servers that are contributing geospatial data collected for local purposes to the NSDI for discovery and use by others (U.S. Federal Geographic Data Committee 2005b).

Also in 1994, the U.S. National Science Foundation (NSF) initiated its digital library program by funding six projects for four years. One of those projects was the Alexandria Digital Library (ADL) at the University of California at Santa Barbara (UCSB). The goal of the ADL project, as stated in the proposal to NSF, was "to develop a user-friendly digital library system that provides a comprehensive..."
range of services to collections of maps, images, and spatially-referenced information.” Researchers at UCSB and their partners proposed to “design, develop and test a distributed, high-performance digital library, in which collections of spatially-indexed information in digital form as well as users are dispersed geographically ... [as] a major step towards the evolution of a distributed digital library supporting both textual and spatially-indexed sources of information and scalable to the national level.” Acknowledging that technical issues relating to spatially indexed collections and services would require attention, the proposal states that the “long-term goal is to remove the distinction between mainstream libraries focusing on text and special libraries focusing on less conventional materials” (UC Santa Barbara 1994). The ADL project resulted in a series of prototype implementations and cycles of user evaluations to inform the next version, as well as a specification for the architecture of a distributed georeferenced digital library. At the end of the four-year funding period, ADL was, and continues to be, an ongoing operational service of UCSB’s Davidson Library with collections of maps, remote sensing images, and aerial photography and an online user interface presenting geographic and other search parameters and visualization of the footprints of individual collection objects (figure 1.6). During the next round of digital library funding by NSF, UCSB applied its ADL experience to integrating digital library support into undergraduate education (known as the ADEPT project: the Alexandria Digital Earth ProtoType Project). Distributed digital library architectural and gazetteer design work continued through this funding period, resulting in digital library software available for downloading, content standards and specifications, and the integration of distributed collections of georeferenced collections to supplement the holdings at UCSB (Alexandria Digital Library 2005).

The precursors to the ADL project were (1) the exemplary collections and services of the Map and Imagery Laboratory (MIL) of UCSB’s Davidson Library, and (2) a project of the Research Libraries Group (RLG) known as the GRIN project—the Geo-Referenced Information Network. Before the ADL project, MIL had already established itself as a forward-looking organization with a collection of historical aerial photography, a growing collection of remote sensing imagery, an extensive collection of maps, and income-generating services in addition to supporting on-campus education, interlibrary cooperative services, and professional map library associations. It participated in the GRIN project, which aimed to create a geoinformation control and retrieval system to provide access to descriptions of materials and data characterized by geographic location. The GRIN design included a name-coordinate thesaurus to associate placenames to geographic footprints and
Figure 1.6
Screenshot of an in-process search using the Alexandria Digital Library search interface (Alexandria Digital Library 2005). At the top right, the map browser shows the search area as a striped box, which was drawn by the user. Within the box is a small square showing the geographic coverage of the top item listed below the map browser. The listings include thumbnail graphics of the images. On the left is a portion of the Catalog Search panel.

graphic displays of the footprints associated with the text description of collection items so that the user could see how the items related to the user’s area of interest (“RLG Enters New Sphere with Geoinformation Project,” 1989). Ideas from GRIN provided the model for the initial ADL demonstration prototype.

In the United Kingdom, the Joint Information Systems Committee (JISC), working on behalf of the higher education community’s funding bodies, funds digital library development for the academic community. JISC has funded a range of geospatial services provided by EDINA, a National Data Centre in Edinburgh, and its partners (EDINA 2005; Reid et al. 2004). The goal of the services is to facilitate the
discovery and use of the geospatial resources available for higher education for the widest possible audience. Among the services and projects are

- Go-Geo! (www.gogeo.ac.uk), an online resource discovery tool that allows for the identification and retrieval of georeferenced metadata records from distributed collections; the current geographic scope is the UK (figure 1.7).
- geoXwalk ("geo crosswalk"), a project that has developed a middleware protoservice for UK academia that incorporates gazetteer services into place-based information services to translate between placenames, postal codes, or other labels and the equivalent UK spatial reference system notations. This allows queries to be sent as geospatial queries to distributed collections of many types of georeferenced information (figure 1.8).

