1

A GENTLE INTRODUCTION TO GIS

Unit Structure :

1.0 OBJECTIVES

- Illustrate how we think geographically and spatially daily with mental maps to highlight the importance of asking geographic questions.
- Explain how the fundamental concepts of scale, location, direction, distance, space, and navigation are relevant to geography and geographic information systems.
- Define how a geographic information system is applied, its development, future and representation in real world.

1.1 INTRODUCTION

The purpose of this chapter is to provide a general overview of some of the terms, concepts and ideas, which will be covered in detail in later sections. The acronym GIS stands for geographic information system. As the name suggests, a GIS is a tool for working with geographic information. It contains formal definition, Geographic information the key functions that set GIS apart from other kinds of information systems. GIS have rapidly developed since the late 1970's in terms of both technical and processing capabilities, and today are widely used all over the world for a wide range of purposes.

1.2 THE NATURE OF GIS

A geographic information system (GIS) is a computer system for capturing, storing, checking, and displaying data related to positions on Earth's surface. By relating seemingly unrelated data, GIS can help individuals and organizations had better understand spatial patterns and relationships.

Following are the some of the examples of GIS where it is used:

A biologist might be interested in the impact of slash-and-burn practices on the populations of amphibian species in the forests of a mountain range to obtain a better understanding of long-term threats to those populations;

A natural hazard analyst might like to identify the high-risk areas of an- nual monsoon-related flooding by investigating rainfall patterns and ter- rain characteristics;

A geological engineer might want to identify the best localities for construct- ing buildings in an earthquake-prone area by looking at rock formation characteristics;

A mining engineer could be interested in determining which prospective copper mines should be selected for future exploration, taking into account parameters such as extent, depth and quality of the ore body, among others;

A Geoinformatics engineer hired by a telecommunications company may want to determine the best sites for the company's relay stations, taking into ac- count various cost factors such as land prices, undulation of the terrain etc.

A forest manager might want to optimize timber production using data on soil and current tree stand distributions, in the presence of a number of operational constraints, such as the need to preserve species diversity in the area.

A hydrological engineer might want to study a number of water quality parameters of different sites in a freshwater lake to improve understanding of the current distribution of Typha reed beds, and why it differs from that of a decade ago.

1.3 SOME FUNDAMENTAL OBSERVATIONS

Our world is dynamic. Many aspects of our daily lives and our environment are constantly changing, and not always for the better. Some of these changes appear to have natural causes (e.g. volcanic eruptions, meteorite impacts), while others are the result of human modification of the environment (e.g. land use changes or land reclamation from the sea, a favourite pastime of the Dutch).

There are also a large number of global changes for which the cause remains un- clear: these include global warming, the El Nin˜o/La Nin˜a events, or at smaller scales, landslides and soil erosion. In summary, we can say that changes to the Earth's geography can have natural or man- made causes, or a mix of both. If it is a mix of causes, we usually do not fully understand the changes.

For background information on El Nin˜o, please refer to Figure. This Figure presents information related to a study area (the equatorial Pacific Ocean), with positional data taking a prominent role. Although quite a complex phenomenon, we will use the study of El Nin˜o as an example application of GIS in the remainder of this chapter.

In order to understand what is going on in our world, we study the processes or phenomena that bring about geographic change. In many cases, we want to broaden or deepen our understanding to help us make decisions, so that we can take the best course of action. For instance, if we understand El Nin˜o better, and can forecast that another event may take place in the year 2012, we can devise an action plan to reduce the expected losses in the fishing industry, to lower the risks of landslides caused by heavy rains or to build up water supplies in areas of expected droughts.

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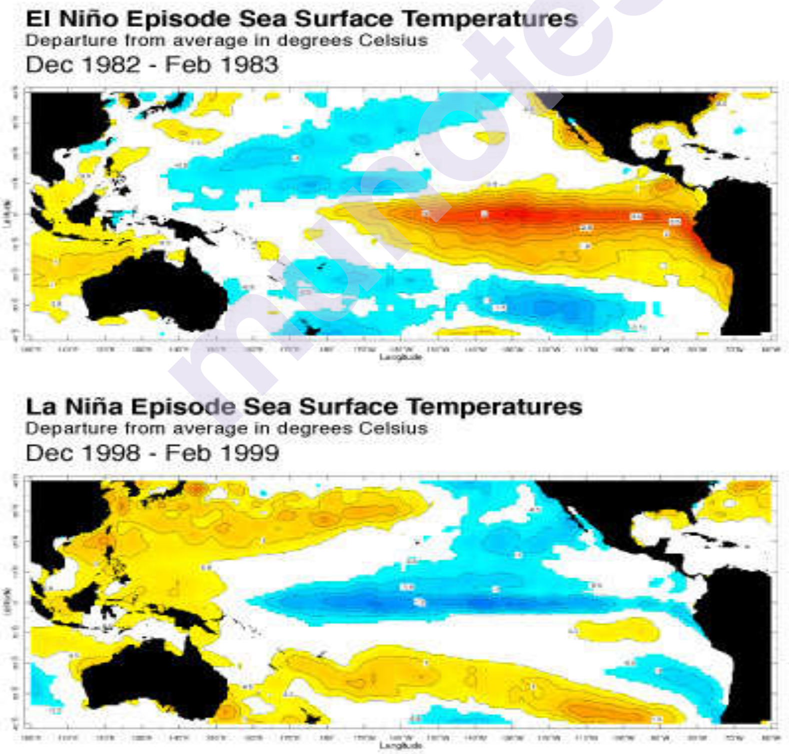


Figure 1.1: Sea-surface temperature anomalies during a strong El Niño event (top) and La Niña event (bottom). Figures made in the IRI ENSO Maproom.

The El Nin˜o event is a good example of such a phenomenon, because sea surface temperatures differ between locations, and sea surface temperatures change from one week to the next.

1.3.1 Defining GIS

A GIS is a computer-based system that provides the following four sets of capabilities to handle geo-referenced data:

1.Data capture and preparation

2.Data management

3.Data manipulation and analysis

4.Data presentation

1. Data Capture and Preparation

Data capture is tedious job in GIS. A GIS can be used to emphasize the spatial relationships among the objects being mapped. If the data to be used are not already in digital form that is in a form a computer can understand and recognize, various techniques are available to capture the information. Maps can be digitized, or hand traced with a computer mouse, to collect the coordinates of the features. Electronic scanning devices will also convert map lines and points to digits.

In the El Nin˜o case, data capture refers to the collection of sea water tempera- tures and wind speed measurements. This is achieved by placing buoys with measuring equipment at various places in the ocean. Each buoy measures a number of things: wind speed and direction; air temperature and humidity; and sea water temperature at the surface and at various depths down to 500 metres. For the sake of our example we will focus on sea surface temperature (SST) and wind speed (WS).

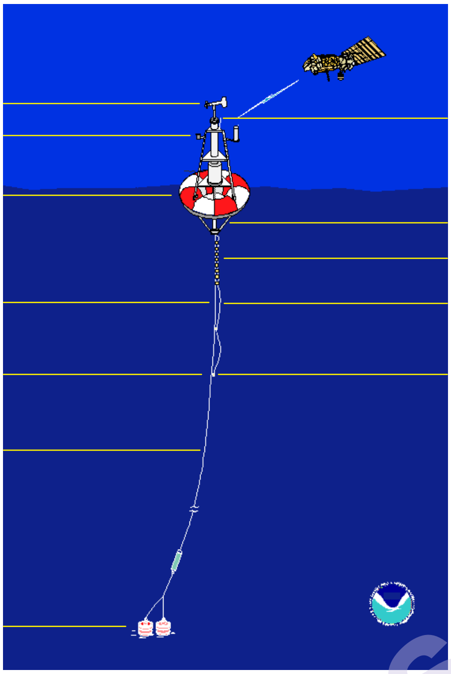
A typical buoy is illustrated in Figure 1.2, which shows the placement of various sensors on the buoy.

Figure 1.2: SchematicoverviewofanATLAStypebuoyformonitoringsea water temperatures intheElNiñoproject

WS sensor

3.8mabovesea

Humiditysensor



Argosantenna

Logger Argosantenna

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TorroidalbuoyØ2.3m

2. Data Management

Thisphase requires a decision to be made on how best to *represent* our data, both in term soft heirspatial properties and the various at tribute values which weneed to store. D ata manipulation includes data verification, attributes data management, insertion, updating, deleting and retrieval in different forms.For our example data management refers to the storage and maintenance of the data transmitted by the buoys via satellite communication.

3. Data Manipulation and analysis

Data analysis can be done, when data has been collected and organized in computer system. In above example, considering data generated at the buoys was processed before map production. A Figure 1.1 reveals that the data being presented are based on the monthly averages for SST and WS (for two months), not on single measurements for a specific date.

1. For each buoy, the average SST for each month was computed, using the daily SST measurements for that month. This is a simple computation.

2. For each buoy, the monthly average SST was taken together with the geographic location, to obtain a georeferenced list of averages, as illustrated in the following table:

Buoy	Geographicposition	Dec.1997avg.SST
B0789	(165°E,5° N)	28.02°C
B7504	(180°E,0° N)	27.34°C
B1882	(110°W,7°30'S)	25.28°C
...	...	...

4. Data Presentation

After the data manipulations , our data is prepared for producing output. This data presentation phase deals with putting it all together into a format that communicates the result of data analysis in the best possible way. Before data is presented, we need to consider what the message is that we want to portray, who the audience is, what kind of presentation medium will be used, which rules of aesthetics apply, and what techniques are available for representation.

1.3.2 GI System, GI Science and GI Applications

A geographic information system (GIS) is a type of database containing geographic data (that is, descriptions of phenomena for which location is relevant), combined with software tools for managing, analyzing, and visualizing those data. GIS software, a general-purpose application program that is intended to be used in many individual geographic information systems in a variety of application domains.Starting in the late 1970s, many software packages have been created specifically for GIS applications, including commercial programs such as Esri, ArcGIS, Autodesk and MapInfo Professional and open source programs such as QGIS, GRASS GIS and MapGuide.

Geo-Information (GI) Science is the scientific field that attempts to integrate dif-ferent disciplines studying the methods and techniques of handling spatial information. Geographical information science (GIScience or GISc) is the scientific discipline that studies geographic information, including how it represents phenomena in the real world, how it represents the way humans understand the world, and how it can be captured, organized, and analyzed.

Project-based GIS applications usually have a clear-cut purpose, and these appli- cations can be short-lived: the research is carried out by collecting data, entering data in the GIS, analysing the data, and producing informative maps. An ex- ample is rapid earthquake damage assessment.

1.3.3 Spatial data and geo-information

Spatial data we mean data that contains positional values, such as (x, y) co-ordinates. Sometimes the more precise phrase geospatial data is used a safurther refinement, which refers to spatial data that is geo referenced. 'spatialdata' is also known as 'geo referenced data'. Geo information is a specific type of information resulting from the interpretation of spatial data.

In recent years, increasing availability and decreasing cost of data capture equipment has resulted in many users collecting their own data. However, the collection and maintenance of 'base' data remain the responsibility of the various governmental agencies, such as National Mapping Agencies (NMAs), which are responsible for collecting topographic data for the entire country following preset standards. Key components of spatial data quality include positional accuracy (both horizon- tal and vertical), temporal accuracy (that the data is up to date), attribute accuracy (e.g. in labelling of features or of classifications), lineage (history of the data including sources), completeness (if the data set represents all related features of reality), and logical consistency (that the data is logically structured).

1.4 THE REAL WORLD AND REPRESENTATIONS IF IT

Sometimes, we need to represent some part of the real world as it is, as itwas, or perhaps as we think it will be but in real world its not possible to exactly represent it.

1.4.1 Models and Modeling

Modelling' is a term used in many different ways and which has many different meanings. Are presentation of some part of the real world can be considereda *model* because the representation will have certain characteristics in commonwith the real world. Models as representations come in many different flavours. In the GIS environment, the most familiar model is that of a map. A map is a miniature representation of some part of the real world.

A 'real world model' is a representation of a number of phenomena that we can observe in reality, usually to enable some type of study, administration, computation and/or simulation. In this book we will use the term application models to refer to models with a specific application, including real-world models and so-called analytical models. The phrase 'data modelling' is the common name for the design effort of structuring a database. This process involves the identification of the kinds of data that the database will store, as well as the relationships between these kinds of data.

Most maps and databases can be considered static models. At any point in time, they represent a single state of affairs. Usually, developments or changes in the real world are not easily recognized in these models. Dynamic models or process models address precisely this issue. They emphasize changes that have Dynamic models taken place, are taking place or may take place sometime in the future. Dynamic models are inherently more complicated than static models, and usually require much more computation. Simulation models are an important class of dynamic models that allow the simulation of real world processes. Observe that our El Nin˜o system can be called a static model as it stores state-of- affairs data such as the average December 1997 temperatures. But at the same time, it can also be considered a simple dynamic model, because it allows us to compare different states of affairs.

1.4.2 Maps

Maps have been used for thousands of years to represent information about the real world, and continue to be extremely useful for many applications in various domains. Their conception and design has developed into a science with a high degree of sophistication. A disadvantage of the traditional paper map is that it is generally restricted to two-dimensional static representations,

and that it is always displayed in a fixed scale. The map scale determines the spatial resolution of the graphic feature representation. The smaller the scale, the less detail a map can show. The accuracy of the base data, on the other hand, puts limits to the scale in which a map can be sensibly drawn. Hence, the selection of a proper map scale is one of the first and most important steps in map design.

A map is always a graphic representation at a certain level of detail, which is determined by the scale. Map sheets have physical boundaries, and features spanning two map sheets have to be cut into pieces. Cartography, as the science and art of map making, functions as an interpreter, translating real world phenomena (primary data) into correct, clear and understandable representations for our use. Maps also become a data source for other applications, including the development of other maps.With the advent of computer systems, analogue cartography developed into digital cartography, and computers play an integral part in modern cartography.

Cartography, the art of creating maps, deals with interpreted data. A cartographer, or map-maker creates a visual hierarchy when he or she decides how features appear on a map to illustrate data. Map making can be both subjective or objective-but its goal is always the visualizing of data with some spatial dimension.

1.4.3 Databases

A database is a repository for storing large amounts of data. It comes with a number of useful functions:

1. A database can be used by multiple users at the same time—i.e. it allows concurrent use,
2. A database offers a number of techniques for storing data and allows the use of the most efficient one—i.e. it supports storage optimization,
3. A database allows the imposition of rules on the stored data; rules that will be automatically checked after each update to the data—i.e. it supports data integrity,
4. A database offers an easy to use data manipulation language, which allows the execution of all sorts of data extraction and data updates—i.e. it has a query facility,
5. A database will try to execute each query in the data manipulation lan- guage in the most efficient way—i.e. it offers query optimization.

Databases can store almost any kind of data in different forms like tables etc.

For the ElN inoproject, one may assume that the buoys report their measurements on a daily basis and that these measurements are stored in a single, large table ex. Day Measurements

Buoy	*Date*	*SS*	*T*	*WS*	*Humid*	*Temp10*	...
B0749	1997/12/03	28.2 °C		NNW 4.2	72%	22.2 °C	...
B9204	1997/12/03	26.5 °C		NW 4.6	63%	20.8 °C	...
B1686	1997/12/03	27.8 °C		NNW 3.8	78%	22.8 °C	...
B0988	1997/12/03	27.4 °C		N1.6	82%	23.8 °C	...
B3821	1997/12/03	27.5 °C		W3.2	51%	20.8 °C	...
B6202	1997/12/03	26.5 °C		SW 4.3	67%	20.5 °C	...
B1536	1997/12/03	27.7 °C		SSW 4.8	58%	21.4 °C	...
B0138	1997/12/03	26.2 °C		W1.9	62%	21.8 °C	...
B6823	1997/12/03	23.2 °C		S3.6	61%	22.2 °C	...
...	...	...		...	...	...	...

1.4.4 Spatial databases and spatial analysis

A spatial database is a general-purpose database (usually a relational database) that has been enhanced to include spatial data that represents objects defined in a geometric space, along with tools for querying and analyzing such data. The SQL/MM Spatial ISO/IEC standard is a part the SQL/MM multimedia standard and extends the Simple Features standard with data types that support circular interpolations.

A geodatabase (also geographical database and geospatial database) is a database of geographic data, such as countries, administrative divisions, cities, and related information. Such databases can be useful for websites that wish to identify the locations of their visitors for customization purposes. A geodatabase is not the same thing as a GIS, though both systems share a number of characteristics. These include the functions listed above for databases in general: concurrency, storage, integrity, and querying, specifically, but not only, spatial data.

A GIS, on the other hand, is tailored to operate on spatial data. It 'knows' about spatial reference systems, and supports all kinds of analyses that are inherently geographic in nature, such as distance and area computations and spatial interpolation. This is probably GIS's main strength: providing various ways to combine representations of geographic phenomena.

Spatial analysis or spatial statistics includes any of the formal techniques which studies entities using their topological, geometric, or geographic properties. Spatial analysis includes a variety of techniques, many still in their early development, using different analytic approaches and applied in fields as diverse as astronomy. For example, in the El Nin˜o case, we may want to identify the the steepest gradient in water temperature. The aim of spatial analysis is usually to gain a better understanding of geographic phenomena through discovering patterns that were previously unknown to us, or to build arguments on which to base important decisions. It should be noted that some GIS functions for spatial analysis are simple and easy-to-use, others are much more sophisticated, and demand higher levels of analytical and operating skills. Successful spatial analysis requires appropriate software, hardware, and perhaps most importantly, a competent user.

