Chapter 2
Geodata and Geoinformatics

> *"A human being is part of a whole, called by us the universe, a part limited in time and space. He experiences himself, his thoughts and feelings, as something separated from the rest, a kind of optical delusion of his consciousness. This delusion is a kind of prison for us, restricting us to our personal desires and to affection for a few persons nearest us. Our task must be to free ourselves from this prison by widening our circles of compassion to embrace all living creatures and the whole of nature in its beauty."*
>
> Albert Einstein (1879–1955)

2.1 Dimensions of Space, Time and Scale

Understanding the characteristics of and possibilities in using geodata is premised on proper comprehension of the underlying concepts of space, time and scale, contextualized within the Earth's framework. Although these concepts are used in everyday parlance, often without much afterthought, they are not trivial at all. For instance, looking back throughout the entire history of mankind, the concepts of space and time have been the subject of animated philosophical, religious and scientific debates. In this section, we attempt to present a background of each of these dimensions of geodata, both independently and collectively, as well as highlight their relevance in influencing the character of geodata.

Space is that boundless, three-dimensional extent in which objects and events occur and have relative position and direction (Britannica 2011). In analytical geometry, one examines "spaces" with different dimensionality and underlying structures. Indeed, the concept of space is considered to be of fundamental importance to an understanding of the physical universe although disagreement continues between

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philosophers over whether it is itself an entity, a relationship between entities, or part of a conceptual framework (Wikipedia 2011).

Philosophical debates on the nature, essence and the mode of existence of space date back to antiquity. From treatises like that championed by *Timaeus of Plato* in his reflections on what the Greeks called *khora* (i.e. space), to the physics of *Aristotle* in the definition of *topos* (i.e. place), or to even the geometrical conception of place as *"space qua extension"* by *Alhazen* (El-Bizri 2007).

Many of the classical philosophical assertions were later discussed and reformulated in the seventeenth century, particularly during the early development of classical mechanics. For example, in *Sir Isaac Newton's* view, space was absolute, in the sense that it existed permanently and independent of whether there were any matter in the space (French and Ebison 2007). However, other philosophers like *Gottfried Leibniz* were of the different view that space was a collection of relations between objects, given by their distance and direction from one another (Wikipedia 2011).

Up until around the eighteenth century, and within the framework of *Euclidean geometry*, space was perceived by most mathematicians to be flat. However, between the nineteenth and twentieth centuries mathematicians began to examine *non-Euclidean geometries*, in which space was inferred to be curved, rather than flat. According to *Albert Einstein's* theory of general *relativity*, space around gravitational fields deviates from Euclidean space (Carnap 1995). Furthermore, experimental tests of general relativity have confirmed that non-Euclidean space provides a better model for the shape of space as illustrated in Fig. 2.1.

Turning to the dimension of time, time is considered to be part of the measuring system used to sequence events, to compare the durations of events and the intervals between them, and to quantify rates of change such as the motions of objects (Internet Encyclopedia of Philosophy 2011). The temporal position of events with respect to the transitory present is continually changing. For example, future events become present, then pass further back into the past. In the *Bible*, time is traditionally regarded as a medium for the passage of predestined events. Subsequently, there is an appointed time for everything, see e.g., *Ecclesiastes 3:1–8* (Bible 2011). Evidently, time has been a major subject in religion, philosophy, and science, but defining it in a non-

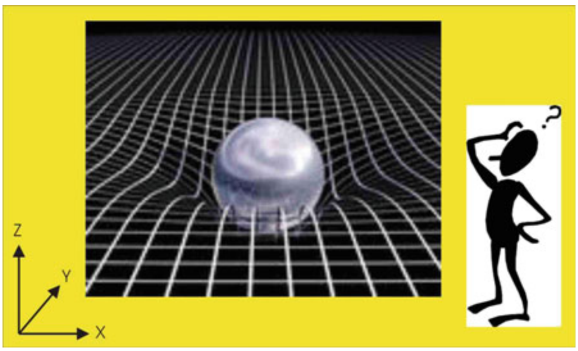

Fig. 2.1 Concept of non-Euclidean space

controversial manner applicable to all fields of study has consistently eluded the greatest scholars (Wikipedia 2011).