Leading up to and paralleling all of this activity was the CARTO-NET project at the University of Edinburgh and related research funded by the British Library, as well as the individual ideas and projects of professional map librarians. The CARTO-NET project was a shared cataloging system for maps that had a map interface for users. Users could zoom the map into an area of interest and match that area against the maps, gazetteer entries, aerial photographs, and satellite imagery held by the library (Morris 1988). Alan Griffiths and Michael Lynch (1987) at the University of Sheffield used British Library funding to investigate geographic information systems from a library perspective; they identified many of the key problems of placenames in information management systems, including the use of the same name for different places, named places with uncertain boundaries (e.g., "South of England"), name changes through time, and newly named places that are not clearly documented. Several years later, Daniel Holmes (1990), librarian for the Department of Geography at the University of California at Berkeley, published his thoughts about "Computer and Geographic Information Access" that drew from his experience as a member of a team that developed a prototype system called ImageQuery for geographic indexing and retrieval of photographic images using a graphic interface. He saw the need to expand this approach to "all types of media" to develop a powerful tool for "administering and cataloging the holdings of libraries, museums, agencies, organizations, and individuals," which would include "a comprehensive place name listing with appropriate footprint coordinates." Before all of this activity, visionaries such as Nancy Pruett (1986) foresaw graphical user interfaces for geoscience libraries and information services where a search for maps, journal articles, field-trip guidebooks, dissertations, data, and even the names of experts would be carried out by drawing on a computer screen the outline of the area of interest while interacting with an online bibliographic-type database.
GoGeo Catalogue
Wales Enumeration Districts for the 1971 Census

Where

System of Spatial Referencing By Coordinates:

Bounding Rectangle: West: -5.469675, East: 2.446660, North: 53.540167, South: 51.273465

Bounding Polygon:

Nations:

Administrative Areas:

Postcode Districts:

Map

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Figure 1.7
Screenshot of the search interface for the EDINA Go-Geo discovery service for georeferenced information in distributed collections in the UK. (Reprinted from Reid et al. 2004, with permission.)
Supporting cross searching different services

‘Find resources for this postcode’
(NB postcode often used to geo-reference survey data files)

Figure 1.8
Illustration of the EDINA geoXwalk project, where the query starts with a postal code and is translated into coordinates, placenames, and parish names for distribution to distributed collections using different forms of georeferencing. (Reprinted from Reid et al. 2004, with permission.)

By the time of these early library-oriented georeferencing activities, developments in computer-aided mapping and theoretical work on geographic data structures and analysis software had advanced to the point that GIS was a well-known term for a mature technology. In the 1980s, a GIS infrastructure developed (e.g., books, journals, and conferences) and the NSF created the National Center for Geographic Information and Analysis (NCGIA), which developed a college curriculum and a research agenda for GIS. In the 1990s, many fields of study, professions, and work environments, including geology, archeology, epidemiology, and criminal justice, were transformed by the adoption of GIS as a desktop computer technology. The capabilities advanced rapidly: data capture directly from global positioning systems (GPS), the availability of high-resolution imagery as a reference base for data analy-
sis, and the emergence of the Internet and e-commerce and web-based GIS (Clarke 2001).

Advancement in GIS has resulted in commercial products, standards, education and training, and infrastructures for professionals, services, and data management. Outside of the GIS environments, progress in the use of geospatial referencing has been less dramatic. This book is intended to provide some basics to introduce geospatial referencing into other types of information systems outside of the traditional GIS domains, and to facilitate the integration of placename and geospatial georeferencing in information systems of all types.

The Basics

Chapter 2 focuses on the users of georeferencing information services, providing a brief overview of some relevant insights from the field of cognitive psychology into how humans perceive and respond to geographic space. This is the basis of all of our attempts to represent geography in useful ways; in particular, it forms the basis for building information systems that incorporate georeferencing in ways that resonate with and are effective tools for users.

Chapter 3 contains basic information about types of geospatial information objects (e.g., maps, remote sensing images from spacecraft and aerial photography), and the scanning and digitizing processes that turn hardcopy maps and images into georeferenced datasets. To complete the picture of types of georeferenced information objects, examples of georeferenced text are included.

Fundamental concepts of geospatial referencing are covered in chapter 4 on a nontechnical level. This includes an explanation of why “longitude, latitude” is probably a better order of referencing than “latitude, longitude” and what difference the geodetic basis of coordinates makes. The meaning of “small scale” versus “large scale” for maps is explained as well as how “scale” compares to “resolution.” Methods of projecting the Earth’s three-dimensional surface onto a two-dimensional display are described, as well as some of the problems that result (e.g., distortions and discontinuities). Also included are issues of data uncertainty, ways of generalizing geographic footprints, and types of geospatial relationships between places.

Chapter 5 is devoted to gazetteers and to their role in georeferenced information systems. Ways of modeling gazetteer data—that is, descriptive and definitional information about a named geographic place—are covered, with diagrams to illustrate the arrangement and nesting of descriptive elements as structured by several
gazetteer models. Sources of gazetteer data are discussed along with issues of gazetteer interoperability and gazetteer data conflation. Examples of applications of gazetteers in information services are given, including the process of computer analysis of texts to identify placename references so that the text can be related to spatial locations (known as geoparsing).