1.5 SUMMARY

This chapter gives us a 'gentle' introduction of GIS. It introduces GI systems, GI Science and GIS applications. Geographic Information system applications in real life with software etc. GIS has basic four phases: data capture and preparation, data management, data manipulation and analysis, and data presentation. Also it gives brief introduction about data modelling, maps, spatial databases, geo-referencing and spatial databases.

1.6 REFERENCES

1. Principles of Geographic Information Systems -An introductory textbook by

   Otto Huisman and Rolf A. de By

2. Introduction to Geographic Information Systems by Chang Kang-tsung (Karl) McGrawHill

3. Fundamentals of Geographic Information Systems by Michael N.Demers Wiley Publications

4. https://www.educba.com/applications-of-gis/

1.7 QUESTIONS

1. Define GIS. Briefly explain any two capabilities of GIS.
2. What is GI System, GI Science and GIS applications? Explain
3. How modelling helps in representing real world? Explain.
4. Write a short note on nature of GIS.
5. What is geo-spatial data and geo-information?

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2

GEOGRAPHIC INFORMATION AND SPATIAL DATABASE

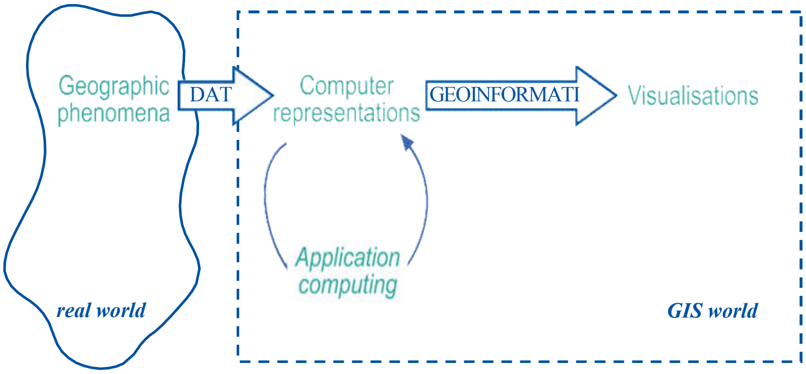
Unit Structure :

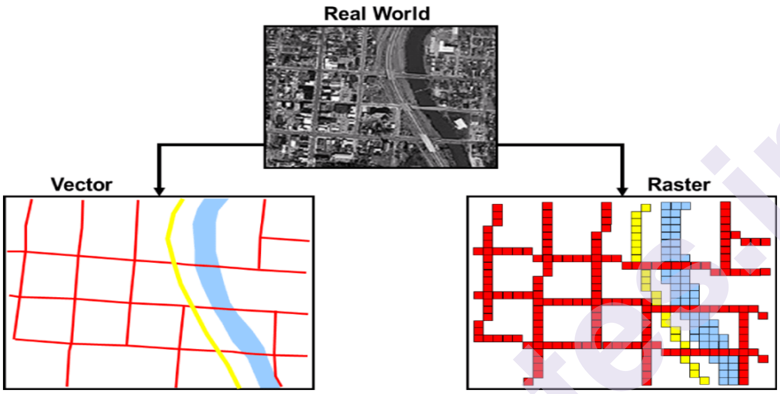
2.1 MODELS AND REPRESENTATIONS OF THE REAL WORLD

GIS helps to analyse and understand more about processes and phenomena in the real world. Section 1.2.1 re- ferred to the process of modelling, or building a representation which has certain characteristics in common with the real world. In practical terms, this refers to the process of representing key aspects of the real world digitally (inside a com- puter). These representations are made up of spatial data, stored in memory in the form of bits and bytes, on media such as the hard drive of a computer. This digital representation can then be subjected to various analytical functions (computations) in the GIS, and the output can be visualized in various ways.

Modelling is the process of producing an abstraction of the 'real world' so that some part of it can be more easily handled.

Depending on the application domain of the model, it may be necessary to ma- nipulate the data with specific techniques. To investigate the geology of an area, we may be interested in obtaining a geological classification. This may result in additional computer representations, again stored in bits and bytes. To examine how the data is stored inside the GIS, one could look into the actual data files, but this information is largely meaningless to a normal user.





In order to better understand both our representation of the phenomena, and our eventual output from any analysis, we can use the GIS to create visualizations from the computer representation, either on-screen, printed on paper, or otherwise. It is crucial to understand the fundamental differences between these notions. The real world, after all, is a completely different domain than the 'GIS' world, in which we build models or simulations of the real world. The above two are types of representations of real world using vector and raster representation methods.

2.2 GEOGRAPHINC PHENOMENA

GIS operates under the assumption that the relevant spatial phenomena occurin a two- or three-dimensional *Euclidean space*, unless otherwise specified. Euclidean space can be informally defined as a model of space in which locations are represented by coordinates—(x, y) in 2D; (x, y, z) in 3D—and distance and di- rection can defined with geometric formulas.In the 2D case, this is known as the Euclidean plane, which is the most common Euclidean space in GIS use. In order to be able to represent relevant aspects real world phenomena inside a GIS, we first need to define what it is we are referring to. We might define a geographic phenomenon as a manifestation of an entity or process of interest that:

- Can be *named* or *described*,
- Can be *georeferenced*, and
- Can be assigned a *time (interval)* at which it is/was present.

2.2.1 Types of Geographic Phenomena

1. Geographic Fields

A (geographic) field is a geographic phenomenon for which, for every point in the study area, a value can be determined. Some common examples of geographic fields are air temperature, barometric pressure and elevation. These fields are in fact continuous in nature. Examples of discrete fields are land use and soil classifications. For these too, any location in the study area is attributed a single land use class or soil class.

A field is a geographic phenomenon that has a value 'everywhere' in the study area. We can therefore think of a field as a mathematical function f that asso- ciates a specific value with any position in the study area. Hence if (x, y) is a position in the study area, then f (x, y) stands for the value of the field f at local- ity (x, y).

Fields can be discrete or continuous. In a continuous field, the underlying function is assumed to be 'mathematically smooth', meaning that the field values along any path through the study area do not change abruptly, but only gradually. Good examples of continuous fields are air temperature, barometric pressure, soil salinity and elevation. Continuity means that all changes in field values are gradual. A continuous field can even be differentiable, meaning we can determine a measure of change in the field value per unit of distance anywhere and in any direction. For example, if the field is elevation, this measure would be slope, i.e. the change of elevation per metre distance; if the field is soil salinity, it would be salinity gradient, i.e. the change of salinity per metre distance. Figure illustrates the variation in elevation in a study area in Spain. A colour scheme has been chosen to depict that variation. This is a typical example of a continuous field.

Discrete fields divide the study space in mutually exclusive, bounded parts, with all locations in one part having the same field value. Typical examples are land classifications, for instance, using either geological classes, soil type, land use type, crop type or natural vegetation type. An example of a discrete field—in this case identifying geological units in the Falset study area—is provided in Figure 2.3. Observe that locations on the boundary between two parts can be as- signed the field value of the 'left' or 'right' part of that boundary. One may note that discrete fields are a step from continuous fields towards geographic objects: discrete fields as well as objects make use of 'bounded' features. Observe, how- ever, that a discrete field still assigns a value to every location in the study area, something that is not typical of geographic objects.

Essentially, these two types of fields differ in the type of cell values. A discrete field like landuse type will store cell values of the type ‘integer’. Therefore it is also called an integer raster. Discrete fields can be easily converted to polygons, since it is relatively easy to draw a boundary line around a group of cells with the same value. A continuous raster is also called a ‘floating point’ raster. A field-based model consists of a finite collection of geographic fields: we may be in- terested in elevation, barometric pressure, mean annual rainfall, and maximum daily evapotranspiration, and thus use four different fields to model the relevant phenomena within our study area.

2.2.2 Data types and values

Since we have now differentiated between continuous and discrete fields, we may also look at different kinds of data values which we can use to represent our ‘phenomena’. It is important to note that some of these data types limit the types of analyses that we can do on the data itself:

1. Nominal data values are values that provide a name or identifier so that we can discriminate between different values, but that is about all we can do. Specifically, we cannot do true computations with these values. An example are the names of geological units. This kind of data value is called categorical data when the values assigned are sorted according to some set of non-overlapping categories. For example, we might identify the soil type of a given area to belong to a certain (pre-defined) category.

2. Ordinal data values are data values that can be put in some natural sequence but that do not allow any other type of computation. Household income, for instance, could be classified as being either ‘low’, ‘average’ or ‘high’. Clearly this is their natural sequence, but this is all we can say—we can not say that a high income is twice as high as an average income.

3. Interval data values are quantitative, in that they allow simple forms of com- putation like addition and subtraction. However, interval data has no arithmetic zero value, and does not support multiplication or division. For instance, a temperature of 20 ◦C is not twice as warm as 10 ◦C, and thus centigrade temperatures are interval data values, not ratio data values.

4. Ratio data values allow most, if not all, forms of arithmetic computation.

Rational data have a natural zero value, and multiplication and division of values are possible operators (distances measured in metres are an ex- ample). Continuous fields can be expected to have ratio data values, and hence we can interpolate them.

We usually refer to nominal and categorical data values as ‘qualitative’ data, be- cause we are limited in terms of the computations we can do on this type of data. Interval and ratio data is known as 'quantitative' data, as it refers to quantities.

However, ordinal data does not seem to fit either of these data types. Often, ordinal data refers to a ranking scheme or some kind of hierarchical phenom- ena. Road networks, for example, are made up of motorways, main roads, and residential streets. We might expect roads classified as motorways to have more lanes and carry more traffic and than a residential street.

2.2.3 Geographic objects

When a geographic phenomenon is not present everywhere in the study area, but somehow 'sparsely' populates it, we look at it as a collection of geographic objects. Such objects are usually easily distinguished and named, and their po- sition in space is determined by a combination of one or more of the following parameters:

- Location (where is it?),
- Shape (what form is it?),
- Size (how big is it?), and
- Orientation (in which direction is it facing?).

How we want to use the information about a geographic object determines which of the four above parameters is required to represent it. For instance, in an in-car navigation system, all that matters about geographic objects like petrol stations is where they are. Thus, location alone is enough to describe them in this particular context, and shape, size and orientation are not necessarily relevant. In the same system, however, roads are important objects, and for these some notion of location (where does it begin and end), shape (how many lanes does it have), size (how far can one travel on it) and orientation (in which direction can one travel on it) seem to be relevant information components.

Shape is usually important because one of its factors is dimension. This relates to whether an object is perceived as a point feature, or a linear, area or volume fea- ture. The petrol stations mentioned above apparently are zero-dimensional, i.e. they are perceived as points in space; roads are one-dimensional, as they are considered to be lines in space. In another use of road information—for instance, in multi-purpose cadastre systems where precise location of sewers and manhole covers matters—roads might well be considered to be two-dimensional entities, i.e. areas within which a manhole cover may fall.

Collections of geographic objects can be interesting phenomena at a higher ag- gregation level: forest plots form forests, groups of parcels form suburbs, streams, brooks and rivers form a river drainage system, roads form a road network, and SST buoys form an SST sensor network. It is sometimes useful to view geo-Geographic scale graphic phenomena at this more aggregated level and look at characteristics like coverage, connectedness, and capacity. For example:

Which part of the road network is within 5 km of a petrol station? (A coverage question)

What is the shortest route between two cities via the road network? (A connectedness question)

How many cars can optimally travel from one city to another in an hour? (A capacity question)

2.2.4 Boundaries

Where shape and/or size of contiguous areas matter, the notion of boundary comes into play. This is true for geographic objects but also for the constituents of a discrete geographic field. Location, shape and size are fully determined if we know an area's boundary, so the boundary is a good candidate for representing it. This is especially true for areas that have naturally crisp boundaries. A crisp boundary is one that can be determined with almost arbitrary precision, dependent only on the data ac- quisition technique applied. Fuzzy boundaries contrast with crisp boundaries in that the boundary is not a precise line, but rather itself an area of transition.

As a general rule-of-thumb, crisp boundaries are more common in man-made phenomena, whereas fuzzy boundaries are more common with natural phe- nomena. In recent years, various research efforts have addressed the issue of explicit treatment of fuzzy boundaries, but there is still limited support for these in existing GIS software. The areas identified in a geological classification, like that of Figure 2.3, are typically vaguely bounded in reality, but applications of this geological information probably do not require high positional accuracy of the boundaries involved. Therefore, an assumption that they are actually crisp boundaries will have little influence on the usefulness of the data.

2.3 COMPUTER REPRESENTATIONS OF EOGRAPHIC INFORMATION

geographic phenomena have the characteris- tics of continuous functions over space. Elevation, for instance, can be measured at many locations, even within one's own backyard, and each location may give a different value. In order to represent such a phenomenon faithfully in com- puter memory, we could either:

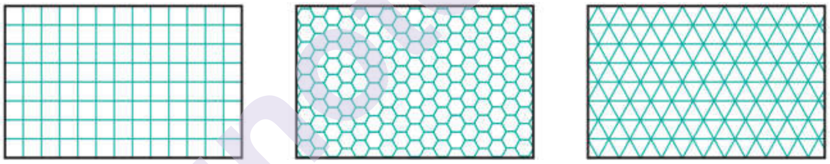
- Try to store as many (location, elevation) observation pairs as possible, or

Try to find a symbolic representation of the elevation field function, as a formula in x and y—like (3.0678x2 + 20.08x 7.34y) or so—which can be evaluated to give us the elevation at any given (x, y) location.

Both of these approaches have their drawbacks. The first suffers from the fact that we will never be able to store all elevation values for all locations; after all, there are infinitely many locations. The second approach suffers from the fact that we do not know just what this function should look like, and that it would be extremely difficult to derive such a function for larger areas. In GISs, typically a combination of both approaches is taken. We store a finite, but intelligently chosen set of (sample) locations with their elevation. This gives us the elevation for those stored locations, but not for others. We can use an interpolation function that allows us to infer a reasonable elevation value for locations that are not stored. A simple and commonly used interpolation function takes the elevation value of the nearest location that is stored. But smarter interpola- tion functions (involving more than a single stored value), can be used as well, as may be understood from the SST interpolations

1. Regular Tessellations

A tessellation (or tiling) is a partitioning of space into mutually exclusive cells that together make up the complete study space. With each cell, some (thematic) value is associated to characterize that part of space.In a regular tessellation, the cells are the same shape and size. The simplest example is a rectangular raster of unit squares, represented in a computer in the 2D case as an array of n m elements. Following are the three types of tesselation



The three most common types of regular tessellation: from left to right, square cells, hexagonal cells and triangular cells.

In all regular tessellations, the cells are of the same shape and size, and the field attribute value assigned to a cell is associated with the entire area occu- pied by the cell. The square cell tessellation is by far the most used, mainly because georeferencing a cell is so straightforward. These tessellations are known under various names in different GIS packages, but most frequentlyas *rasters*.

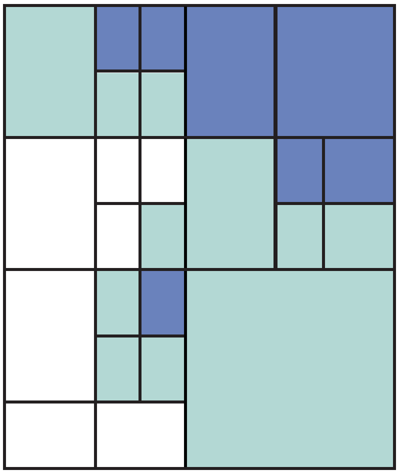
A raster is a set of regularly spaced (and contiguous) cells with associated (field) values. The associated values represent cell values, not point values. This means that the value for a cell is assumed to be valid for all locations within the cell A raster is a set of regularly spaced (and contiguous) cells with associated (field) values. The associated values represent cell values, not point values. This means that the value for a cell is assumed to be valid for all locations within the cell. The location associated with a raster cell is fixed by convention and may be the cell centroid (mid-point) or, for instance, its left lower corner. Values for other positions than these must be computed through some form of interpola- tion function, which will use one or more nearby field values to compute the value at the requested position. This allows us to represent continuous, even differentiable, functions.

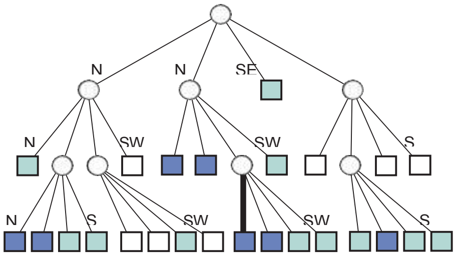
An important advantage of regular tessellations is that we know how they parti- tion space, and we can make our computations specific to this partitioning. This leads to fast algorithms. An obvious disadvantage is that they are not adaptive to the spatial phenomenon we want to represent. The cell boundaries are both artificial and fixed: they may or may not coincide with the boundaries of the phenomena of interest. For example, suppose we use any of the above regular tessellations to represent elevation in a perfectly flat area. In this case we need just as many cells as in a strongly undulating terrain: the data structure does not adapt to the lack of relief. We would, for instance, still use the m n cells for the raster, although the elevation might be 1500 m above sea level everywhere.

2. Irregular Tesselations

Irregular ssellations are more complex than the regular ones, but they are also more adaptive, which typically leads to a reduction in the amount of memory used to store the data. A well-known data structure in this family—upon which many more variations have been based—is the region quadtree. It is based on a regular tessellation of square cells but takes advantage of cases where neigh- bouring cells have the same field value, so that they can together be represented as one bigger cell. A simple illustration is provided in Figure.