Time is one of the seven fundamental physical quantities defined in the International System of (SI) Units. It is also used to define other quantities, such as velocity. An operational definition of time infers that observing a certain number of repetitions of one or another standard cyclical event (such as the passage of a free-swinging pendulum) constitutes one standard unit such as the second. This view is highly useful in the conduct of both advanced experiments and everyday affairs of life. However, this operational definition ignores the question whether there is something called *time*, apart from the counting activity that transits and can be measured (Wikipedia 2011).

Two contrasting assertions on time divide many prominent philosophers. The first view is that time is part of the fundamental structure of the universe, a dimension in which events occur in sequence. *Sir Isaac Newton* subscribed to this realistic view, and hence it is sometimes referred to as *Newtonian time*, see e.g., Rynasiewicza (1995a, b), Markosian (2002) etc. According to this view, time travel becomes a possibility as other "times" persist like frames of a film strip, spread out across the time line.

The second and opposing view contends that time does not refer to any kind of "container" that events and objects "move through", nor to any entity that "flows", but that it is instead part of a fundamental intellectual structure (together with space and number) within which humans sequence and compare events. This assertion, in the tradition of *Gottfried Leibnitz* (Burnham 2006) and *Immanuel Kant* (see e.g., Mattey 1997, McCormick 2006 etc) holds that time is neither an event nor a thing, and thus it is not itself measurable nor can it be traveled.

Temporal measurement has occupied the minds of scientists for a long time and was the prime motivation in the disciplines of navigation and astronomy. Periodic events and periodic motion have long served as standards for units of time. Examples include the apparent motion of the sun across the sky, the phases of the moon, the swing of a pendulum, and the beat of a heart. Currently, the international unit of time, the *second*, is defined in terms of radiation emitted by cesium atoms. Time is also of significant social importance and is often viewed as having economic value as captured by the popular adage *time is money*, as well as personal value, due to an awareness of the limited and finite time in each day and in the human life span (Wikipedia 2011). Consequently, different time scales are employed in different application domains, such as geological time (Harland et al. 1989; Haq 2006; Kulp 1961), biological time (Winfree 2001; Enright 1965; Hochachka and Guppy 1987) etc.

From the above discussion, regardless of the school of thought advanced, it is evident that historically, the dimensions of space and time have been closely related. As a matter of fact, it is virtually impossible to describe either of the two dimensions without inferring the other. Put together, these two dimensions represent the *space-time* concept expressed in Einstein's special relativity and general relativity theories. According to these theories, the concept of time depends on the spatial reference frame of the observer, and the human perception as well as the measurement by instruments such as clocks are different for observers in relative motion. Subsequently, the past is the set of events that can send light signals to the observer, whilst the future is the set of events to which the observer can send light signals (Wikipedia 2011).

This then brings us to the dimension of scale. The scale of a map is an important metric that defines the level of detail of geoinformation that can be extracted from such a map (see Sect. 19.1). Scale also gives an indication of the resolution in the geodata. In general, a larger scale means that more geodata would be captured, including fuzzy detail that might otherwise be generalized or glossed over at smaller scales. The interpretation of scale is therefore important. For instance, by simply varying the map scale alone, the estimated distance between two points would vary. Many researches have studied the scale dimension and its perception and meaning in different applications, see e.g., Mandelbrot (1967), Fisher et al. (2004), Levin (1992), Tate and Wood (2001) etc. A review of space, time and scale from a geographer's perspective is given in Meentemeyer (1989).

For many years, the dimension of scale was not explicitly integrated into data modeling. Therefore, scale was assumed to be uniform within a spatio-temporal context. This was done ostensibly to keep the whole geo-modeling problem simplified. The fact that classical maps could only be produced at one specific scale probably reiterates this. By convention, national mapping agencies had to designate certain mapping scales for different map coverages. This therefore enabled map users to identify the maps that were suitable for different applications. For example, in typical civil engineering work, whereas a scale of 1:50,000 would be appropriate at the reconnaissance or preliminary planning stage, larger scales of 1:500–1:2,000 would be required at the construction or maintenance phases.