The ways in which georeferencing has been included in metadata structures is the topic for chapter 6. Because these formal descriptive structures for georeferencing have emerged through the last 35 years and have built on one another to some extent, the different structures are presented in roughly chronological order by when they first appeared, but described in their current versions. Diagrams are included in this chapter as well to provide a pictorial view of the structures of the descriptive elements used to document both the placename and geospatial associations of the information object represented by the metadata. The chapter ends with a discussion of general considerations for geospatial metadata elements for future metadata design.

This all leads us to the focus of chapter 7 on geographic information retrieval (GIR). Given that the geographic associations of information have been identified and documented and the information is held in accessible collections, how is GIR implemented? The basics of spatial matching operations are described, including methods of calculating spatial similarity between a query region and the geospatial footprints of the information objects in the collections. But how do we know how effective these methods are in returning relevant information to the user? Issues surrounding the evaluation of the effectiveness of GIR for both placename and footprint searching are presented.

Terminology and Meanings

In georeferencing, multiple fields of study and interest overlap and each brings its own terminology to the discussion, often with contextual, community-based meanings that are not apparent to others. Throughout the book, many terms with special meaning are used and an attempt is made to make their meanings, as used in this book, clear both in the chapters and in the glossary. Some terms with potentially confusing meaning are introduced here since they apply throughout.

For geographers, the terms geography and geographic are terms that are inherently geospatial and thus can be used to mean the geospatial representation of physical location by use of, for example, longitude and latitude coordinates. This is geography as the undivided, continuous surface of the Earth that contains discrete
named locations and physical features but is not limited to such features. For others, the use of placenames alone and the use of hierarchical schemes for the administrative relationships of places is a sufficient representation of geography, with the addition of geospatial coordinates an added bit of information. For this discussion of a unified georeferencing framework and way of thinking, it is necessary to make a clear distinction between geospatial (continuous) and named-feature (discrete) georeferencing. Therefore, the terms formal and informal georeferencing are used. Others refer to this distinction as a difference between quantitative and qualitative, which indicates the difference between representations that can be treated mathematically and those that cannot. Geospatial representation is associated with formal quantitative georeferencing. This distinction is discussed more fully in the succeeding chapters.

The term information systems is meant to include a wide assortment of collections and information services, including but not limited to the collections and services associated with libraries and museums. Georeferencing applies to any information system where the associations of information and data to place are relevant and important. The focus in this book is on the design of georeferenced information systems—on users, collections, the representation of formal and informal georeferencing, metadata, and information retrieval—outside the realm of GIS environments.

In information systems, some confusion is caused because the information object of different systems and communities is not at the same level of granularity. Giving some illustrative examples is probably the best way to explain why this is important. Libraries have traditionally treated the book, journal, or map as their information object, which they describe in a catalog record with the author or producer, the title, the publisher and date, and so on. Digital libraries do this as well but also recognize collections (a higher level of granularity) and chapters of books (a lower level of granularity) as information objects. Archivists have traditionally considered collections of manuscripts or correspondence as the objects in their care, as well as the individual manuscripts and letters in those collections. Museums similarly treat collections as objects, as well as the individual artifacts, specimens, art works, and other holdings in those collections. Bibliographic indexes, such as Engineering Index, treat the individual journal article or conference paper as their information object, each of which is referenced to the journal or conference to which it belongs. Internet search services have evolved ways of handling nested web pages that variously represent collections of pages as a single object and individual pages as components of those objects. Granularity can be thought of as being a level of detail or a level in a hierarchy of object types. For example, an administrative hierarchy for
named geographic places will have the nation/country level, a state or province level, a county or parish level, and so forth. An information system that uses such a hierarchy will choose the level of hierarchy (i.e., granularity) that best suits its purposes. Geographic information systems (GIS) typically consider individual features and data points as their information objects; this fine level of granularity supports analysis, visualization, conflation, and similar activities. The important point is that georeferencing can be and is applied at any level of information object granularity, and different communities will be dealing with different levels of detail. The principles and ways of thinking about georeferencing in this book are applicable across the board.

Some terms are introduced simply to make the reader aware of their existence in the context of georeferencing. These are terms that come up from time to time or add links to the way concepts are discussed in related literatures. Often they do not get full development because they are not central to the discussion. Useful terms are brought together in the glossary.