It shows a small 8x8 raster with three possible field values: white, green and blue. The quadtree that represents this raster is constructed by repeatedly splitting up the area into four quadrants, which are called NW, NE, SE, SW for obvious rea- sons. This procedure stops when all the cells in a quadrant have the same field value. The procedure produces an upside-down, tree-like structure, known as a quadtree. In main memory, the nodes of a quadtree (both circles and squares in the figure below) are represented as records. The links between them are point- ers, a programming technique to address (i.e. to point to) other records.



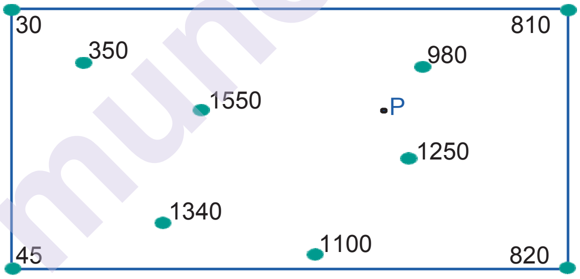


An 8 8, three-valued raster (here: colours) and its repre- sentation as a region quadtree. To construct the quadtree, the field is successively split into four quadrants until parts have only a single field value. After the first split, the southeast quadrant is entirely green, and this is indicated by a green square at level two of the tree. Other quadrants had to be split further.

Quadtrees are adaptive because they apply the spatial autocorrelation principle, i.e., that locations that are near in space are likely to have similar field values. When a conglomerate of cells has the same value, they are represented together in the quadtree, provided boundaries coincide with the predefined quadrant boundaries. Therefore, we can also state that a quadtree provides a nested tessellation: quadrants are only split if they have two or more values. The square nodes at the same level represent equal area sizes, allowing quick computation of the area associated with some field value. The top node of the tree represents the complete raster.

3. Vector Representations

In vector representations, an attempt is made to explicitly associate georeferences with the geographic phenomena. A georeference is a coordinate pair from some geographic space and is also known as a vector. This explains the name. Below, we discuss various vector representa- tions. We start with our discussion with the TIN, a representation for geographic fields that can be considered a hybrid between tessellations and vector representations.



Input locations & their(elevation) values for a TIN construction. The location P is an arbi- trary location that has no associated elevation measurement.

A commonly used data structure in GIS software is the triangulated irregular net- work, or TIN. It is one of the standard implementation techniques for digital terrain models, but it can be used to represent any continuous field. The principles behind a TIN are simple. It is built from a set of locations for which we have a measurement, for instance an elevation. The locations can be arbitrar- TINs represent a continuously scattered in space and are usually not on a nice regular grid. Any location together with its elevation value can be viewed as a point in three-dimensional space.

4. Point representations

Points are defined as single coordinate pairs (x, y) when we work in 2D, or co-ordinate triplets (x, y, z) when we work in 3D. Points are used to represent objects that are best described as shape- and size- less, one-dimensional features. For a tourist city map, a park will not usually be considered a point feature, but perhaps a museum will, and certainly a public phone booth might be represented as a point.

5. Line representations

Line data are used to represent one-dimensional objects such as roads, railroads, canals, rivers and power lines. Again, there is an issue of relevance for the appli- cation and the scale that the application requires. For the example application of mapping tourist information, bus, subway and streetcar routes are likely to be relevant line features. Some cadastral systems, on the other hand, may consider roads to be two-dimensional features, i.e. having a width as well.

The two end nodes and zero or more internal nodes or vertices define a line. Other terms for 'line' that are commonly used in some GISs are polyline, arc or edge. A node or vertex is like a point (as discussed above) but it only serves to define the line, and provide shape in order to obtain a better approximation of the actual feature.

The straight parts of a line between two consecutive vertices or end nodes are called line segments. Many GISs store a line as a simple sequence of coordinates of its end nodes and vertices, assuming that all its segments are straight. This is usually good enough, as cases in which a single straight-line segment is con- sidered an unsatisfactory representation can be dealt with by using multiple (smaller) line segments instead of only one.

6. Area representations

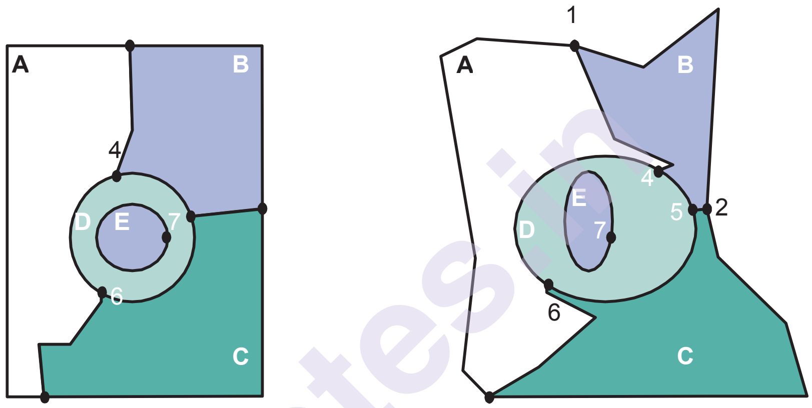
When area objects are stored using a vector approach, the usual technique is to apply a boundary model. This means that each area feature is represented by some arc/node structure that determines a polygon as the area's boundary. Common sense dictates that area features of the same kind are best stored in a single data layer, represented by mutually non-overlapping polygons. In essence, what we then get is an application-determined (i.e. adaptive) partition of space.

Observe that a polygon representation for an area object is yet another example of a finite approximation of a phenomenon that inherently may have a curvi- linear boundary. In the case that the object can be perceived as having a fuzzy boundary, a polygon is an even worse approximation, though potentially the only one possible. Such information could be stored in database tables.

7. Topology and Spatial Relationships

Topology deals with spatial properties that do not change under certain transfor- mations. For example, features drawn on a sheet of rubber (as in Figure) can be made to change in shape and size by stretching and pulling the sheet. However, some properties of these features do not change:

- Area E is still inside area D,
- The neighbourhood relationships between A, B, C, D, and E stay intact, and their boundaries have the same start and end nodes, and
- The areas are still bounded by the same boundaries, only the shapes and lengths of their perimeters have changed.



Topology refers to the spatial relationships between geographical elements in a data set that do not change under a continuous transformation.

Topological relationships are built from simple elements into more complex el- ements: nodes define line segments, and line segments connect to define lines, which in turn define polygons. The fundamental issues relating to order, connectivity and adjacency of geographical elements form the basis of more sophisticated GIS analyses. These relationships (called topological properties) are invariant under a continuous transformation, referred to as a topological mapping.

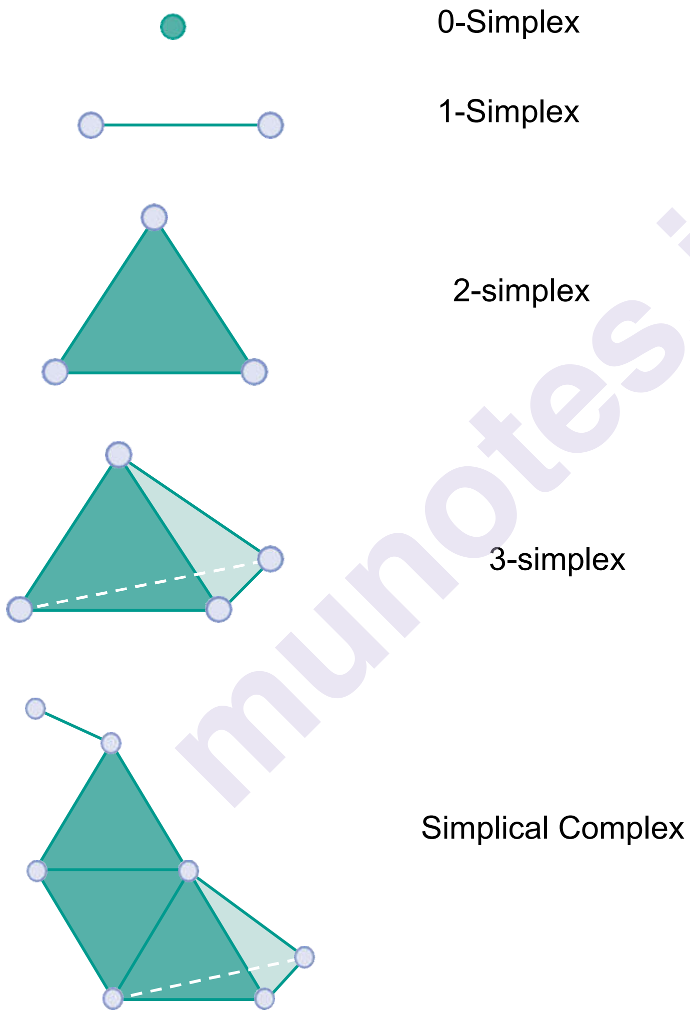
The mathematical properties of the geometric space used for spatial data can be described as follows:

The space is a three-dimensional Euclidean space where for every point we can determine its three-dimensional coordinates as a triple (x, y, z) of real numbers. In this space, we can define features like points, lines, polygons, and volumes as geometric primitives of the respective dimension. A point is zero-dimensional, a line one-dimensional, a polygon two-dimensional, and a volume is a three-dimensional primitive.

- The space is a metric space, which means that we can always compute the distance between two points according to a given distance function. Such a function is also known as a metric.

- The space is a topological space, of which the definition is a bit complicated. In essence, for every point in the space we can find a neighbourhood around it that fully belongs to that space as well.
- Interior and boundary are properties of spatial features that remain invari- ant under topological mappings. This means, that under any topological mapping, the interior and the boundary of a feature remains unbroken and intact.

There are a number of advantages when our computer representations of ge - ographic phenomena have built-in sensitivity of topological issues. Questions related to the 'neighbourhood' of an area are a point in case.

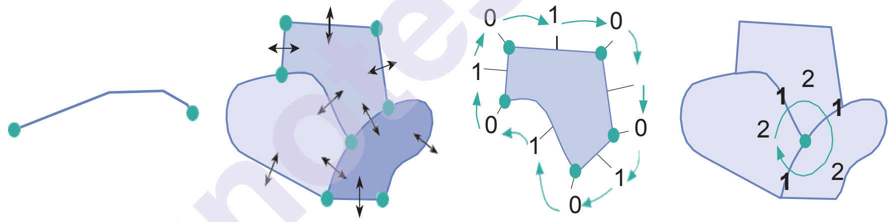


Simplices and a simplicial complex. Features are approxi- mated by a set of points, line segments, triangles, and tetrahedrons.

the topological properties of interior and boundary to define rela- tionships between spatial features. Since the properties of interior and bound- ary do not change under topological mappings, we can investigate their possi- ble relations between spatial features.4 We can define the interior of a region R as the largest set of points of R for which we can construct a disk-like environment around it (no matter how small) that also falls completely inside R. The boundary of R is the set of those points belonging to R but that do not belong to the interior of R, i.e. one cannot construct a disk-like environment around such points that still belongs to R completely.

The five rules of topological consis- tency in two-dimensional space

1. Every 1-simplex (‘arc’) must be bounded by two 0-simplices (‘nodes’,namely its begin and end node)
2. Every 1-simplex border two 2-simplices (‘polygons’, namely its ‘left’and ‘right’ polygons)
3. Every 2-simplex has a closed boundary consisting of an alternating(and cyclic) sequence of 0- and 1-simplices.
4. Around every 0-simplex exists an alternating (and cyclic) sequence of1- and 2-simplices.
5. 1-simplices only intersect at their (bounding) nodes.



rule (1) rules (2, 5) rule (3) rule (4)

8. Scale and Resolution

Map scale can be defined as the ratio between the distance on paper map andthe distance of the same stretch in the terrain. A 1:50,000 scale map means that 1 cm on the map represents 50,000 cm, i.e., 500 m, in the terrain. ‘Large-scale’means that the ratio is large, so typically it means there is much detail, as in a 1:1,000 paper map. ‘Small-scale’ in contrast means a small ratio, hence less detail, as in a 1:2,500,000 paper map. When applied to spatial data, the term resolution is commonly associated with the cell width of the tessellation applied. When digital spatial data sets have been collected with a specific map-making purpose in mind, and these maps were designed to be of a single map scale, like 1:25,000, we might suppose that the data carries the characteristics of “a 1:25,000digital data set.”

9. Representation of Geographic Fields

A geographic field can be represented through a tessellation, through a TIN or through a vector representation. The choice between them is determined by the requirements of the application at hand. It is more common to use tessellations, notably rasters, for field representation, but vector representations are in use too. We have alredy looked at TINs. We provide an example of the other two below.

10. Representation of Geographic objects

The representation of geographic objects is most naturally supported with vec- tors. After all, objects are identified by the parameters of location, shape, size and orientation and many of these parameters can be expressed in terms of vectors. However, tessellations are still commonly used for representing geographic objects.

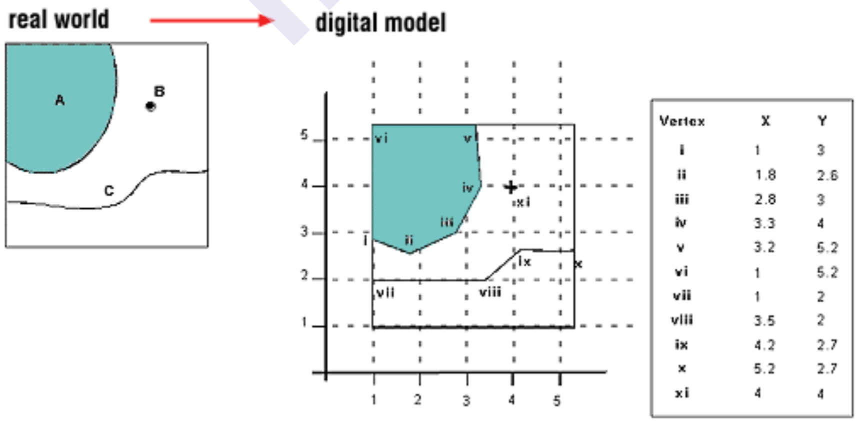
11. Tessellations to represent geographic objects

Remotely sensed images are an important data source for GIS applications. Un- processed digital images contain many pixels, with each pixel carrying a re- flectance value. Various techniques exist to process digital images into classified images that can be stored in a GIS as a raster. Image classification attempts to characterize each pixel into one of a finite list of classes, thereby obtaining an interpretation of the contents of the image.

Line and point objects are more awkward to represent using rasters. After all, we could say that rasters are area-based, and geographic objects that are perceived as lines or points are perceived to have zero area size. Standard classification techniques, moreover, may fail to recognize these objects as points or lines.

12. Vector representations of geographic objects

A vector-based GIS is defined by the vectorial representation of its geographic data. According with the characteristics of this data model, geographic objects are explicitly represented, and, within the spatial characteristics, the thematic aspects are related.

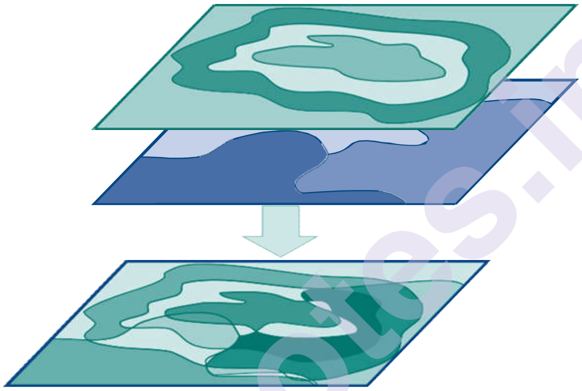


2.4 ORGANIZING AND MANAGING SPATIAL DATA

The main principle of data organization applied in GIS system is a spatial data layer. A spatial data layer is either a representation of a continuous or discrete field, or a collection of objects of the same kind. Usually, the data is organized so that similar elements are in a single data layer. For example, all telephone booth point objects would be in one layer, and all road line objects in another.

A data layer contains spatial data and attribute (or: thematic) data, which further describes the field or objects in the layer. Attribute data is quite often arranged in tabular form, maintained in geodatabase. Data layers can be overlaid with each other, inside the GIS package, to study combinations of geographic phenomena. We shall see later that a GIS can be used to study the spatial relationships between different phenomena, requiring computations which overlay one data layer with another.

Two different object layers can be over- laid to look for spatial cor- relations, and the result can be used as a separate (object) layer.



2.5 THE TEMPORAL DIMENSION

Besides having geometric, thematic, and topological properties, geographic phenomena are also dynamic; they change over time. For an increasing number of applications, these changes themselves are the key aspect of the phenomenon to study. Examples include identifying the owners of a land parcel in 1972, or how land cover in a certain area changed from native forest to pastures over a specific time. We can note that some features or phenomena change slowly, such as geological features, or as in the example of land cover given above. Other phenomena change very rapidly, such as the movement of people or atmospheric conditions. For different applications, different scales of mea- surement will apply.

Examples of the kinds of questions involving time include:

- Where and when did something happen?
- How fast did this change occur?
- In which order did the changes happen?

1. Discrete and continuous time

Time can be measured along a discrete or continuous scale. Discrete time is composed of discrete elements (seconds, minutes, hours, days, months, or years). In continuous time, no such discrete elements exist, and for any two different points in time, there is always another point in between. We can also structure time by events (points in time) or periods (time intervals). When we represent time peri- ods by a start and end event, we can derive temporal relationships between events and periods such as ‘before’, ‘overlap’, and ‘after’.