Evidently, the scale dimension has not evoked as much controversy as the twin dimensions of space and time. The issue with the scale dimension has been more to do with the scientific challenge of identifying appropriate data models and structures. Indeed, consideration of scale as an extra dimension of geographic information, fully integrated with the other dimensions, is a fairly recent proposition (Oosterom and Stoter 2010). Whereas 3D space captures the geometrical characteristics of geodata, 4D integrates the temporal representation, with the 5D providing the scale definition. Meentemeyer (1989) avers that most geographic research is now conducted with a relativistic view of space rather than a view of space as a "container". However, spatial scales for relative space are more difficult to define than those for the absolute space of cartography and remote sensing (Meentemeyer 1989).

In concluding this section, it is important to recognize that the five dimensions of space, time and scale are integral to the unambiguous definition of position for they help to fully integrate 5D data modeling. Realizing this would ensure that geodata is used seamlessly with no undesirable overlaps or gaps and assuming consistency across space, time and scale dimensions. In future, probably the existence and relative importance of different classes in diverse applications could also be considered in a more integrated manner as the sixth dimension of geodata—the *semantic* dimension (Oosterom and Stoter 2010).

Table 2.1 Hierarchy of decision making support infrastructure

Level of decision-making support infrastructure	Ease of sharing	Example
Wisdom	Impossible	Policies developed and accepted by stakeholders e.g., ideal use for parcel
⇑		
Knowledge	Difficult (especially tacit knowledge)	Personal knowledge about places and issues e.g., adjoining parcel boundaries
⇑		
Evidence	Often not easy	Results of spatial analysis of datasets or scenarios e.g., parcel area
⇑		
Information	Easy	Contents of a database assembled from raw facts e.g., owner of parcel
⇑		
Data	Easy	Raw facts and figures e.g., geographic coordinates

Modified after Longley et al. (2005)

2.2 Geodata

Data is simply defined as any set of raw facts or figures that have been collected, often in a systematic manner, and from which inference(s) may be drawn. Similarly, *information* is defined as any useful data that satisfies some user need(s). This is generally required to support the making of decisions. Apparently, data and information constitute the basic building blocks in the decision-making support infrastructure that also includes *evidence*, *knowledge* and *wisdom* as summarized in Table 2.1.

An *information system* is a combination of technical and human resources, together with a set of organizing procedures that produces information in support of decision-making usually to meet some managerial requirement. Thus an information system should be able to receive, store, process, update, output and distribute data and information. Classical information systems for general management are called *Management Information Systems* (MIS). They are distinguished from *Geographic Information Systems*, which are information systems that deal with spatially referenced data and are discussed in more detail in Sect. 13.1.

Data is distinguished as *geodata* (or *geospatial* data) if it can be geographically referenced in some consistent manner using for example; latitudes and longitudes, national coordinate grids, postal codes, electoral or administrative areas, watershed basins etc. As mentioned in Sect. 2.1, although geodata is normally defined in 3D in many practical applications, it needs to be redefined in 5D for geodata to be used without any restrictions in space, time or scale. The first three dimensions describe the geometric characteristics of geodata usually in 3D space. The fourth dimension provides the temporal representation that denotes how geodata has changed over time, while the scale is represented by the fifth dimension. This dimensional view of geodata is important for it ensures that there are no gaps or overlaps in the data. Furthermore, it also maintains the consistency of geodata across space, time and scale dimensions. Section 6.6.1 reviews typical datums used in surveying.

Geodata may be collected by both government organizations as well as private agencies. A key characteristic of this type of data is its potential for diverse and multiple applications. Moreover, geodata can be shared and re-used by different users and applications through the *spatial data infrastructure* (SDI), see e.g., Groot and McLaughlin (2000), Nebert (2004), Maguire and Longley (2005) etc. To infer the correct decision(s), it is imperative that the geodata be *accurate, complete, consistent* and *timely*. Furthermore, it is important that the required geodata be made available and that in addition, it also be allowed to flow unhindered to and between the various users and applications.

2.3 Digital Earth Concept

Digital Earth is the name given to a concept coined by former US vice president Al Gore in 1998, that describes a virtual representation of the Earth that is spatially referenced and interconnected with the world's digital knowledge archives.[1] Furthermore, the greater part of this knowledge store would be free to all via the *Internet*. However, a commercial marketplace of related products and services was envisioned to co-exist, in part in order to support the expensive infrastructure that such a system would require (Wikipedia 2011).