The one-word version of placename is used in this book. It represents an important concept in georeferencing—a concept that is strongly associated with place while also being a type of name. This is one of those terms that has been migrating from two words to a hyphenated term and now to one word by those who use it often. This happens to a lot of words in English. For example, such a migration happened to the word today. It started out as two words (to day) and then became a hyphenated term (to-day). Now, it is hard to imagine a time when it wasn’t a single word. Similar concatenations are happening with many computer-related terms, such as from on-line to online. Geo-referencing is also seen as a hyphenated term. Georeferencing, however, is a concept and an activity that is mature enough to warrant its own one-word label; likewise placename.

Some of the concepts referred to in this book are commonly known by more than one term. Place name is one example; other terms that are used for this are geographic name and feature name. In these cases, one expression for a concept is used most of the time, though not all of the time because sometimes one of the other expressions seems to fit the context better. These equivalencies of terms are indicated every now and then with something like “placenames (aka feature names, geographic names).”
Spatial Cognition and Information Systems

This chapter focuses on how humans deal with geographic information, specifically on the aspects of spatial cognition that relate to georeferenced information system design. This includes some of the insights that are supported by research on how we acquire, store, and access geographic knowledge; how we categorize geographic knowledge; and how we communicate about geographic spaces, especially how we ask questions about geographic features and routes and what sorts of answers are useful to us. To some degree, this depends on individual, cultural, and disciplinary preferences that need to be taken into account when designing georeferenced information systems.

Some Basic Concepts of Spatial Cognition

Research supports the notion that our internal representation of geographic knowledge in long-term memory is fragmentary and incomplete. It is not a coherent maplike representation, as is implied by the mental-map metaphor, but more like a cognitive collage containing geographic knowledge stored in different formats, from multiple sources, and from different points of view (Hirtle 1998; Tversky 1993). From this collage, we mentally construct spatial models about particular places and environments for particular purposes, as needed for immediate use to navigate, give directions, ask questions, understand references to places in the news, and so on. Geographic knowledge in long-term memory has been characterized as being like architectural models that include the spatial relationships among the landmarks in the environment in a perspective-free manner that allows the taking of many perspectives on them (Tversky and Taylor 1998).

Because this knowledge is incomplete and most likely does not contain all the information we need for particular situations, we estimate and extrapolate, and in the process we routinely distort the information in predictable ways. Experiments
have shown, for example, that the recall of distances and directions between geographic features is systematically distorted. One pattern is to estimate the distance to a well-known landmark from a less well known location as shorter than the distance from that landmark to that other location (e.g., Lloyd and Heivly 1987). For example, I might estimate that the distance from where I live to city hall is 4 miles, but if asked how far it is from city hall to my house I might estimate a greater distance—say, closer to 5 miles. A similar effect is seen in our treatment of the relationship between a well-known prototype and a variant of that prototype. It is immediately clear, for example, that the meaning of robin is closely related to the meaning of bird, but in tests that measure response time it takes us a bit longer to decide that bird is conceptually close in meaning to robin (Tversky 1977). Another effect is to remember shapes and geographic relationships as more schematic (e.g., straight lines and right angles) than they really are (Barkowsky 2002).

Our sense about the details of a place (e.g., how big, how high, exactly where it is) and about relationships between places (e.g., how far away and in what direction) can be based on belief or knowledge, with belief being something that we assert to be true and knowledge being justified by evidence or inference (Worboys and Duckman 2004, chap. 9). Geographic knowledge is acquired from observation and personal navigation in the environment, as well as from secondary sources such as verbal descriptions, maps, and texts. If the geographic facts and relationships we believe to be true are contradicted by actually being there, we can adjust what we know. Or as Gordon Livingston says, quoting a platoon sergeant in his book Too Soon Old, Too Late Smart (2004, 1–2), “If the map don’t agree with the ground, then the map is wrong.”

Researchers have classified human spatial cognition in several ways based on the research literature in the field (Golledge 1991; Mark 1993). One classification of three basic types of geographic knowledge is widely accepted:

- **Declarative geographic knowledge** consists of geographic facts that may or may not be associated with the map locations of the associated feature. For example, a person may know about the historical or current events that occurred in Somalia or Belgrade without a clear idea where to find these places on a map of the world.

- **Procedural geographic knowledge** allows us to find our way around our environment—that is, to find our way by using cues and learned responses or conscious decisions along a path. This navigation information contributes to a person’s store of declarative geographic knowledge, and the accumulation of a set of routes in an area leads to the development of a survey-type mental model that can be used to derive shortcuts and paths to other destinations. Such conceptualizations are not
necessarily grounded in the culturally defined and learned orientation of most maps, which have north at the top.