2. Valid time and transaction time

Valid time (or world time) is the time when an event really happened, or a string of events took place. Transaction time (or database time) is the time when the event was stored in the database or GIS. Observe that the time at which we store something in the data- base/GIS typically is (much) later than when the related event took place.

3. Linear, branching, and cyclic time

Time can be linear, ex-tending from the past to the present (‘now’), and into the future. This view gives a single timeline. For some types of temporal analysis, branching time—in which different timelines from a certain point in time onwards are possible—and cyclic time—in which repeating cycles such as seasons or days of a week are recognized, make more sense and can be useful.

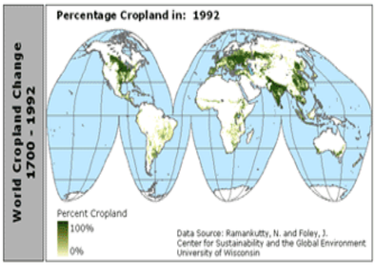
4. Time granuality

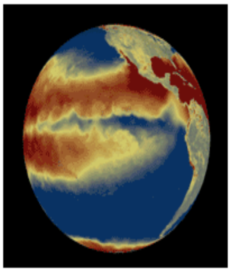
When measuring time, we speak of granularity as the precision of a time value in a GIS or database (e.g., year, month, day, sec- ond, etc.). Different applications may obviously require different granu- larity. In cadastral applications, time granularity might well be a day, as the law requires deeds to be date-marked; in geological mapping applica- tions, time granularity is more likely in the order of thousands or millions of years.

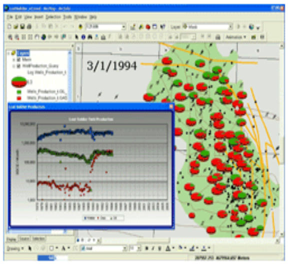
5. Absolute and relative time

Time can be represented as absolute or relative. Absolute time marks a point on the timeline where events happen (e.g., ‘6 July 1999 at 11:15 p.m.’). Relative time is indicated relative to other points in time (e.g., ‘yesterday’, ‘last year’, ‘tomorrow’, which are all relative to ‘now’, or ‘two weeks later’, which is relative to some other arbitrary point in time.).

Temporal data is simply data that represents a state in time, such as the land-use patterns of Hong Kong in 1990, or total rainfall in Honolulu on July 1, 2009. Temporal data is collected to analyze weather patterns and other environmental variables, monitor traffic conditions, study demographic trends, and so on. This data comes from many sources ranging from manual data entry to data collected using observational sensors or generated from simulation models. Below are some examples of temporal data.







Wyoming Oil and Gas Conservation Commission

2.6 SUMMARY

Geographic phenomena are present in the real world that we study, their computer representations only live inside computer systems. This chapter has discussed different types of geographic phenomena and examined the ways that these can be represented in a computer system, such as a GIS. The first type of phenomena we called fields, the second calledc objects. Amongst fields, we identified continuous and discrete phenomena. Continuous phenomena could even be differentiable, meaning that for locations factors such as gradient and aspect can be determined. Amongst objects, important classification parameters include location, shape, size and orientation. Also, this chapter elaborated on the techniques with which the above phenomena are stored in a computer system. At the end of the chapter, it contains topological. Spatial relations and temporal dimension.

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4. https://www.educba.com/applications-of-gis/

5. https://desktop.arcgis.com/en/arcmap/10.3/map/time/what-is-temporal-data.htm

2.8 QUESTIONS

1. Write a short note on Geographic phenomenon.
2. How real-world objects are represented using Model in GIS? Explain.
3. Define Geographic field. Explain its different data type and values.
4. What is regular and irregular tesselation? Explain it.
5. What is topology and spatial representations of geographic objects.
6. Explain temporal dimension in brief with example.

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3

HARDWARE AND SOFTWARE TRENDS IN GEOGRAPHIC INFORMATION SYSTEM

Unit Structure :

3.0 OBJECTIVES

The objective of this chapter is to make students understand the following concept

- Capability of GIS
- Architecture of GIS
- Functionality of GIS
- Spatial Data infrastructure
- Stages of Spatial data handling

3.1 INTRODUCTION

- The Abbreviation GIS stands for geographic information system.
- We can say that GIS is a tool for working with geographic information.
- A system is a set of things that are working together as parts of a mechanism or an interconnecting network.
- GIS system also contain software and hardware.
- Spatial data refers to "where" things are, or perhaps, where they were or will be.
- In other words, spatial data means data that contains positional values, such as (x, y) co-ordinates.
- The Spatial data is also known as geospatial data.
- A working GIS requires both hardware and software, and also people such as GI Systems the database creators or administrators, analysts who work with the software, and the users of the end product.
- Data processing system refers to hardware and software components which are able to process, store and transfer data or the components of systems that facilitate the management and processing of geo information.

3.2 HARDWARE AND SOFTWARE TRENDS

- There has been a tremendous amount of change in computer hardware at an ever-increasing rate.
- It appears that computer hardware is advancing at an ever-increasing rate.
- A faster, more powerful processor generation replaces the previous one every few months.
- Furthermore, computers are becoming increasingly portable, while offering increased performance.
- In comparison to the first PC hand-held computers introduced in the early 1980's, today's handheld computers have a multiple of the computing power.
- Current PCs are thousands of times faster than 25-year-old "minicomputers".
- To illustrate this trend: compare an early 1980's PC with a 2 MHz CPU, 128 Kbytes of main memory, and a 10 MByte hard drive with today's desktop PC.

- The cost of computers is also decreasing.
- Nowadays, handheld computers are commonplace in business and personal use, providing field surveyors with powerful tools, including GPS capabilities.
- As a result of these hardware trends, software providers continue to create application programs and operating systems with an increasing amount of functionality while consuming an increasing amount of memory as well.
- It is generally believed that software technology has developed somewhat slower than hardware technology and as a result cannot fully utilise the capabilities offered by the ever-expanding hardware capabilities.
- Existing software obviously performs better when run on faster computers.
- Along with these trends, there have also been significant developments in computer networks.
- Nowadays, almost any computer on Earth can connect to some network, and contact computers virtually anywhere else, allowing fast and reliable exchange of (spatial) data.
- Mobile phones are more and more frequently being used to connect to computers on the Internet.
- The UMTS protocol (Universal Mobile Telecommunications System), allows digital communication of text, Mobile communication audio, and video at a rate of approximately 2 Mbps.
- The new HSDPA (High-Speed Downlink Packet Access) protocol offers up to 10 times the speed of UMTS.
- Bluetooth version 2.0 is a standard that offers up to 3 Mbps connections, especially between palm- and laptop computers and their peripheral devices, such as a mobile phone, GPS or printer at short range.
- Wireless LANs (Local Area Networks), under the so-called Wi-Fi standard, nowadays offer a bandwidth of up to 108 Mbps on a single connection point, to be shared between computers.
- They are more and more used for constructing a computer network in office buildings and in private homes.
- When the medium of communication is not the air, but copper or fibre optics cables that is structured networks then the speed is different.
- Standard 'Dial-up' telephone modems allow rates up to 56 kbps.

- Digital telephone links (ISDN) support much higher rates: up to 1.5 Mbps.
- ADSL (Asymmetric Digital Subscriber Line) technology widely available through telephone companies on standard copper-wire networks supports transfer rates anywhere between 2 and 20 Mbps towards the customer (downstream), and between 1 and 8 Mbps towards the network (upstream) depending on the internet provider and quality of the network infrastructure.
- Wide-area computer networks (national, continental, global) have a capacity of several Gbps.
- ITC's dedicated Local Area Network (LAN), which is partially fibre optics-based, supports a transmission rate locally of 1 Gbps.

3.3 GEOGRAPHIC INFORMATION SYSTEMS

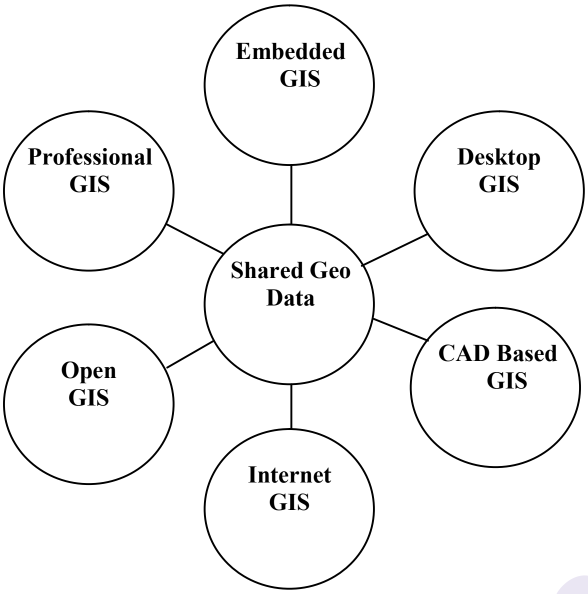
- A GIS is a computer-based system that provides the following four sets of capabilities to handle georeferenced data:
  1. Data capture and preparation
  2. Data management, including storage and maintenance
  3. Data manipulation and analysis
  4. Data presentation
- For many years, analogue data sources were used, processing was done manually, and paper maps were produced.
- The introduction of modern techniques has led to an increased use of computers and digital information in all aspects of spatial data handling.
- Spatial data refers to where things are, or perhaps, where they were or will be. To be more precise, these professionals deal with questions Spatial data related to geographic space, which we define as having positional data relative to the Earth's surface. Spatial data represent positional data.
- Most planning projects require data from a number of national institutes, such as national mapping agencies, soil and forest survey institute, and national census bureaus, as well as spatial and non-spatial sources.
- The data sources obtained may be from different time periods, and the spatial data may be in different scales or projections.
- With the help of a GIS, the spatial data can be stored in digital form in world coordinates.

- With this software, scaling transformations can be avoided, and map projections can be converted easily.
- With the spatial data thus prepared, spatial analysis functions of the GIS can then be applied to perform the planning tasks.

3.3.1 GIS software

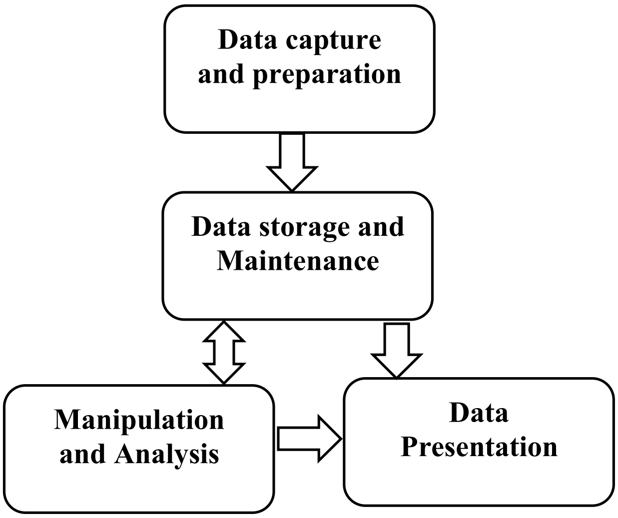
- GIS can be considered as a system that stores spatial data (positional data), a toolbox, a technology, an information source or a field of science.
- The main characteristics of a GIS software package are its analytical functions that provide means for obtaining new geoinformation from existing spatial and attribute data.
- Geographic information science is driven by the use of GIS tools, which in turn are improved by the insights and information gained from their application to various scientific fields.
- Spatial information theory is one such field, which focuses specifically on providing the background for the production of tools for the handling of spatial data.
- All GIS packages available on the market have their strengths and weaknesses, typically resulting from the development history and/or intended application domain(s) of the package.
- There are some GIS tools that are designed to support raster-based functionality, while others focus on (vector-based) spatial objects
- We can state that any package that provides support for only rasters or only objects, is not a complete GIS. Well-known, full-fledged GIS packages include **ILWIS, Intergraph's Geo Media, ESRI's Arc GIS, and Map Info from Map- Info Corp**.
- Generally, no one GIS package is 'better' than another: it depends on factors such as the intended application and the user's expertise.
- **ILWIS's** traditional strengths are in raster processing and scientific spatial data analysis, especially in project-based GIS applications.
- **Intergraph, ESRI and Map Info** products have been known better for their support of vector- based spatial data and their operations, user interface and map production.

Software Development in GIS



3.3.2 GIS architecture and functionality

- As we know that a geographic information system in the wider sense consists of software, data, people, and an organization in which it is used.
- we should also note that organizational factors will define the context and rules for the capturing, processing and sharing of geo information, as well as the role which GIS plays in the organization as a whole.
- A GIS consists of several functional components—components which support key GIS functions.
- The several functional components of GIS are data **capture and preparation, data storage, data analysis, and presentation of spatial data.**
- Figure 3.3.2 shows the diagram of these components, with arrows indicating the data flow in the system.



- For a particular GIS, each of these components may provide many or only a few functions.
- If any of these components is missing, the system cannot be called a geographic information system.
- However it is important to note that the same function may be offered by different components of the GIS, for instance, data capture and data storage may have functions in common, and the same holds for data preparation and data analysis.

3.3.3 Spatial data infrastructure

- Organizations are increasingly working in cooperation in order to obtain and provide geographic information to other organizations as well as the general public for reasons of efficiency and legislation.
- Data dissemination, security, copyright, and pricing must all be addressed when spatial data is shared between the GISs of those organizations.
- The design and maintenance of a Spatial Data Infrastructure (SDI) deals with these issues.
- An SDI is defined as "the relevant base collection of technologies, policies and institutional arrangements that facilitate the availability of and access to spatial data".
- A fundamental component of those arrangements is a broad understanding of the agreements between organizations and a narrower understanding of the agreements between software systems on how to share geographic data.

- In SDI, standards are often the starting point for those agreements. Standards exist for all facets of GIS, ranging from data capture to data presentation.
- They are developed by different organizations, of which the most prominent are the Inter- national Organization for Standardisation (ISO) and the Open Geospatial Consortium (OGC).
- Typically, an SDI provides its users with different facilities for finding, viewing, downloading and processing data.
- Because the organizations in an SDI are normally widely distributed over space, computer networks are used as the means of communication.
- With the development of the internet, the functional components of GIS have been gradually become available as web-based applications.
- Much of the functionality is provided by so called **geo-webservices**, software programs that act as an intermediate between geographic databases and the users of the web.
- Geo-webservices can vary from a simple map display service to a service which involves complex spatial calculations.

Basic Software component of SDI

- Software client:

  To display, query & analyse spatial data (web or desktop GIS)
- Catalogue service:

  discovering, browsing & querying of metadata or spatial data (datasets)
- Spatial data service:

  allows delivery of data via internet
- Processing service:

  data, projection and scale transformation
- Spatial data repository:

  to store data
- GIS software:

  to create & update data

3.4 STAGES OF SPATIAL DATA HANDLING

The various stages of spatial data handling are as follows: -

1. Spatial data capture and preparation
2. Spatial data storage and maintenance
3. Spatial query and analysis
4. Spatial data presentation

3.4.1 Spatial data capture and preparation

- Data capture is closely related to surveying engineering, photogrammetry, remote sensing, and digitization, i.e., the conversion of analogue data into digital representations.
- Remote sensing is the field that provides photographs and images as the raw base data from which spatial data sets are derived.
- Field surveys are often needed to collect data that cannot be obtained through remote sensing, or to validate data thus obtained.
- Traditional techniques for obtaining spatial data, typically from paper sources, included manual digitizing and scanning.
- Table 3.4.1 lists the main methods and devices used for data capture.

Method	**Devices**
Manual digitizing	• coordinate entry via keyboard • digitizing tablet with cursor • mouse cursor on the computer monitor (heads-up digitizing) • (digital) photogrammetry
Automatic digitizing	• scanner
Semi-automatic digitizing	• line-following software
Input of available digital data	• CD-ROM or DVD-ROM • via computer network or internet (including geo-webservices)

Table 3.4.2 : Spatial data in-put methods and devices used

- In recent years there has been a significant increase in the availability and sharing of digital geospatial data.
- Computer networks and media play an important role in disseminating this data, particularly the internet.
- In some cases, the data may not yet be ready for use in the system when it is obtained in some digital format.
- This may be because the format obtained from the capturing process is not quite the format required for storage and further use, which means that some type of data conversion is required.
- This problem may also arise if the captured data is only raw base data, from which the real data objects of interest to the system will need to be constructed.
- For example, semi- automatic digitizing may produce line segments, while the applications requirements are that non-overlapping polygons are needed. A build-and-verification phase would then be needed to obtain these from the captured lines.

3.4.2 Spatial data storage and maintenance

Data organization

- The way that data is stored plays a central role in the processing and the eventual understanding of that data.
- In most of the available systems, spatial data is organized in layers by theme and/or scale.
- For instance, the data may be organized in thematic categories, such as land use, topography and administrative subdivisions, or according to map scale.
- An important underlying need or principle is a representation of the real world that has to be designed to reflect phenomena and their relationships as naturally as possible.
- In a GIS, features are represented with their geometric and non-geometric attributes and relationships.
- The geometry of features is represented using primitives of the relevant dimension: a windmill might be a point; a field of crops might be a polygon.
- The primitives follow either the vector, or the raster approach.

Cells, pixels and voxels

- As we know, vector data types describe an object through its boundary, thus dividing the space into parts that are occupied by the respective objects.