Clearly, many aspects of this vision have been realized, evidenced in part by the popularity of virtual globe geo-browsers such as *Google Earth*[2] for commercial, social and scientific applications as discussed in Chap. 18. But the Gore speech outlined a truly global, collaborative linking of systems that has yet to be fully realized (Wikipedia 2011). That vision has been continually interpreted and refined by the growing global community of interest. As technological advances have made the unlikely possible, the vision has evolved and become more concrete, and as we better understand the interdependence of the environment and social activities, there is greater recognition of the need for such a system. Digital Earth has come to stand for the large and growing set of web-based geographic computing systems worldwide. These are both useful and promising, but do not yet constitute the envisioned *global commons* (Wikipedia 2011).

[1] In a speech prepared for the California Science Center in Los Angeles on January 31, 1998, Gore described a digital future where school children—indeed all the world's citizens—could interact with a computer-generated three-dimensional spinning virtual globe and access vast amounts of scientific and cultural information to help them understand the Earth and its human activities.

[2] http://www.earth.google.com

The global dimension of the digital Earth concept is perhaps best captured by two excerpts from the Beijing declaration[3] on digital Earth, which state as follows (Beijing 2009):

(a) Digital Earth is an integral part of other advanced technologies including: Earth observation, geo-information systems, global positioning systems, communication networks, sensor webs, electromagnetic identifiers, virtual reality, grid computation, etc. It is seen as a global strategic contributor to scientific and technological developments, and will be a catalyst in finding solutions to international scientific and societal issues;
(b) Digital Earth should play a strategic and sustainable role in addressing such challenges to human society as natural resource depletion, food and water insecurity, energy shortages, environmental degradation, natural disasters response, population explosion, and, in particular, global climate change.

A consortium of international geographic and environmental scientists from government, industry, and academia brought together by the *Vespucci Initiative for the Advancement of Geographic Information Science, and the Joint Research Center of the European Commission* published a position paper that outlined the eight key next generation digital Earth elements to include the following (Craglia et al. 2008):

(1) Not one digital Earth, but multiple connected globes/infrastructures addressing the needs of different audiences: citizens, communities, policy-makers, scientists, educationalists;
(2) Problem oriented: e.g., environment, health, societal benefit areas, and transparent on the impacts of technologies on the environment;
(3) Allowing search through time and space to find similar/analogous situations with real time data from both sensors and humans (different from what existing GIS can do, and different from adding analytical functions to a virtual globe);
(4) Asking questions about change, identification of anomalies in space in both human and environmental domains (flag things that are not consistent with their surroundings in real time);
(5) Enabling access to data, information, services, and models as well as scenarios and forecasts: from simple queries to complex analyses across the environmental and social domains;
(6) Supporting the visualization of abstract concepts and data types (e.g., low income, poor health, and semantics);
(7) Based on open access, and participation across multiple technological platforms, and media (e.g., text, voice and multi-media); and
(8) Engaging, interactive, exploratory, and a laboratory for learning and for multidisciplinary education and science.

[3] Ratified on September 12, 2009 at the 6th international symposium on digital earth in Beijing, Peoples Republic of China.

2.4 Fundamentals of Geoinformatics

Having introduced the 5D datum paradigm that needs to be adequately dealt with to define geodata accurately, consistently, timely and completely so that it can be used without any restrictions in space, time or scale and further, having appreciated the truly global dimension of the digital Earth, to put everything in perspective, it is now appropriate to focus on geoinformatics. Like for all other disciplines elaborated in this book it is only right to begin this discussion with pertinent definitions.

Although geoinformatics is a fairly recent terminology, various definitions of the same have been advanced by different authors. For instance, Raju (2003) describes geoinformatics as "the science and technology dealing with the structure and character of spatial information, its capture, its classification and qualification, its storage, processing, portrayal and dissemination, including the infrastructure necessary to secure optimal use of this information". Similarly, Ehlers (2003) defines geoinformatics as "the art, science or technology dealing with the acquisition, storage, processing, production, presentation and dissemination of geoinformation".