- **Configurational geographic knowledge** (aka survey knowledge) is maplike and ranges from a basic topological sense of the associations between features in the environment without any sense of direction or distance (i.e., *in the neighborhood of or far away*) to a general sense of directions and distances amongst landmarks and, at the most advanced stage, to nearly complete knowledge of the coordinates of features and the distribution of features in geographic space (Smith and Mark 2001). Configurational geographic knowledge incorporates and contributes to declarative geographic knowledge.

Golledge (1991) proposes that declarative and procedural knowledge develop quite easily in most people, but configurational knowledge develops less in some people and more in others (also see Nygeres 1993). Developing configurational geographic knowledge is related both to individual differences in spatial ability and exposure to map reading and spatial reasoning skills through formal education and through the use of maps in daily activities.

Psychological research has indicated that humans make use of different mental strategies for small-scale spaces in contrast to large-scale spaces. In this case, *small scale* is defined as a space in which the whole area and everything in it can be seen from one vantage point (*proximate space*) and *large scale* as a space where navigation or secondary sources (e.g., maps) are needed (*distal space*). Linguist David A. Zubin has also broken down the continuum between these extremes into a typology of geographic spaces that is based on the size of objects within the space compared to the human body, and whether or not spaces can be seen as a whole or must be mentally constructed from known components (Freundschuh 1998; Mark 1993). Based on such schemes, Daniel Montello developed four classes of “psychological spaces” depending on a person’s point of view: *figural space* is the space of desktops, pictures, visualizations (including maps), and small three-dimensional objects—in other words, things we can view and perhaps handle without moving about; *vista space* is small-scale space such as a single room or a town square that can be seen from one vantage point; *environmental space* encompasses things such as neighborhoods and cities that surround us, so that the spatial layout can be understood given enough exploration and time; *geographical space* is much larger and must be learned through symbolic representations (i.e., maps and models) or from images taken from a great distance (e.g., from spacecraft). Maps and images themselves are small items that can be handled and are therefore part of *figural space* even though they represent *geographical space* (Montello 1993).
Panel 2
Geographic Points of View

When I was a child, I was taught that there were seven continents in the world: North America, South America, Europe, Africa, Asia, Australia, and Antarctica. This could be seen on the map in any classroom: North and South America at the center of the world, Europe and Africa to the right (or the “east”) and Asia and Australia to the left (or the “west”). Antarctica was the white blur spread across the bottom of some maps, missing from others altogether.

Many years later, during a discussion of the continents among my first group of students of English as a Second Language, I was at first puzzled when my students insisted there were six continents. I thought that they had forgotten Antarctica, or even mistaken “six” for “seven.” But of course, the geographic reality is that Eurasia is a single continent, an obvious, indeed, an undisguisable fact on any map that places Tokyo or Beijing at the center of the world.

I now live and work at the imaginary continental divide of my childhood, in a place vaguely named “Central (Eur)Asia.” The librarians at my university have been frustrated for many years in the search for good maps of this place, particularly for atlases in which the areas of greatest interest to our students do not disappear into the center binding of the book. We look forward to access to georeferenced materials that will demonstrate to the future policymakers studying here the larger consequences of local actions, in hopes of preventing future regional problems such as the shrinking of the Aral Sea.

Leslie Champeny
Library Director
KIMEP (Kazakhstan Institute of Management, Economics and Strategic Research)

The geographic knowledge we store from procedural and secondary sources is more qualitative than quantitative. We are more likely to understand that a place is near or far than to know the exact mileage; more likely to know that the direction is generally north than the actual angle of the relationship; more likely to know generally where a city is within a state than its coordinates. But this general knowledge allows us to create more geographic detail than we actually know by estimating from our base of geographic knowledge and thus serves us reasonably well (Barkowsky 2002). Mark (1993, 57) also makes the observation that we are able to relate the spatial knowledge and reasoning skills acquired within familiar small-scale, procedural geographic knowledge spaces to geographic knowledge represented as maps, even though maps do not represent the world as it is experienced. Those who study map reading and spatial reasoning skills and teachers who teach these skills realize that learning to do it involves the juxtaposition of personal
experiences in physical space to abstracted, symbolic map visualizations and learning to make the transition (e.g., Ishikawa and Kastens 2005).

Our mental processes for geographic information are the basis for some common errors in our geographic assumptions. If you ask a group of people what direction Reno, Nevada, is from San Diego, California, or to draw a sketch of the North American and South American continents, chances are that many of the answers will not agree with what is on the ground (figure 2.1). Since the state of California is west of the state of Nevada, many will factor this knowledge into their answers and assume that San Diego is further west than Reno (it is not). Since the North and South American continents constitute a unit separated by large oceans from other continents, many will draw South America more or less under North America rather than being offset to the east to the point where the west coast of South America is nearly in line with the east coast of Florida.