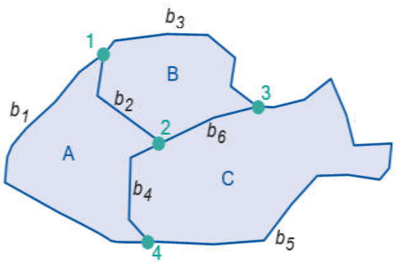
- The raster approach subdivides space into regular cells, mostly as a square tessellation of dimension two or three.
- These cells are called either cells or pixels in 2D, and voxels in 3D.
- Each cell contains a description of the real world feature it represents, if it represents a discrete field.
- For continuous fields, the cell holds a representative value.
- Table 3.4.2 lists advantages and disadvantages of raster and vector representations.

Raster representation	Vector representation
Advantage s	
• simple data structure • simple implementation ofoverlays • efficient for image processing	• efficient representation of topology • adapts well to scale changes • allows representing networks • allows easy association with attribute data
Disadvanta ges	
• fewer compact data structure • difficulties in representingtopology • cell boundaries independent of feature boundaries	• complex data structure • overlay more difficult to implement • inefficient for image processing • more update-intensive

Raster encoding

- The storage of a raster is straightforward. It is stored in a file as a long list of values, one for each cell, preceded by a small list of extra data called as ‘file header’ that informs how to interpret the long list.
- The order of the cell values in the list can be—but need not be—left-to-right, top-to-bottom.
- This simple encoding scheme is known as row ordering.
- The header of the raster file will typically inform how many rows and columns the raster has, which encoding scheme is used, and what sort of values are stored for each cell.
- Raster files can be quite big data sets. Computationally, it makes sense to arrange the long list of values of cells in a way that spatially nearby cells are also close together in the list.

- Low-level storage structures for vector data are much more complicated. The best natural understanding can be obtained from Figure 3.4.2, where a boundary model for polygon objects is illustrated. Similar structures are in use for line objects.



line	*from*	*to*	*left*	*right*	*vertexlist*
b_1	4	1	W	A	...
b_2	1	2	B	A	...
b_3	1	3	W	B	...
b_4	2	4	C	A	...
b_5	3	4	W	C	...
b_6	3	2	C	B	...

Figure:3.4.2: A Simple boundary model for the polygons A, B and C for each arc, we store the start and end node, its left and right polygon. The 'polygon' W denotes the outside world polygon.

- The boundary model is sometimes also called the topological data model as it captures some topological information, such as polygon neighbourhood.

DBMS and Spatial Database

- The GIS software packages support both spatial and attribute data, i.e., spatial data storage using vectors and attribute data storage using tables.
- Historically, database management systems (DBMSs) have been based on tables for data storage.
- Many GIS applications have been able to access external databases to store attribute data and utilize their superior data management capabilities for some time.
- Currently, all major GIS packages provide facilities to link with a DBMS and ex- change attribute data with it.
- Spatial (vector) and attribute data are still some- times stored in separate structures, although they can now be stored directly in a spatial database.
- Spatial data is associated with geographic locations such as cities, towns etc. A spatial database is optimized to store and query data representing objects.

Data maintenance

- Maintenance of spatial data is the process of keeping the data set current and supportive to the user community.
- It deals with obtaining new data, and entering them into the system, possibly replacing outdated data.
- The purpose is to have an up-to-date stored dataset available.
- For example, after a major earthquake, we may need to update our road network data to reflect that road have been washed away or have become blocked.
- It is important to update spatial data in order to meet the requirements of data users as well as the fact that many aspects of the real world are constantly changing.
- These data updates can take different forms. It may be that a complete, new survey has been carried out, from which an entirely new data set is derived that will replace the current set.
- Such a situation is common if the spatial data originate from remotely sensed data, such as a new vegetation cover set or digital elevation model.
- It may also be that local ground surveys have revealed local changes, for instance, new constructions, or changes in land use or ownership. In such cases, local change to the large spatial data set is more typically required. Such local changes should respect matters of data consistency, i.e., they should leave other spatial data within the same layer intact and correct.

3.4.3 Spatial query and analysis

SDSS

- The most distinguishing parts of a GIS are its functions for spatial analysis, i.e., operators that use spatial data to derive new geoinformation.
- Spatial queries and process models play an important role in this functionality.
- One of the key uses of GISs has been to support spatial decisions.
- Spatial decision support systems (SDSS) are a category of information systems composed of a database, GIS software, models, and a so-called knowledge engine which allow users to deal specifically with locational problems.

Spatial data analysis

- In a GIS, data are usually grouped into layers (or themes).
- Usually, several themes are part of a project.
- The analysis functions of a GIS use the spatial and non-spatial attributes of the data in a spatial database to provide answers to user questions.
- GIS functions are used for maintenance of the data, and for analysing the data in order to infer information from it.
- Analysis of spatial data can be defined as computing new information that provides new insight from the existing, stored spatial data.
- Consider an example from the domain of road construction. In mountainous areas this is a complex engineering task with many cost factors, which include the amount of tunnels and bridges to be constructed, the total length of the runway, and the volume of rock and soil to be moved.
- GIS can help to compute such costs on the basis of an up-to-date digital elevation model and soil map.
- The exact nature of the analysis will depend on the application requirements, but computations and analytical functions operate on both spatial and non-spatial data.

3.4.4 Spatial data presentation

- The presentation of spatial data, whether in print or on-screen, in maps or in tabular displays, or as 'raw data', is closely related to the disciplines of cartography, printing and publishing.
- The presentation may either be an end-product, for example as a printed atlas, or an intermediate product, as in spatial data made available through the internet.

Method	*Devices*
Hard copy	• Printer • plotter (pen plotter, ink-jet printer, thermal transfer printer, electrostatic plotter) • film writer
Soft copy	• computer screen
Output of digital data sets	• magnetic tape • CD-ROM or DVD • The internet

Table 3.4.4: Spatial data presentation

- Table 3.4.4 lists several different methods and devices used for the presentation of spatial data.
- Cartography and scientific visualization make use of these methods and devices to produce their products.

3.5 SUMMARY

- A system is a set of things that are working together as parts of a mechanism or an interconnecting network.
- GIS system also contain software and hardware.
- Spatial data means data that contains positional values, such as (x, y) co-ordinates.
- A working GIS requires both hardware and software, and also people such as GI Systems the database creators or administrators, analysts who work with the software, and the users of the end product.
- A faster, more powerful processor generation replaces the previous one every few months.
- Nowadays, handheld computers are commonplace in business and personal use, providing field surveyors with powerful tools, including GPS capabilities.
- It is generally believed that software technology has developed somewhat slower than hardware technology.
- The UMTS protocol (Universal Mobile Telecommunications System), allows digital communication of text, Mobile communication audio, and video at a rate of approximately 2 Mbps.
- The new HSDPA (High-Speed Downlink Packet Access) protocol offers up to 10 times the speed of UMTS.
- Bluetooth version 2.0 is a standard that offers up to 3 Mbps connections, especially between palm- and laptop computers and their peripheral devices, such as a mobile phone, GPS or printer at short range.
- Wireless LANs (Local Area Networks), under the so-called Wi-Fi standard, nowadays offer a bandwidth of up to 108 Mbps on a single connection point, to be shared between computers.
- Standard 'Dial-up' telephone modems allow rates up to 56 kbps.
- Digital telephone links (ISDN) support much higher rates: up to 1.5 Mbps.

- ADSL (Asymmetric Digital Subscriber Line) technology widely available through telephone companies on standard copper-wire networks supports transfer rates anywhere between 2 and 20 Mbps towards the customer (downstream), and between 1 and 8 Mbps towards the network (upstream) depending on the internet provider and quality of the network infrastructure.

- A GIS is a computer-based system that provides the following four sets of capabilities to handle georeferenced data:
  1. Data capture and preparation
  2. Data management, including storage and maintenance
  3. Data manipulation and analysis
  4. Data presentation

- We can state that any package that provides support for only rasters or only objects, is not a complete GIS. Well-known, full-fledged GIS packages include **ILWIS, Intergraph's GeoMedia, ESRI's ArcGIS, and MapInfo from Map- Info Corp**.

- The several functional components of GIS are data **capture and preparation, data storage, data analysis, and presentation of spatial data.**

- The various stages of spatial data handling are as follows: -
  1. Spatial data capture and preparation
  2. Spatial data storage and maintenance
  3. Spatial query and analysis
  4. Spatial data presentation

3.6 QUESTIONS

1. List Functional component of GIS.Explain any two of them in details.
2. Differentiate between vector data and raster data.
3. Write a note on Spatial data infrastructure.
4. What are the different ways of spatial data capture and preparation? Explain.
5. Write a note on spatial data presentation.

3.7 MCQ QUESTIONS

1. Among the following which do not come under the components of GIS?
   a) Hardware
   b) Software
   c) Data
   d) Compiler

2. GIS uses the information from which of the following sources?
   a) Non-spatial Information System
   b) Spatial information System
   c) Global Information System
   d) Position Information System

3. Which of the following doesn't determine the capability of GIS?
   a) Defining a map
   b) Representing cartographic feature
   c) Retrieving data
   d) Transferring data

4. Boundary model is also known as _____.
   a) Topological data model
   b) Topological discrete model
   c) Temporal data model
   d) Temporal continuous model

5. Which of the following is not full-fledged GIS packages?
   a) ILWIS
   b) GeoMedia
   c) ArcGIS
   d) Autocad

6. **SDI stands for**
   a) Spatial Data Interface
   b) Spatial Data Infrastructure
   c) Spatial Data Intention
   d) Spatial Data International

7. **ArcGIS is product of the____**
   a) Environmental System Research Center
   b) Caliper corporation
   c) Autodesk
   d) Clark's lab

8. Spatial Data capturing involves ______.
   a) surveying, engineering, photogrammetry, remote sensing and digitization
   b) digitization, finding statistical values, creating maps
   c) rasterization, creating maps and presenting on output device
   d) surveying engineering and digitization

9. UMTS protocol (Universal Mobile Telecommunications System) allows digital communication of text, audio and video at a rate of approximately ______
   a) 8 Mbps
   b) 6 Mbps
   c) 2Mbps
   d) 4 Mbps

10. Which Protocol allows digital communication of text,audio & video
    a) GIS
    b) HSDPA
    c) UMTS
    d) SDI

11. Digital telephone links (ISDN) support network speed rates up to _____.
    a) 8 Mbps
    b) 2.5 Mbps
    c) 1.5 Mbps
    d) 5 Mbps

3.8 REFERENCES

- Principles of Geographic Information Systems, Otto Huisman, Rolf A. de By (eds.)

4

DBMS, GIS AND SPATIAL SYSTEM

Unit Structure :

4.0 OBJECTIVE

The objective of this chapter is to understands the following concept:

- Database management system
- Reasons for using DBMS
- Alternative for DBMS
- Spatial Database

4.1 INTRODUCTION

- A database is an organized collection of structured information, or data, typically stored electronically in a computer system.

- A database is usually controlled by a database management system (DBMS).

- Data, DBMS, and applications together make up a database system, also called database or database system.

- Spatial data are relative geographic information about the Earth and its features.
- A specific location on Earth is defined by a pair of latitude and longitude coordinates.
- There are two types of spatial data, raster data and vector data, depending on how they are stored.
- Raster data is made up of grid cells that are identified by row and column. The entire geographic area is divided into groups of individual cells, each of which represents a different image.
- Points, polylines, and polygons make up vector data. Points represent wells, houses, and so on. Polylines are used to represent roads, rivers, and streams, among other things. Polygons represent villages and towns.
- The purpose of a spatial database is to store and retrieve information about objects.
- These are the objects that have a geometric space definition.

4.2 DATABASE MANAGEMENT SYSTEMS

- A database is a large, computerized collection of structured data.
- Since the 1960's, databases have been used for non-spatial purposes such as managing bank accounts, tracking stock, managing salaries, order bookkeeping, and booking flights.
- In all these applications, the amount of data is usually quite large, but the data itself is simple and regular in structure.

Database design and maintenance

- Designing a database is not an easy task.
- Before creating a database, one should carefully consider what its purpose is, and who its users will be.
- To organize the data within the database, one must identify the data sources and define their format.
- This format is usually called the database structure.
- Lastly, data can be entered into the database.
- It is important to keep the data up-to-date, and it is therefore wise to set up the processes for this, and make someone responsible for regular maintenance of the database.
- Documentation of the database design and set-up is crucial for an extended database life.

- Many enterprise databases tend to outlive the professional careers of their original designers.
- A **database management system (DBMS)** is a software package that allows the user to set up, use and maintain a database.
- Like a GIS allows the set-up of a GIS application, a DBMS offers generic functionality for database organization and data handling.
- Many standard PCs are equipped with a DBMS called MS Access.
- This package offers a useful set of functions, and the capacity to store terabytes of information.

4.2.1 Reasons for using a DBMS

There are several reasons why one might want to use a DBMS for data storage and processing.

- A DBMS supports the storage and manipulation of very large data sets.
  - Some data sets are so big that storing them in text files or spreadsheet files becomes too difficult for use in practice. The result may be that finding simple facts takes minutes, and performing simple calculations perhaps even hours. A DBMS is specifically designed for this purpose.
- A DBMS can be instructed to guard over data correctness.
  - For example, an important aspect of data correctness is data entry checking: ensuring that the data entered into the database does not contain obvious errors.
  - For instance, since we know the study area we are working in, we also know the range of possible geographic coordinates, so we can ensure the DBMS checks them.
  - The above is a simple example of the type of rules, generally known as integrity constraints, that can be defined in and automatically checked by a DBMS.
  - More complex integrity constraints are certainly possible, and their definition is part of the design of a database.
- A DBMS supports the concurrent use of the same data set by many users.
  - Large data sets are built up over time, which means that substantial investments are required to create and maintain them, and that probably many people are involved in the data collection, maintenance and processing.
  - These data sets are often considered to be of a high strategic value for the owner(s), which is why many may want to make use of them within an organization.

- Moreover, for different users of the database, different views on the data can be defined.
- In this way, users will be under the impression that they operate on their personal database, and not on one shared by many people.
- They may all be using the database at the same time, without affecting each other's activities. This DBMS function is called **concurrency control.**

• A DBMS provides a high-level, declarative query language.

- The most important use of the language is the definition of queries.
- A query is a computer program that extracts data from the database that meet the conditions indicated in the query.

• A DBMS supports the use of a **data model**.

- A data model is a language with which one can define a database structure and manipulate the data stored in it.
- The most prominent data model is the relational data model. Its primitives are tuples (also known as records, or rows) with attribute values, and relations, being sets of similarly formed tuples.

• A DBMS includes **data backup and recovery functions** to ensure data availability at all times.

- As potentially many users rely on the availability of the data, the data must be safeguarded against possible calamities.
- Regular back-ups of the data set, and automatic recovery schemes provide an insurance against loss of data.

• A DBMS allows the control of **data redundancy**.

- A well-designed database takes care of storing single facts only once.
- Storing a fact multiple times give rise to a phenomenon known as data redundancy.
- Data redundancy can lead to situations in which stored facts may contradict each other, causing reduced usefulness of the data.
- Redundancy, however, is not necessarily always problematic, as long as we specify where it occurs so that it can be controlled for.

4.2.2 Alternatives for data management

• The decision to use a DBMS will depend, among other things, on how much data there is or will be, what type of use it will be put to, and how many users will be involved.

- On the small-scale side of the spectrum—when the data set is small, its use is relatively simple, and with just one user—we might use **simple text files, and a text processor**.
- Think of a personal address book as an example, or a small set of simple field observations.
- Text files does not offer support for data analysis, except maybe sorting in alphabetical order.
- If our data set is still small and numeric by nature, and we have a single type of use in mind, a **spread sheet program** will be sufficient.
- This might be the case if we have a number of field observations with measurements that we want to prepare for statistical analysis.
- However, if we carry out region or nationwide censuses, with many observation stations and/or field observers and all sorts of different measurements, one quickly needs a database to keep track of all the data.
- It should also be noted that spreadsheets do not accommodate concurrent use of the data set well, although they do support some data analysis, especially when it comes to calculations over a single table, like averages, sums, minimum and maximum values.
- All such computations are usually restricted to just a single table of data.
- When one wants to relate the values in the table with values of another nature in some other table, some expertise and significant amounts of time are usually required to make this happen.

4.2.3 The relational data model

- A data model is a language that allows the definition of:
  - The structures that will be used to store the base data,
  - The integrity constraints that the stored data has to obey at all moments in time, and
  - The computer programs used to manipulate the data.
- For the relational data model, the structures used to define the database are attributes, tuples, and relations.
- Computer programs either perform data extraction from the database without altering it, in which case we call them queries, or they change the database contents, and we speak of updates or transactions.
- The technical terms surrounding database technology are defined below.
- Let us look at a tiny database example from a cadastral setting. It is illustrated in Figure 4.2.3. This database consists of three tables, one for

storing people's details, one for storing parcel details and a third one for storing details concerning title deeds. Various sources of information are kept in the database such as a taxation identifier (TaxId) for people, a parcel identifier (PId) for parcels and the date of a title deed (Deed Date).

PrivatePerson	Tax ID	Surname	Birth Date
	101-367	Georgia	10/05/1952
	134-788	Wilson	26/01/1964
	101-490	Thomas	14/09/1931

Parcel	PID	Location	AreaSize
	3421	2001	467
	8871	1462	550
	2109	2323	1090
	1515	2003	290

Title Deed	Plot	Owner	Deed Date
	2109	101-367	10/12/1996
	8871	101-490	10/01/1984
	1515	134-788	1/09/1991
	3421	101-367	25/9/1996

Figure: 4.2.3 : A small example database consisting of three relations (tables), all with three attributes, and three, four and four tuples respectively. PrivatePerson / Parcel / TitleDeed are the names of the three tables. Surname is an attribute of the PrivatePerson table; the Surname attribute value for person with TaxId '101-367' is 'Georgia'.