The bottom line is that there is no globally accepted definition of geoinformatics. However, as a multidisciplinary field, geoinformatics has at its core different technologies that support the acquisition, analysis and visualization of geodata. The geodata is usually acquired from Earth observation sensors as remotely sensed images, analyzed by geographic information systems (GIS) and visualized on paper or on computer screens. Furthermore, it combines geospatial analysis and modeling, development of geospatial databases, information systems design, human-computer interaction and both wired and wireless networking technologies. Geoinformatics uses geocomputation and geovisualization for analyzing geoinformation. Typical branches of geoinformatics include: *cartography, geodesy, geographic information systems, global navigation satellite systems (GNSS), photogrammetry, remote sensing, and web mapping*. These different disciplines that have been developed over different time epochs form the main subject matter of this book.

By combining the ever-increasing computational power, modern telecommunications technologies, abundant and diverse geodata, and more advanced image analysis algorithms available, and integrating technologies such as remote sensing, GIS and GNSS, many opportunities for application of geoinformatics have been realized. Today, many applications routinely benefit from geoinformatics including; urban planning and land use management, in-car navigation systems, virtual globes, public health, local and national gazetteer management, environmental modeling and analysis, military, transport network planning and management, agriculture, meteorology and climate change, oceanography and coupled ocean and atmosphere modeling, business location planning, architecture and archaeological reconstruction, telecommunications, criminology and crime simulation, aviation and maritime transport etc.

Consequently, geoinformatics has become a very important technology to decision-makers across a wide range of disciplines, industries, commercial sector, environmental agencies, local and national government, research and academia,

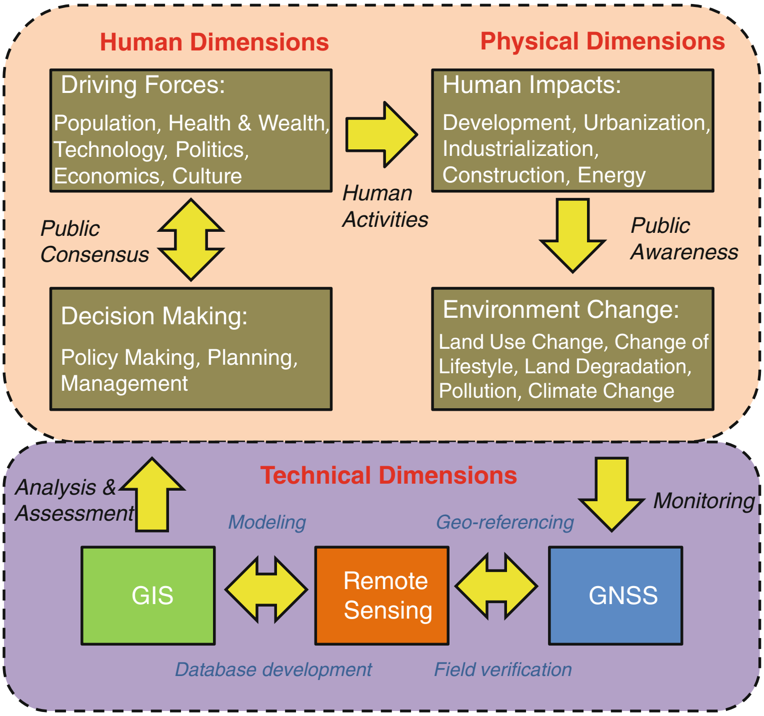

Fig. 2.2 Conceptual framework showing the role of geoinformatics in spatial decision support (Modified after Murai 1999)

national survey and mapping organizations, international organizations, United Nations, emergency services, public health and epidemiology, crime mapping, transportation and infrastructure, information technology industries, GIS consulting firms, environmental management agencies, tourist industry, utility companies, market analysis and e-commerce, mineral exploration etc. Increasingly, many government and non government agencies worldwide are using geodata and geoinformatics for managing their day to day activities. Figure 2.2 shows a conceptual framework that underlines the role of geoinformatics in supporting spatial decision-making.

2.5 Concluding Remarks

Although still unusual in many practical mapping constructs worldwide, a 5D coordinate reference framework is, nonetheless, desirable. This would not only ensure that geodata are defined accurately, consistently, timely and completely, but also guarantee that they are employed without any restrictions whatsoever in terms of space, time and/or scale. There is no doubt that, perhaps more that ever before, humanity faces a myriad of complex and demanding challenges today. These include natural resource depletion, food and water insecurity, energy shortages, environmental degradation, intermittent natural disasters, population explosion, global climate change etc. To develop pragmatic and sustainable solutions to address these and many other similar challenges requires the use of geodata and the application of geoinformatics.

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