In an investigation using 108 students at the University of Alberta, Jean-Claude Muller (1985) found additional evidence that this type of distortion of spatial relationships at the global level is common. His research presented a list of fifteen cities distributed around the world and asked the students to put them in order from west to east. Another list of fifteen cities was presented for the task of ordering them
Table 2.1
Lists of city names used to test the geographic knowledge of students at the University of Alberta in 1985

<table>
<thead>
<tr>
<th>To rank by longitude from west to east:</th>
<th>To rank by latitude from north to south:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canton</td>
<td>Madras</td>
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<td>Boston</td>
<td>Tananarive (Madagascar)</td>
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<td>St. Louis</td>
<td>Bogota (Colombia)</td>
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<tr>
<td>Tunis</td>
<td>Dakar (Senegal)</td>
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<tr>
<td>Casablanca (Morocco) (rank #1)</td>
<td>Vancouver</td>
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<tr>
<td>Winnipeg</td>
<td>Cape Town</td>
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<td>Sydney</td>
<td>Bombay</td>
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<tr>
<td>Washington</td>
<td>Los Angeles</td>
</tr>
<tr>
<td>Tehran</td>
<td>Anchorage (Alaska) (rank #1)</td>
</tr>
<tr>
<td>St. John's (Newfoundland)</td>
<td>Tashkent</td>
</tr>
<tr>
<td>Denver (Colorado)</td>
<td>Buenos Aires</td>
</tr>
<tr>
<td>Havana (Cuba)</td>
<td>Milan</td>
</tr>
<tr>
<td>Johannesburg</td>
<td>Saigon</td>
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<tr>
<td>Singapore</td>
<td>New Orleans</td>
</tr>
<tr>
<td>Caracas</td>
<td>Cologne</td>
</tr>
</tbody>
</table>

from north to south. The city lists are shown in table 2.1. The correct arrangement of these lists is printed in an appendix to this chapter for the curious.

Muller's lists made sense when this research was done twenty years ago—lists of places that were "fairly well known" for students in a Canadian university, with the addition of the country or state for "quicker identification" when needed. They are republished here just in case someone wants to try the experiment again. Muller reports that some of the distortions revealed by the north-south and east-west orderings were expected, such as "Europe being perceived much further south relative to North America"; some were surprising, such as "Buenos Aires being south of Cape Town."

These experiments are contrived in some sense because the participants did not have a personal need for the information they were asked for. They also depend on the ability to recall spatial knowledge. Our ability to recall what we have experienced or learned varies from person to person and to the degree that the information has been strongly or weakly integrated into our store of knowledge. Recognition, on the other hand, allows us to access knowledge that cannot be recalled since we are provided with cues that tap into our stored knowledge. Recognition often comes into play in geospatial contexts. We can recognize where we are by the surroundings, landmarks, and other contextual clues. Spatial displays
(e.g., maps, globes, aerial photographs) can provide the spatial context we need to navigate and understand the relationships of features and objects in geographic space. On seeing the map and remote sensing image in figure 2.1, the orientations of Reno and San Diego and North America and South America are recognized even if we may not recall the orientations correctly.

There is research to suggest that choice of expression to describe geography to nonspecialists results in different interpretations and will therefore affect the results of tests of geographic knowledge, ease of navigation of user interfaces for information systems, and so on. Smith and Mark (2001) ran an experiment where they asked students in two large sections of an undergraduate “World Civilization” course to write down the first responses that came to mind during a thirty-second time period for each of these categories: “a kind of geographic feature,” “a kind of geographic object,” “a geographic concept,” “something geographic,” and “something that could be portrayed on a map.” Some terms came up frequently for all of the categories—for example, mountain, river, and lake. But “geographic feature” elicited almost exclusively natural physical features; “geographic object” generated small, portable items such as maps and atlases; the only term for “something geographic” that did not show up elsewhere was world; the phrase “geographic concept” generated the lowest degree of agreement on what that meant; and only in response to “something that could be portrayed on a map” were “things produced by people, either through construction or by fiat,” written down, like city, road, park, and building. The authors conclude that for the students participating in this exercise “being geographical and being portrayable on a map are definitely different concepts.”