Relations, tuples and attributes

- In the relational data model, a database is considered as a collection of relations, commonly also known as tables.
- A table or relation is itself a collection of tuples (or records). In fact, each table is a collection of tuples that are similarly shaped.
- It means that a tuple has a fixed number of named fields, also known as attributes or column. All tuples mean row in the same relation have the same named fields.
- As in Figure 4.2.3, relations can be displayed as tabular form data.
- An attribute is a named field of a tuple, with which each tuple associates a value, the tuple's attribute value.

- The example provided in the figure 4.3.2 shows that Private- Person table has three tuples; the Surname attribute value for the first tuple illustrated is 'Georgia'
- The phrase 'that are similarly shaped' requires that all values for the same attribute come from a single domain of values.
- An attribute's domain is a (possibly infinite) set of atomic values such as the set of integer number values, the set of real number values, etc.
- In our example cadastral database, the domain of the Surname attribute, for instance, is string, so any surname is represented as a sequence of text characters, i.e., as a string. The availability of other domains depends on the DBMS, but usually integer (the whole numbers), real (all numbers), date, yes/no and a few more are included.

PrivatePerson (TaxId:string,Surname:string,Birthdate:date)
Parcel
(Pid:number,Location:polygon,AreaSize:number)**TitleDeed**(Plot :number, Owner :string, DeedDate :date)

Table 4.2.3: The relation schemas for the three tables of the database in Figure 4.2.3

When a relation is created, we need to indicate what type of tuples it will store. This means that we must

1. Provide a name for the relation,
2. Indicate which attributes it will have, and
3. Set the domain of each attribute.

- A relation definition obtained in this way is known as the relation schema of that relation.
- The definition of relation schemas is an important part of database design.
- Our example database has three relation schemas; one of them is Title Deed.
- The relation schemas together make up the database schema.
- For the database of Figure 4.2.3, the relation schemas are given in Table 4.2.3.
- Underlined attributes Primary key (and their domains) indicate the primary key of the relation.
- Relation schemas are stable, and will hardly change over time.
- The tuples stored in a table, on the other hand, are often changing, either because new ones are added, others are removed, or their attribute values.

- The set of tuples in a relation at some point in time is called the relation instance at that moment.
- This tuple set is always finite: It is possible to count how many tuples there are.
- Figure 4.2.3 gives us a single database instance, i.e., one relation instance for each relation. One relation instance has three tuples, two of them have four.
- Any relation instance always contains only tuples that comply with the relation schema of the relation.

Finding tuples and building links between them

- The database system is particularly useful for storing large amounts of data, as we have already discussed. Note: our example database is not even small, it is tiny.
- The DBMS must support quick searches amongst many tuples.
- This is why the relational data model uses the notion of a key.
- A key of a relation comprises one or more attributes. A value for these attributes uniquely identifies a tuple.
- In other words, there will always be one tuple in the table with that combination of values if each key attribute has a value.
- It remains possible that there is no tuple for the given combination.
- In our example database, the set {TaxId, Surname}is a key of the relation PrivatePerson: if we know both a TaxId and a Surname value, we will find at most one tuple with that combination of values.
- Every relation has a key, though possibly it is the combination of all attributes.
- When searching for tuples, however, such a large key is not useful since we must supply a value for each of its attributes.
- There should be as few attributes as possible on a key: the fewer, the better.
- If a key has just one attribute, it obviously cannot have fewer attributes.
- Some keys have two attributes; an example is the key {Plot, Owner} of relation TitleDeed.
- We need both attributes because there can be many title deeds for a single plot (in case of plots that are sold often) but also many title deeds for a single person (in case of wealthy persons).

- When we provide a value for a key, we can look up the corresponding tuple in the table (if such a tuple exists).
- A tuple can refer to another tuple by storing that other tuple's key value.
- For instance, a TitleDeed tuple refers to a Parcel tuple by including that tuple's key value.
- The TitleDeed table has a special attribute Plot for storing such values.
- The Plot attribute is called a foreign key because it refers to the primary key (Pid) Foreign key of another relation (Parcel). This is illustrated in Figure 4.2.3.1.
- Two tuples of the same relation instance can have identical foreign key values: for instance, two TitleDeed tuples may refer to the same Parcel tuple.
- A foreign key, therefore, is not a key of the relation in which it appears, despite its name.
- A foreign key must have as many attributes as the primary key that it refers to.

Parcel	PID	Location	AreaSize
	3421	2001	467
	8871	1462	550
	2109	2323	1090
	1515	2003	290

Title Deed	Plot	Owner	Deed Date
	2109	101-367	10/12/1996
	8871	101-490	10/01/1984
	1515	134-788	1/09/1991
	3421	101-367	25/9/1996

Figure: 4.2.3.1 : The table TitleDeed has a foreign key in its attribute Plot. This attribute refers to key values of the Parcel rela- tion, as indicated for two TitleDeed tuples. The table TitleDeed actually has a second foreign key in the attribute Owner, which refers to PrivatePerson.

4.2.4 Querying a relational database

- There are three most elementary query operators. They are quite powerful because they can be combined to create more complex queries.
- The three query operators have some characteristics in common.
- First, all of them require input and produce output, and both input and output are relations.
- This guarantees that the output of one query (a relation) can be the input of another query, and this gives us the possibility to build more and more complex queries, if we want.
- The three Query operator are:
  1. Tuple Selection
  2. Attribute Projection
  3. Join

Tuple Selection

- The first query operator is called tuple selection; it is illustrated in Figure 4.2.4(a).
- Tuple selection works like a filter: it allows tuples(rows) that meet the selection condition to pass, and disallows tuples that do not meet the condition.
- The operator is given some input relation, as well as a selection condition about tuples in the input relation.
- A selection condition is a truth statement about a tuple's attribute values such as: Area Size > 1000. For some tuples in Parcel this statement will be true, for others it will be false.
- Tuple selection on the Parcel relation with this condition will result in a set of Parcel tuples for which the condition is true.

Parcel	PID	Location	Area Size
	3421	2001	467
	8871	1462	550
	2109	2323	1090
	1515	2003	290
	3434	2020	486
	6371	1802	950
	2209	3542	1840
	1505	2609	145

↓

Tuple Selection S

↓

PID	Location	AreaSize
2109	2323	1090
2209	3542	1840

Figure 4.2.4 (a) tuple selection has a single table as input and produces another table with less tuples. Here, the condition was that Area- Size must be over 1000;

- The most common way of defining queries in a relational database is through the SQL language. SQL stands for Structured Query Language.
- The Query of figure 4.2.4(a) is given by:

  SELECT * FROM Parcel WHERE Area Size >1000;

- Above is the tuple selection from the Parcel relation, using the condition AreaSize > 1000. This indicates that we want to extract all attributes of the input relation and only tuples that satisfy the condition should be included in output relation.

Attribute Projection

- A second operator is shown in Figure 4.2.4(b).
- It is called attribute projection.
- This operator requires an input relation, along with a list of attributes, all of which should be attributes of the input relation.
- The output relation of this operator has as its schema only the list of attributes given, and we say that the operator projects onto these attributes.
- Contrary to the first operator, which produces fewer tuples, this operator produces fewer attributes compared to the input relation.

Parcel	PID	Location	AreaSize
	3421	2001	467
	8871	1462	550
	2109	2323	1090
	1515	2003	290
	3434	2020	486
	6371	1802	950
	2209	3542	1840
	1505	2609	145

Attribute Projection P

PID	Location
3421	2001
8871	1462
2109	2323
1515	2003
3434	2020
6371	1802
2209	3542
1505	2609

Figure 4.2.4 (b) attribute projection has a single table as input and produces another table with fewer attributes. Here, the projection is onto the attributes PId and Location.

- The Query of figure 4.2.4(b) is given by:
  SELECT PId, Location FROM Parcel;

- Above is the attribute projection from the Parcel relation. The SELECT-clause indicates that we only want to extract the two attributes PId and Location. There is no WHERE-clause in this query.

- Virtual tables
  - Above two Queries do not create stored tables in the database.
  - This is why the result tables have no name: they are virtual tables.
  - The result of a query is a table that is shown to the user who executed the query. Whenever the user closes her/his view on the query result, that result is lost.

- However, the SQL code for the query is stored for future use. The user can re-execute the query again to obtain a view on the result once more.

Join

- Third type of query operator differs from the above two operators in that it requires two input relations.
- The operator is called the join, and is illustrated in Figure 4.2.4(c).
- The join operator combines two input relations to form one output relation, gluing two tuples (one from each input relation), to form a bigger tuple, if they meet a specified condition.
- This operator produces an output relation with both the first and second input relations as attributes.
- The number of attributes is therefore increases.
- The output tuples are obtained by taking a tuple from the first input relation and 'gluing' it to a tuple from the second input relation.
- The join operator uses a condition that expresses which tuples from the first relation are combined with which tuples from the second.
- The example of Figure 4.2.4(c) combines TitleDeed tuples with Parcel tuples, but only those for which the foreign key Plot matches with primary key PId.
- The above join query is also easily expressed in SQL as follows.
  SELECT * FROM TitleDeed, Parcel WHERE TitleDeed. Plot = Parcel.Pid;
- The FROM-clause identifies the two input relations; the WHERE-clause states the join condition.
- It is often not sufficient to use just one operator for extracting sensible information from a database.
- The strength of the above operators hides in the fact that they can be combined to produce more advanced and useful query definitions.
- Suppose in figure 4.2.4(c)we really wanted to obtain combined TitleDeed/Parcel information, but only for parcels with a size over 1000, and we only wanted to see the owner identifier and deed date of such title deeds.
- We can take the result of the above join, and select the tuples that show a parcel size over 1000. The result of this tuple selection can then be taken as the input for an attribute selection that only leaves Owner and DeedDate. This is illustrated in Figure 4.2.4 (d).
- The SQL statement that would give us the result of Figure 4.2.4 (d) can be written as

SELECT Owner, Deed Date FROM Title Deed, Parcel WHERE Title Deed. Plot = Parcel. PId AND Area Size > 1000;

Title Deed	Plot	Owner	Deed Date
	2109	101-367	10/12/1996
	8871	101-490	10/01/1984
	1515	134-788	1/09/1991
	3421	101-367	25/9/1996

Parcel	PID	Location	Area Size
	3421	2001	467
	8871	1462	550
	2109	2323	1090
	1515	2003	290

Join

Plot	Owner	Deed Date	PID	Location	AreaSize
2109	101-367	10/12/1996	2109	2323	1090
8871	101-490	10/01/1984	8871	1462	550
1515	134-788	1/09/1991	1515	2003	290
3421	101-367	25/9/1996	3421	2001	467

Figure: 4.2.4(c) **:** The essential binary query operator: join. The join condition for this example is TitleDeed.Plot= Parcel.Pid, which expresses a foreign key/key link between TitleDeed and Parcel. The result relation has 3 + 3 = 6 attributes.

Title Deed	Plot	Owner	Deed Date
	2109	101-367	10/12/1996
	8871	101-490	10/01/1984
	1515	134-788	1/09/1991
	3421	101-367	25/9/1996

Parcel	PID	Location	Area Size
	3421	2001	467
	8871	1462	550
	2109	2323	1090
	1515	2003	290

Join

Plot	Owner	Deed Date	PID	Location	Area Size
2109	101-367	10/12/1996	2109	2323	1090
8871	101-490	10/01/1984	8871	1462	550
1515	134-788	1/09/1991	1515	2003	290
3421	101-367	25/9/1996	3421	2001	467

Tuple Selection

Plot	Owner	Deed Date	PID	Location	Area Size
2109	101-367	10/12/1996	2109	2323	1090

Attribute Projection

Owner	Deed Date
101-367	10/12/1996

Figure: 4.2.4(d)**:** A combined selection/projection/join query, selecting owners and deed dates for parcels with a size larger than 1000. The join is carried out first, then follows a tuple selection on the result tuples of the join. Finally, an attribute projection is carried out.

4.3 GIS AND SPATIAL DATABASES

4.3.1 Linking GIS and DBMS

Storing spatial and attribute Data

- GIS software provides support for spatial data and the matic or attribute data.
- GISs have traditionally stored spatial data and attribute data separately.
- This required the GIS to provide a link between the spatial data that is represented with rasters or vectors, and their non-spatial attribute data.

- Geographic information systems are strong because they have built-in capabilities for analyzing, storing, and producing maps that are derived from their understanding of geographical space.

- GIS packages themselves can store tabular data, however, they do not always provide a full-fledged query language to operate on the tables.

External DBMS

- DBMSs have a long tradition in handling attribute data that is administrative, non- spatial, tabular, thematic data in a secure way, for multiple users at the same time.

- Arguably, DBMSs offer much better table functionality, since they are specifically designed for this purpose.

- A lot of the data in GIS applications is attribute data, so it made sense to use a DBMS for it.

- For this reason, many GIS applications have made use of external DBMSs for data support.

- In this role, the DBMS serves as a centralized data repository for all users, while each user runs her/his own GIS software that obtains its data from the DBMS.

- This meant that a GIS had to link the spatial data represented with rasters or vectors, and the attribute data stored in an external DBMS.

Linking objects and tables

- With **raster representations**, each raster cell stores a characteristic value.

- This value can be used to look up attribute data in an accompanying database table.

- For instance, the land use raster of Figure 4.3.1 indicates the land use class for each of its cells, while an accompanying table provides full descriptions for all classes, including perhaps some statistical information for each of the types.

- Observe the similarity with the key/foreign key concept in relational databases.

- With **vector representations**, our spatial objects—whether they are points, lines, or polygons—are automatically given a unique identifier by the system.

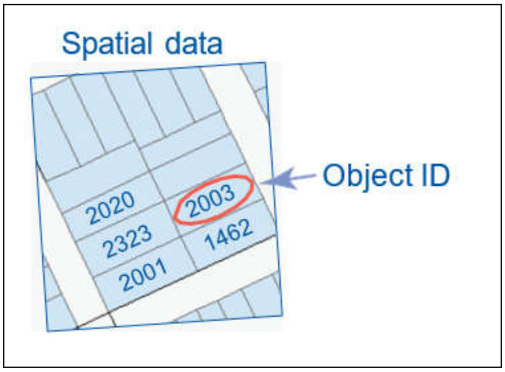
- This identifier is usually just called the object ID or feature ID and is used to link the spatial object as represented in vectors with its attribute data in an attribute table.
- The principle applied here is similar to that in raster settings, but in this Linking objects and tables

- In the vector system, ID functions as a key, and any reference to an ID value in the attribute database is a foreign key reference.
- For example, in Figure 4.3.2, parcel is a table with attributes, linked to the spatial objects stored in a GIS by the Location column. Obviously, several tables may make references to the vector system, but it is not uncommon to have some main table for which the ID is also the key.

A	A	A	B	B	B
A	A	F	B	B	B
F	F	A	B	C	E
F	F	C	C	E	E
F	F	C	E	E	A

Land UseClass	ID	Description	Perc
	A	Primary forest	11.3
	B	Secondary vegetation	25.5
	C	Pasture	31.2
	E	Built-up area	25.5
	F	Rivers, lakes	4.1

Figure4.3.1: A raster resenting land use and arelated table providing fulltextdescriptions(amongstothers) of each land useclass.



Parcel	PID	Location	OwnerID
	3421	2001	435
	8871	1462	550
	2109	2323	1040
	1515	2003	245
	3434	2020	486
	6371	1802	950

Spatial Attribute

Figure 4.3.2: Storage and linking of vector attribute data between GIS and DBMS

4.3.2 Spatial database functionality

Spatial DBMS

- Over the last two decades, DBMS vendors have recognized the need to store more complex data, like spatial data.
- The main problem was that there is additional functionality needed by DBMS in order to process and manage spatial data.
- As the capabilities of our hardware to process information has increased, so too has the desire for better ways to represent and manage spatial data.
- During the 1990's, object-oriented and object-relational data models were developed for just this purpose.
- These extend standard relational models with support for objects, including 'spatial' objects.
- Currently, GIS software packages can store spatial data using a range of commercial and open-source DBMSs such as Oracle, Informix, IBM DB2, Sybase, and Postgre SQL, with the help of spatial extensions.
- Some GIS software have integrated database 'engines,' and therefore do not need these extensions.

- ESRI's ArcGIS, for example, has the main components of the MS Access database software built-in.
- This means that the designer of a GIS application can choose whether to store the application data in the GIS or in the DBMS.
- Spatial databases, also known as geodatabases, are implemented directly on existing DBMSs, using extension software to allow them to handle spatial objects.
- A spatial database allows users to store, query and manipulate collections of spatial data.
- spatial data can be stored in a special database column, known as the geometry column, or feature or shape, depending on the specific software package.
- This means GISs can rely fully on DBMS support for spatial data, making use of a DBMS for data query and storage and also for multi-user support, and GIS for spatial functionality.
- Small-scale GIS applications may not require a multi-user capability, and can be supported by spatial data support from a personal database.
- A geodatabase allows a wide variety of users to access large data sets that include both geographic and alphanumeric, and the management of their relations, guaranteeing their integrity.
- The Open Geospatial Consortium (OGC) has released a series of standards relating to geodatabases that define:
    - Which tables must be present in a spatial database i.e., geometry columns table and spatial reference system table.
    - The data formats, called 'Simple Features' i.e., point, line, polygon, etc.
    - A set of SQL-like instructions for geographic analysis.
- The architecture of a spatial database differs from a standard RDBMS not only because it can handle geometry data and manage projections, but also for a larger set of commands that extend standard SQL language for e.g., distance calculations, buffers, overlay, conversion between coordinate systems, etc.
- The capabilities of spatial databases will continue to evolve over time.
- ArcGIS geodatabases can now store topological relationships directly in the database, supporting different kinds of features (objects) and their behavior (relationships with other objects) and ways to validate these relationships and behaviors.

Querying a spatial database

Spatial query

- A Spatial DBMS provides support for geographic co-ordinate systems and trans- formations.
- It also provides storage of the relationships between features, including the creation and storage of topological relationships.
- As a result, one is able to use functions for 'spatial query' (exploring spatial relationships). To illustrate, a spatial query using SQL to find all the Thai restaurants within 2 km of a given hotel would look like this:

SELECT R. Name FROM Restaurants AS R, Hotels as H WHERE R. Type = "Thai" AND H. name = "Hilton" AND ST_Intersects (R. Geometry, ST Buffer (H. Geometry, 2000))

In the above query the WHERE clause uses the ST Intersects function to perform a spatial join between a 2000 m buffer of the selected hotel and the selected subset of restaurants. The geometry column carries the spatial data.

4.4 SUMMARY

- A database is an organized collection of structured information, or data, typically stored electronically in a computer system.
- A database is usually controlled by a database management system (DBMS).
- Spatial data are relative geographic information about the Earth and its features.
- A **database management system (DBMS)** is a software package that allows the user to set up, use and maintain a database.
- For the relational data model, the structures used to define the database are attributes, tuples, and relations.
- In the relational data model, a database is considered as a collection of relations, commonly also known as tables.
- A key of a relation comprises one or more attributes. A value for these attributes uniquely identifies a tuple.
- The three Query operator are:
  1. Tuple Selection
  2. Attribute Projection
  3. Join
- GIS software provides support for spatial data and the matic or attribute data.

- GISs have traditionally stored spatial data and attribute data separately.
- Spatial databases, also known as geodatabases, are implemented directly on existing DBMSs, using extension software to allow them to handle spatial objects.
- A spatial database allows users to store, query and manipulate collections of spatial data.

4.5 QUESTIONS

1. Explain various reasons for using DBMS in GIS.
2. Explain Relational data model using suitable example.
3. Write a note on Spatial Data Functionality.
4. Explain the linking of GIS with Database.
5. Explain spatial Database querying with suitable example.

4.6 MCQ QUESTIONS

1. Which of the following is not a reason for which DBMS is used with GIS?
   a) A DBMS supports the storage and manipulation of very large data sets.
   b) A DBMS can be instructed to guard over data correctness.
   c) DBMS can also use to represent graphics.
   d) A DBMS supports the concurrent use of the same data set by many users.

2. Attribute projection operation can work on ______ input relation/relations.
   a) Four
   b) three
   c) two
   d) one

3. Spatial database allows user to ______, _______ and ______ collections of spatial data.
   a) analyze, create map, query
   b) create graph, map, analysis
   c) store, represent, create graph
   d) store, query, manipulate

4. What is a 'tuple'?
   a) A row or record in a database table.
   b) Another name for the key linking different tables in a database.
   c) An attribute attached to a record.
   d) Another name for a table in an RDBMS.

5. Which one of the following is correct query?
   a) select * where population>100000 from census
   b) from census select * where population >100000
   c) population >100000 select * from census
   d) select * from census where population >100000

4.7 REFERENCES

- Principles of Geographic Information Systems, Otto Huisman, Rolf A. de By (eds.).

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5

SPATIAL REFERENCING AND POSITIONING

Unit Structure :

5.0 OBJECTIVE

In this chapter we are going to explore more on spatial referencing and positioning systems.

Spatial references are important when building applications that use geographic data.

A spatial reference defines the coordinate system used to locate the geometry for a feature.

It controls how and where features are displayed in a map or scene .

A coordinate system is a method for identifying the location of a point on the earth. Most coordinate systems use two numbers, a coordinate, to identify the location of a point. Each of these numbers indicates the distance between the point and some fixed reference point, called the origin.

Main objectives of this section are to :

- Understand the relevance and actual use of reference surfaces, coordinate systems, and coordinate transformations in mapping.
- Describe and differentiate between coordinate systems and map projections.
- Grasp the logic of map projection equations and the principles of transforming maps from one projection system to another.

We are going to see more about:

- Spatial reference surfaces and datums
  - The Geoid – vertical (height) datum
  - The Ellipsoid – horizontal (geodetic) datum
  - Local and global datums
- Map projections
  - Classification of map projections
  - Map projection selection
  - Map coordinate systems
  - Coordinate transformations

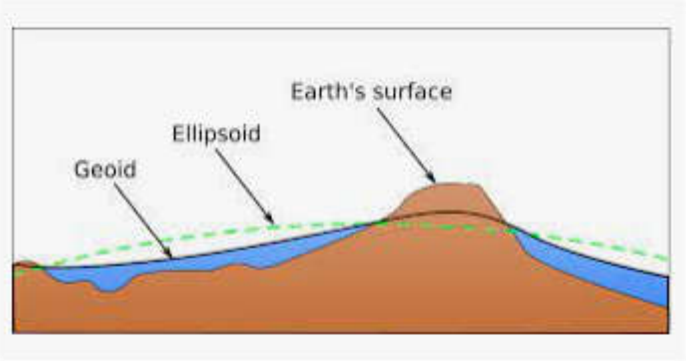
5.1 SPATIAL REFERENCING

- A GIS is to be created from available maps of different thematic layers like soils, land use, temperature, etc.
- The maps are in two-dimensions whereas the earth's surface is a 3-dimensional ellipsoid.
- Every map has a projection and scale.
- To understand how maps are created by projecting the 3-d earth's surface into a 2-d plane of an analogue map, we need to understand the georeferencing concepts.

5.1.1 Reference Surfaces for Mapping:

- The surface of the Earth is uniform.
- The oceans can be treated as reasonably uniform, but the surface or topography of the land masses exhibits large vertical variations between mountains and valleys.
- These variations make it impossible to approximate the shape of the Earth with any reasonably simple mathematical model.

- Two main reference surfaces have been established to approximate the shape of the Earth.
  - One reference surface is called the **Geoid**,
  - The other reference surface is the **ellipsoid**.
- These are illustrated in the figure below.



Fundamentals of cartography and geodesy
volaya.github.io

The Earth's surface, and two reference surfaces used to approximate it: **The Geoid, and a reference ellipsoid**. The deviation between the Geoid and a reference ellipsoid is called geoid separation (N).

➔ Due to irregularities or mass anomalies in this distribution the 'global ocean' results in an undulated surface.

➔ This surface is called the **Geoid**.

➔ The plumb line through any surface point is always perpendicular to it.

➔ Where a mass deficiency exists, the Geoid will dip below the mean ellipsoid.

➔ Conversely, where a mass surplus exists, the Geoid will rise above the mean ellipsoid.

➔ These influences cause the Geoid to deviate from a mean ellipsoidal shape by up to +/- 100 meters.

➔ The deviation between the Geoid and an ellipsoid is called the **Geoid Separation (N) or Geoid Undulation.**

5.1.2 Coordinate System (CS):

Georeferencing involves 2 stages:

a) *The Geographic Coordinate System (GCS)* - specifying the 3-dimensional coordinate system that is used for locating points on the earth's surface, and

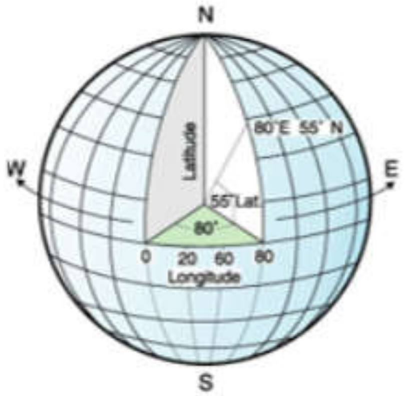
b) *The Projected Coordinate System* - that is used for projecting into two dimensions for creating analogue maps.

a) Geographic Coordinate System (GCS):

- Geographic coordinate systems use a traditional way of representing locations on the surface of the earth.
- The 3-dimensional coordinate system is latitude and longitude to measure and locate features on the globe.
- Geographic coordinate systems use latitude and longitude to measure and locate features on the globe.
- The GCS defines a position as a function of direction and distance from a center point of the globe, where the units of measurement are degrees.
- Any location on earth can be referenced by a point with longitude and latitude coordinates.
- The ellipsoid model that is used to calculate latitude and longitude is called the datum.
- Changing the datum, therefore, changes the values of the latitude and longitude.

In surveying and geodesy, **a datum** is a set of reference points on the earth's surface against which position measurements are made, and (often) an associated model of the shape of the earth (reference ellipsoid) to define a geographic coordinate system.

For example, the below figure shows a geographic coordinate system where a location is represented by the coordinates longitude 80 degree East and latitude 55 degree North.



A Geographic coordinate system.

- The equidistant lines that run east and west each have a constant latitude value called parallels.
- The equator is the largest circle and divides the earth in half.
- It is equal in distance from each of the poles, and the value of this latitude line is zero.
- Locations north of the equator have positive latitudes that range from 0 to +90 degrees, while locations south of the equator have negative latitudes that range from 0 to -90 degrees.
- The lines that run through north and south each have a constant longitude value and form circles of the same size around the earth known as **meridians**.
- The **prime meridian** is the line of longitude that defines the origin (zero degrees) for longitude coordinates.
- The latitude and longitude lines cover the globe to form a grid that is known as a **graticule**. The **point of origin of the graticule is (0,0)**, where the equator and the prime meridian intersect.

b) Projected Coordinate System (GCS):

- A projected coordinate system is defined on a flat, two-dimensional surface.
- In contrast to a geographic coordinate system, a projected coordinate system has constant lengths, angles, and areas across the two dimensions.
- A projected coordinate system is always based on a geographic coordinate system that is based on a sphere or spheroid.
- In a projected coordinate system, locations are identified by x,y coordinates on a grid, with the origin at the center of the grid.
- Each position has two values that reference it to that central location.
- One specifies its horizontal position and the other its vertical position.

- The two values are called the x-coordinate and y-coordinate.
- Using this notation, the coordinates at the origin are x = 0 and y = 0.
- Mathematical formulas are used to convert a three-dimensional geographic coordinate system to a two-dimensional flat projected coordinate system.
- **The transformation is referred to as a map projection**.

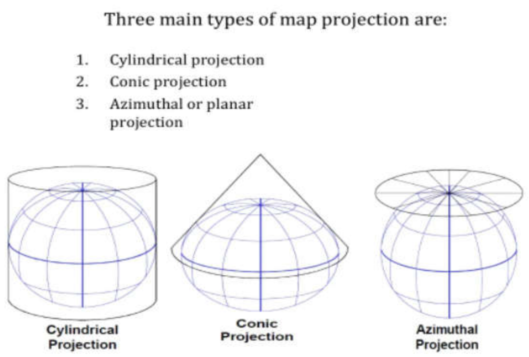
5.1.3 Map Projections and Coordinate Transformations:

- A map projection is one of many methods used to represent the 3-dimensional surface of the earth or other round body on a 2-dimensional plane in cartography (mapmaking).
- This process is typically, but not necessarily, a mathematical procedure (some methods are graphically based).
- The creation of a map projection involves three steps in which information is lost in each step:
    - **Selection of a model** for the shape of the earth or round body (choosing between a sphere or ellipsoid)
    - **Transform geographic coordinates** (longitude and latitude) to plane coordinates (eastings and northings).
    - **Reduce the scale** (in manual cartography this step came second, in digital cartography it comes last)
- **Metric properties of maps**
    - Maps assume that the viewer has an orthogonal view of the map (they are looking straight down on every point).
    - This is also called a perpendicular view or normal view.
    - The metric properties or a map are:
        - Area
        - Shape
        - Direction
        - Distance
        - scale
- There are several different types of projections that aim to accomplish different goals while sacrificing data in other areas through distortion.
    - **Area preserving projection** – equal area or equivalent projection
    - **Shape preserving** – conformal, orthomorphic

- ○ **Direction preserving** – conformal, orthomorphic, azimuthal (only from the central point)

- ○ **Distance preserving** – equidistant (shows the true distance between one or two points and every other point)

The most common types of map projections include:



1) Equal area projections

- These projections preserve the area of specific features.
- These projections distort shape, angle, and scale.
- The Albers Equal Area Conic projection is an example of an equal area projection.

2) Conformal projections

- These projections preserve local shape for small areas.
- These projections preserve individual angles to describe spatial relationships by showing perpendicular graticule lines that intersect at 90-degree angles on the map.
- All the angles are preserved; however, the area of the map is distorted.
- The Mercator and Lambert Conformal Conic projections are examples of conformal projections.

3) Equidistant projections

- These projections preserve the distances between certain points by maintaining the scale of a given data set.
- Some of the distances will be true distances, which are the same distances at the same scale as the globe.
- If you go outside the data set, the scale will become more distorted.
- The Sinusoidal projection and the Equidistant Conic projection are examples of equidistant projections.

4) True-direction or azimuthal projections

- These projections preserve the direction from one point to all other points by maintaining some of the great circle arcs.
- These projections give the directions or azimuths of all points on the map correctly with respect to the center.
- Azimuthal maps can be combined with equal area, conformal, and equidistant projections.
- The Lambert Equal Area Azimuthal projection and the Azimuthal Equidistant projection are examples of azimuthal projections.

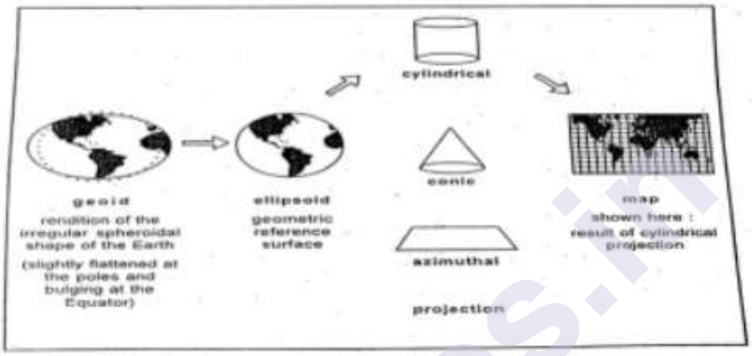
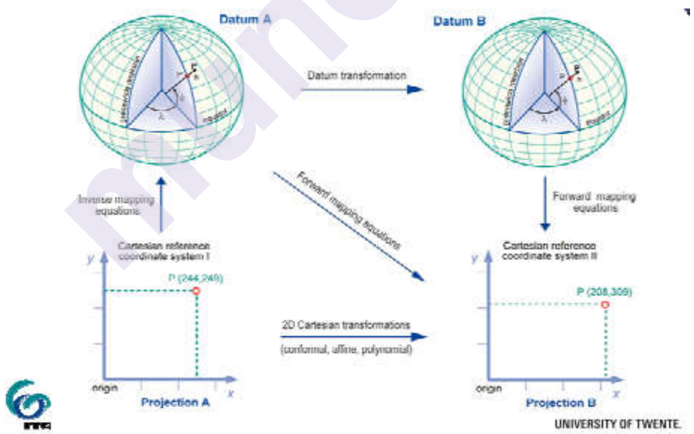


Fig Geoid Ellipsoid - Projection : Relationship

- Coordinate Transformation Overview is given in below diagram:



5.2 SATELLITE-BASED POSITIONING

- Satellites are the cornerstones of modern positioning and navigation.
- They are used by vehicle navigation systems, smartphones and land surveyors alike.
- Based on satellite signals, the receiver can define its position anywhere in the world with an accuracy of a few meters in less than a minute.

- In addition, the time can be defined as a by-product with an accuracy of approximately one hundred nanoseconds.
- Using assistance systems, the position can be pinpointed with an accuracy of a few centimeters.
- Usually, **the US-based GPS** was synonymous to satellite positioning.
- Although we also have, **the Russian GLONASS**, as well as **the European Galileo** and **the Chinese BeiDou** which are at the deployment stage, are openly accessible to all.
- **For this reason, satellite positioning is currently referred to as the Global Navigation Satellite System (GNSS).**
- Satellite positioning is ultimately based on the accurate transfer of time.
- Each of the four satellite positioning systems consists of some 20 to 30 satellites, orbiting at an altitude of approximately 20,000 kilometers.
- All of these satellites are equipped with a precise atomic clock, on the basis of which they transmit a time signal down to Earth, as well as other data that, for example, indicates the satellite position.
- In addition to three-dimensional position coordinates, the fourth factor to be solved is the difference between the receiver clock and the satellite clocks.
- This can be done by using at least four satellites, the positions of which are known – the use of several satellites improves the accuracy and reliability of positioning.
- Because positioning is linked to time, timekeepers also make up a significant group of GNSS users.
- Using GNSS signals, it is possible to synchronize devices and clocks that are located far from each other.
- GNSS receivers do not automatically reveal their location.
- To use GNSS positioning, signals only need to be received.
- This means that users do not automatically reveal their location to the system administrator or anyone else.
- This is a particularly important feature considering the original user of satellite positioning, i.e. the military.
- However, many devices that use satellite positioning, such as smartphones, tracking devices and autonomous vehicles can transmit their location via other channels, for example, to a cloud service or the device manufacturer for their purpose of use, to use performance-enhancing services or for crowdsourcing.