There is also research to suggest that when subjects are given tasks where they are introduced to objects in a spatial setting (e.g., an office layout with objects in file drawers, on desks, and so forth) and the objects are given names, the subjects can recall information about the objects by name more readily than by spatial location (Jones and Dumais 1986). This suggests that names carry a great deal of information concerning the object’s content and its purpose and that an object’s location appears to carry considerably less information (Jones and Dumais 1986, 61). This is an interesting result and can be related to our practice of georeferencing by place-name. Names can be used as cues for associated information and as a means of communicating about geographic locations. However, we may find that geospatially based georeferencing will become more familiar and an equally comfortable way to deal with geographic information in the future as we are more frequently exposed to map-based interfaces to computer-based information systems.
Chapter 2

Vagueness of Georeferencing

A significant aspect of spatial cognition is the inherent vagueness of geographic places. The concept of vagueness applies to the use of placenames for locations with inexact boundaries (e.g., Southern California and the Great Lakes Region) and to spatial prepositions used in informal georeferencing (e.g., near and in) as well as to the use of placenames with specific boundaries but in a general way. An example of the latter is that you might say you are from Dallas when you are in fact from a small, less well known suburb and you are using “Dallas” in the sense of a general area in order to be understood (“Dallas area” would have been more correct). One physical condition that causes inexact borders and thus vagueness is when a feature’s boundary is defined by another feature such as a river, a mountain range, or a coastline. Whether from the use of placenames and geographic references in a general sense or because of inexact boundaries, the vagueness of georeferencing implies the existence of borderline conditions where it is not clear whether an area near the border is part of the feature or not. The core of the area is considered to be 100 percent part of the feature and beyond that there is decreasing agreement about whether territory should or should not be included. For example, everyone agrees that Los Angeles is in Southern California, but is Santa Barbara also in Southern California? Reasonable people will disagree about this or will say that it all depends on how you divide the state up into districts. Essentially vagueness results in a range of interpretations for a place reference and a range of borderline values for the spatial footprint of such a reference.

A term often used in GIS for the opposite of spatial vagueness is crisp, where there is no debate about the boundary of a feature (Worboys and Duckman 2004, chap. 9). However, a crisp, spatial boundary is frequently used to represent a feature that is essentially vague so that mapping, formal reasoning, and mathematical processing can be performed. The problem with this is that such a boundary line is often accepted as being the “truth,” when in fact the line represents a range of possibilities and uncertainties that are not represented with any indication of the fuzziness of the underlying data.

Vagueness and a consequent range of interpretations also apply to the category schemes we create to indicate types of geographic features. Most of the time, we are comfortable with an inherent looseness of definition and with multiple ways of classifying things. For example, think of types of water bodies. These could be subtyped into freshwater and saltwater bodies, or into standing- and moving-water bodies, or into natural and human-made features. In all such schemes, there are borderline
cases and therefore judgment calls about what types to assign to particular features. In natural language, we talk about *lakes, ponds, rivers, streams, reservoirs, oceans,* and *seas* and, most of the time, avoid being precise in our classification of exactly what we mean by these terms. The water body one person calls a *pond* may be equivalent in size to what someone else calls a *lake.* We may not consciously consider the difference between a reservoir and a naturally formed lake when thinking in recreational terms where both function as “lakes” for boating, fishing, and so on, but the difference between human-made and natural will be recognized in other circumstances. Similarly, it may not occur to us that there is no clear boundary between a feature called a *hill* and one called a *mountain* until we try to classify such features according to some typing scheme; one or the other of these designations seems right for a particular feature, influenced by the local terrain and local placename usage. For example, an elevated mound in a flat terrain may be called a *mountain,* while an equivalent feature in a mountainous area may be called a *hill.*

Vagueness is a type of uncertainty; there are other types, including the uncertainty of measurement where the data itself is a definite value but where knowledge of it is uncertain. An example is a measurement of the depth of the sea in a particular location; the known value is compromised by our ability to measure it. Not all imprecision is vague in this sense, however. To say that I am in the United States is imprecise but not vague. Worboys and Duckman (2004, chap. 9) created a hierarchy of terminology for *imperfection* related to GIS that sorts this out: *imperfection* has two subtypes, *inaccuracy* and *imprecision,* and *vagueness* is a subtype of *imprecision.*

Vagueness is not handled well by GIS or by cartography in general where a boundary must be placed somewhere. Users place more confidence in such lines and points than they should. Specificity is forced on the representation even when the data may indicate that a range of values or probabilities for boundary data points is more appropriate. For georeferencing usage outside of GIS and cartography, though, we would like to be able to live with levels of uncertainty more naturally, without being forced to specify a line somewhere. This is an issue for both representation and spatial information retrieval.

Chapter 4 discusses the concept of *uncertainty* as it relates to the representation of geospatial locations.

**Individual Styles of Spatial Cognition and Communication**

Much research has been done to identify the contributing factors to individual differences in dealing with geographic knowledge. One of the most interesting
differences is the choice of method for giving directions (i.e., procedures for navigating from one place to another) (e.g., Bosco, Longoni, and Vecchi 2004). One strategy (more associated with women than men) is to base directions on references to landmarks and topological directions (e.g., right, left, and straight ahead) in verbal directions: “To get to the auditorium, go straight down this street (pointing) until you get to the grocery store on your right; turn left and go down Main Street until you see the cathedral on your left at the intersection with Fifth Street. The auditorium is on your right; the entrance is down the street about half a block.”

The other strategy (more associated with men) is to give the directions in more geometric terms: “Go north on this street for ten blocks, about half a mile, to the intersection with Main Street; turn west and go three blocks to Fifth Street and then turn north again. The entrance to the auditorium will be on your right about fifty yards down.”

Or, both methods can be used when it is tough to come up with the answer to the question “How do I get to...” (see the panel for a great example from Maine’s Down East storytellers, Marshall Dodge and Robert Bryan).

Another strategy is to draw a sketch map and avoid the verbal description altogether. Such a map can have some combination of landmarks, directions, and distances. It may be oriented with north at the top, as are most maps, or oriented to match the direction of travel (the so-called heading-up orientation).

In other situations, a time interval for travel may be the preferred method for indicating distance, particularly where time is of prime importance (e.g., catching a train or getting to the church on time) or where the time to get somewhere varies by time of day (e.g., car travel in the Los Angeles area during rush hours). In answer to a question about how far it is from Santa Barbara to Ventura, you might get the following answer: “It’s about 30 minutes. After 4:00 in the afternoon, however, it could take an hour or more.” This information can be more useful than the distance given in terms of geographic distance (about 30 miles), although again there may be personal preferences for one representation over the other.

Of course, asking for, giving, and receiving geographic advice is a form of communication that works best if both the giver and the receiver have the same preferences. The mismatch that often happens is well illustrated in one of my favorite New Yorker cartoons, by James Stevenson (figure 2.2).

There are also differences traceable to cultural, linguistic, and disciplinary contexts, particularly in the way features of the geographic space are categorized. The motivation to categorize things is universal and, in the case of continuous geographic space, classification is also required in order for us to communicate with one another
Panel 3
Giving Directions

I was standin' outside Southerlands IGA store one mornin' when I heard a flivver approaching down the street toward me.

[sound of an approaching old car that slows down and stops and a voice from the car says]

"Which way to Millinocket?"

Well, you can go west to the next intersection, get onto the turnpike, go north through the toll gate at Augusta, 'till you come to that intersection, well, no...

You can keep right on this tar road, it changes to dirt now and agin, just keep the river on your left, you'll come to a crossroads and, let me see...

Then again, you can take that scenic coastal route that the tourists use, and after you get to Bucksport..., well, let me see now—Millinocket.

Come to think of it, you can't get there from here.


about it. The category schemes reflect the cultures, climates, topologies, and features of local areas and points of view. For example, a forest to a forester is a stand of trees with a fixed boundary, while to an ecologist the same forest will be seen as a plant community and habitat without a sharp boundary (Mark 1993).

Summary

Georeferencing is a human activity based on processes of spatial cognition involving the knowledge of geographic facts and the ability to navigate around our environment, as well as the configurational geographic knowledge for the world at large that we acquire through exposure to and study of maps of the Earth. Much of our
spatial knowledge is not oriented to compass directions but rather to topological relationships (e.g., to the right or left, near or far) and to associations such as the administrative hierarchy of a place (e.g., Detroit is in Michigan). Research has documented that our store of geographic knowledge is fragmentary and that on recall we distort spatial relationships in predictable ways. Some research indicated that some of us make a distinction between geographic and mappable objects and other research, which measured response time for answering questions about objects for which we have both names and spatial locations, found that we perform faster when using names to recall what we have learned. Our geographic knowledge is more likely to be qualitative than quantitative and we operate comfortably with a sense of *vagueness* with the georeferences we use, not expecting them to have *crisp* boundaries and definitions. Individually we adopt different strategies for georeferencing and for navigating, showing a preference for using either landmarks or geo-
metric descriptions when giving directions, for example. Further variations in georeferencing practices are attributed to cultural, linguistic, and disciplinary influences. These aspects of spatial cognition are relevant to the design of georeferenced information systems.

Sources for Further Information


Appendix: Answers to the Geographic-Order Test in Chapter 2

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<thead>
<tr>
<th>Correct rank by longitude from west to east</th>
<th>Correct rank by latitude from north to south</th>
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<tbody>
<tr>
<td>Casablanca (Morocco)</td>
<td>Anchorage (Alaska)</td>
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<td>St. John's (Newfoundland)</td>
<td>Buenos Aires</td>
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*Source: Muller 1985*