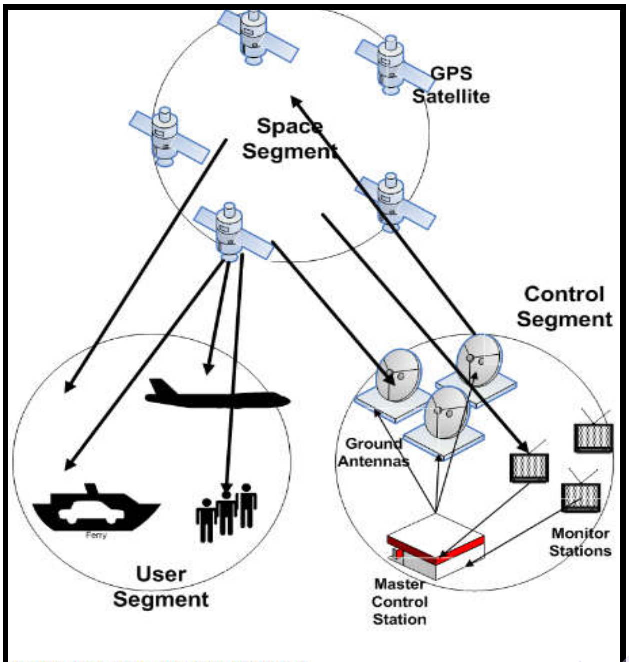
	Description
Global Navigation Satellite System (GNSS)	A global satellite positioning system
Global Positioning System (GPS)	A GNSS system maintained by the US Department of Defense.
Geosynchronous satellite	A satellite with an orbital period of 24 hours, i.e. a single satellite can be seen in the same place at the same time, every day, when viewed from the Earth's surface. The orbit's altitude is approximately 35,000 kilometers
Geostationary orbit	A geosynchronous orbit following the Equator. A geostationary satellite seems to be stationary when viewed from the Earth's surface.
Medium Earth orbit (MEO)	An orbit with a lower altitude than a geosynchronous orbit. Most positioning satellites use an MEO at an altitude of approximately 20,000 kilometers with an orbital period of 12 hours.
Satellite-based augmentation system (SBAS)	An augmentation system which does not produce any navigation signal but provides information about the reliability of GNSS signals.
European Space Agency (ESA)	ESA is responsible for the technical development of the Galileo system, together with the European Commission.
European GNSS Agency (GSA)	GSA is responsible for the services offered by the Galileo and EGNOS systems.
European Geostationary Navigation Overlay Service (EGNOS)	Europe's SBAS.
COSPAS–SARSAT	A satellite system that receives emergency signals transmitted from the Earth, locates their sender, and transmits data to rescue authorities. The 406 MHz frequency is only reserved for this system.

Application fields of Satellite-based Positioning are:

- ➔ Surveying
- ➔ Military operations
- ➔ Engineering
- ➔ Vehicle tracking
- ➔ Flight navigation
- ➔ Car navigation
- ➔ Ship navigation
- ➔ Agriculture
- ➔ Mapping

Global Positioning System (GPS):

- The Global Positioning System (GPS) is a satellite-based navigation system made up of a network of 24 satellites placed into orbit by the U.S. Department of Defense.
- It is one of the global navigation satellite systems (GNSS) that provides geolocation and time information to a GPS receiver anywhere on or near the Earth where there is an unobstructed line of sight to four or more GPS satellites.
- GPS is operated and maintained by the Department of Defense (DoD).
- The National Space-Based Positioning, Navigation, and Timing (PNT) Executive Committee (EXCOM) provides guidance to the DoD on GPS-related matters impacting federal agencies to ensure the system addresses national priorities as well as military requirements.
- The Federal Aviation Administration oversees the use of GPS in civil aviation and receives problem reports from aviation users.
- The Global Positioning System has been successful in virtually all navigation and timing applications, and because its capabilities are accessible using small, inexpensive equipment, GPS is being used in a wide variety of applications across the globe.



1: Overview of the GPS segments [US Army (1996)].

Components of a GPS system

- GPS is a system, and it is made up of three parts: **satellites, ground stations, and receivers.**
- The functionalities of each of these parts:
  - **Satellites** act like the stars in constellations, and we know where they are because they invariably send out signals.
  - The **ground stations** make use of the radar to make sure the satellites are where we think they are.
  - A **receiver** is a device that you might find in your phone or in your car and it constantly seeks for the signals from the satellites.
  - The receiver figures out how far away they are from some of them.
  - Once the receiver calculates its distance from four or more satellites, it knows exactly where you are.

Global Navigation Satellite System (GLONASS)

- Russia started developing GLONASS in 1976 as an experimental military communications system.
- They launched the first GLONASS satellite in 1982 and the constellation became fully operational in 1995.
- The Russian Global Navigation Satellite System (GLONASS) was developed contemporaneously with GPS but suffered from incomplete coverage of the globe until the mid-2000s.

- GLONASS reception in addition to GPS can be combined in a receiver thereby allowing for additional satellites available to enable faster position fixes and improved accuracy, to within two meters (6.6 ft).

- GLONASS or Global Navigation Satellite System is the satellite navigation system developed by Russia that consists of **24 satellites, in three orbital planes, with eight satellites per plane**.

- The satellites are placed into nominally circular orbits with target inclinations of 64.8 degrees and an orbital radius of 19,140 km, about 1,060 km lower than GPS satellites, with an orbit period of 11 hrs and 15 minutes.

Versions of GLONASS:

○ **GLONASS** - These satellites were launched in 1982 for the military and official organizations. They were intended to for weather, positioning, timing and velocity measurements.

○ **GLONASS-M** - These satellites were launched in 2003 to add second civil code, which is important for GIS mapping receivers.

○ **GLONASS-K** - These satellites were launched in 2011 to add third civil frequency. These are of 3 types - K1, K2 and KM.

○ **GLONASS-K2** - These satellites will be launched after 2015 (currently in design phase).

○ **GLONASS-KM** - These satellites will be launched after 2025 (currently in research phase).

Galileo

- Galileo is Europe's Global Satellite Navigation System (GNSS), providing improved positioning and timing information with significant positive implications for many European services and users.

- Galileo allows users to know their exact position with greater precision than what is offered by other available systems.

- The products that people use every day, from the navigation device in your car to a mobile phone, benefit from the increased accuracy that Galileo provides.

- Critical, emergency response-services benefit from Galileo.
- Galileo's services will make Europe's roads and railways safer and more efficient.
- It boosts European innovation, contributing to the creation of many new products and services, creating jobs.
- Until now, GNSS users have had to depend on non-civilian American GPS or Russian GLONASS signals.
- With Galileo, users now have a new, reliable alternative that, unlike these other programmes, remains under civilian control.
- While European independence is a principal objective of the programme, Galileo also gives Europe a seat at the rapidly expanding GNSS global table.
- The programme is designed to be compatible with all existing and planned GNSS and interoperable with GPS and GLONASS.
- In this sense, Galileo is positioned to enhance the coverage currently available – providing a more seamless and accurate experience for multi-constellation users around the world.

System	GPS	GLONASS	Galileo
Owner	United States	Russian Federation	European Union
Orbital altitude	20, 180 km (12, 540 mi)	19, 130 km, (11, 890 mi)	23,222 km , (14, 429 mi)
Period	11.97 h, (11 h 58 min)	11.26 h, (11 h 16 min)	14.08 h, (14h 5min)
Number of satellites	32 (at least 24 by design)	28 (at least 24 by design) including: 24 operational 2 under check by the satellite prime contractor 2 in flight tests phase	4 in-orbit validation satellites + 8 full operation capable satellites in orbit 22 operational satellites budgeted
Frequency	1.57542 GHz (L1 signal) 1.2276 GHz (L2 signal)	Around 1.602 GHz (SP) Around 1.246 GHz (SP)	1.164-1.215 GHz (E5a and E5b) 1.260-1.300 GHz (E6) 1.559-1.592 GHz (E2-L1-E11)
Status	Operational	Operational	8 satellites operational, 22 additional satellites 2016-2020

5.2.1 Absolute positioning

Positioning with GPS can be performed by either of two ways: point positioning or relative positioning.GPS absolute positioning, that is a single point positioning, uses one set receiver to determine the spatial distance between the satellite and the receiver antenna to determine the point coordinates in WGS-84 system carrying through the rear intersection of spatial distances.

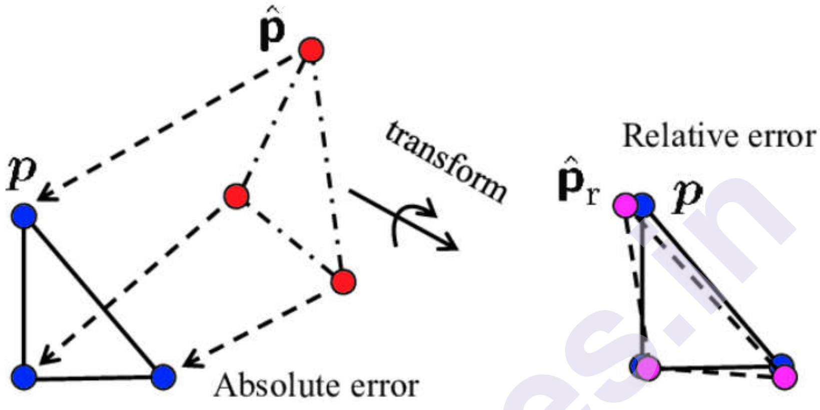
5.2.2 Errors in absolute positioning

- Receiver users are required to be familiar with the technology to avoid real operating blunders such as,

- poor receiver placement or
- incorrect receiver software settings,

which can render positioning results virtually useless.

- Error which is the result of the combination of signals from satellites used for positioning is error related to the relative geometry of satellites and receiver.
- In the following figure we will show an illustration of absolute and relative position errors.



- The blue and red points are true positions and absolute position estimations, respectively.
- The red points are transformed as close to the blue points as possible by minimizing the norm proposed in Section II-C.
- The optimal transformed positions are the pink points which are defined as relative position estimations.
- The constellation of satellites in the sky from the receiver's perspective is the controlling factor in these cases.
- Source of error is known as geometric dilution of precision (GDOP).
- GDOP is lower when satellites are just above the horizon in mutually opposed compass directions.
- However, such satellite positions have bad atmospheric delay characteristics, so in practice it is better if they are at least 15° above the horizon.
- When more than four satellites are in view, modern receivers use "least-squares" adjustment to calculate the best possible positional fix from all the signals.
- An overview of some typical values (without selective availability) is provided in the Table below.

satellite clock (m)	2
satellite position (m)	2.5
ionospheric delay (m)	5
tropospheric delay (m)	0.5
receiver noise (m)	0.3
multi-path (m)	0.5
Total RMSE Range error (m):	
--------------------------- 22 + 2.52 + 52 + 0.52 + 0.32 + 0.52 =	5.99

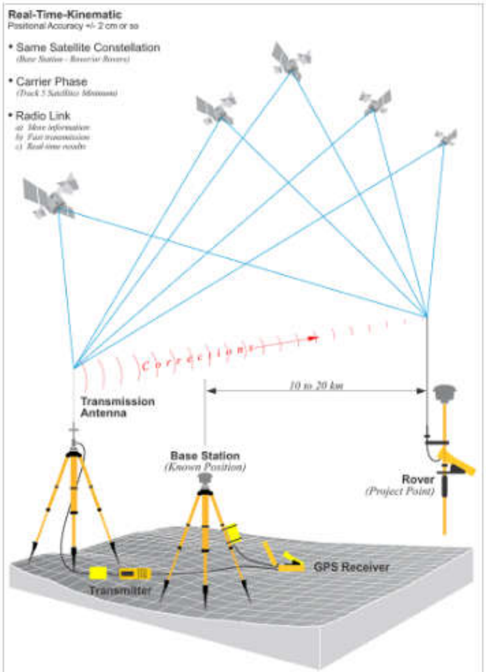
Table: Indication of typical magnitudes of error in absolute satellite-based positioning

- GDOP functions not so much as an independent error source but rather as a multiplying factor, decreasing the precision of position and time values obtained.
- The procedure that we discussed above is known as **absolute, single-point positioning based on code measurement.**
- It is the fastest and simplest, yet least accurate, means of determining a position using satellites.
- It suffices for recreational purposes and other applications that require horizontal accuracies to within 5–10 m.

5.2.3 Relative positioning

- Relative positioning error performance in both indoor and outdoor venues.
- When you set the position relative to an element, without adding any other positioning attributes such as top, bottom, right, left.
- In relative positioning, one of the two receivers involved occupies a known position during the session, known as the base.
- The objective of the work is the determination of the position of the other, the rover, relative to the base.
- Both receivers observe the same constellation of satellites at the same time, and because, in typical applications, the vector between the base and the rover, known as a baseline.
- The two receivers record very similar errors (biases), and since the base's position is known, corrections can be generated there that can be used to improve the solution at the rover.

- Example:

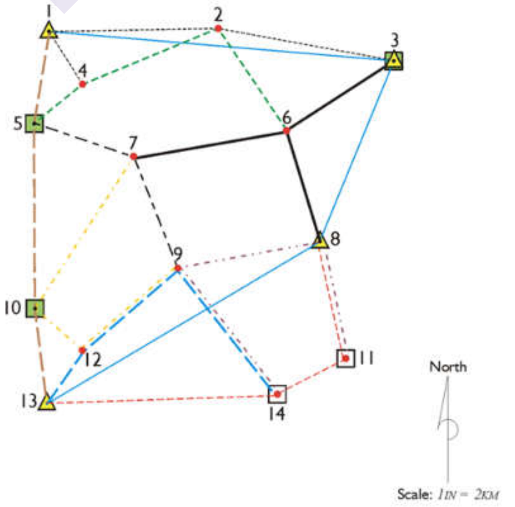


Relative (Differential) with RTK Positioning

Source: GPS for Land Surveyors

5.2.4 Network positioning

- Network and multireceiver positioning are obvious extensions of relative positioning.
- The creation of a closed network of points by combining individually observed baselines.
- The operation of three or more receivers simultaneously has advantages.
- For example, the baselines have redundant measurements and similar, if not identical, range errors (biases).



A GPS Control Network

Source: GPS for Land Surveyors

- The processing methods in such an arrangement can nearly eliminate many of the biases introduced by imperfect clocks and the atmosphere.
- These processing strategies are based on computing the differences between simultaneous GPS carrier phase observations.

5.2.5 Code versus phase measurements

Code phase

- Code phase is one processing technique that gathers data via a C/A (coarse acquisition) code receiver.
- It uses the information contained in the satellite signals (aka the pseudo-random code) to calculate positions.
- After differential correction, this processing technique results in 1–5-meter accuracy.
- 100-meter accuracy can improve to between 5 meters and sub-meter depending on the data collection technique and the data receiver used.
- Differential correction is a data collection technique that removes errors in GPS data created by selective availability, atmospheric delay, and ephemeris errors.
- Some of the other factors (less correctable) that create error in GPS data include:

  1. multipath
  2. low number of visible satellites
  3. large distance between the rover and the base station (10mm

     degradation with every kilometer away from base station)
  4. high PDOP (position dilution of precision- a measure of the

     current satellite geometry)
  5. low SNR (signal to noise ratio)
  6. low satellite elevation
  7. short occupation period
- Pathfinder Office software comes with a differential correction utility that calculates error at a known point (base station) and uses this error to correct (or improve the accuracy of) the rover file data you collected with your GPS unit.

Carrier phase

- Carrier phase is another processing technique that gathers data via a carrier phase receiver, which uses the radio signal (aka carrier signal) to calculate positions.
- The carrier signal, which has a much higher frequency than the pseudo-random code, is more accurate than using the pseudo-random code alone.
- The pseudo-random code narrows the reference then the carrier code narrows the reference even more.
- After differential correction, this processing technique results in sub-meter accuracy.
- The carrier phase receivers are much more accurate than C/A code receivers but require more involved post-processing and stricter data collection requirements.

  ➔ **Code phase processing**- GPS measurements based on the pseudo random code (C/A or P) as opposed to the carrier of that code. (1–5-meter accuracy)

  ➔ **Carrier phase processing**- GPS measurements based on the L1 or L2 carrier signal. (sub-meter accuracy)

5.2.6 Positioning technology

- A positioning system is a mechanism for determining the position of an object in space.
- Technologies for this task exist ranging from worldwide coverage with meter accuracy to workspace coverage with sub-millimetre accuracy.
- Multiple technologies exist to determine the position and orientation of an object or person in a room, building or in the world are as follow:
  - **Time of flight**
    - Time of flight systems determine the distance by measuring the time of propagation of pulsed signals between a transmitter and receiver.
    - When distances of at least three locations are known, a fourth position can be determined using trilateration.
    - Global Positioning System is an example.
  - **Spatial scan**
    - A spatial scan system uses (optical) beacons and sensors. Two categories can be distinguished:
      - Inside out systems where the beacon is placed at a fixed position in the environment and the sensor is on the object

- Outside in systems where the beacons are on the target and the sensors are at a fixed position in the environment
- By aiming the sensor at the beacon, the angle between them can be measured.

○ **Inertial sensing**

- The main advantage of an inertial sensing is that it does not require an external reference.
- Instead, it measures rotation with a gyroscope or position with an accelerometer with respect to a known starting position and orientation.

○ **Mechanical linkage**

- This type of tracking system uses mechanical linkages between the reference and the target.
- Two types of linkages have been used.
  - **One is an assembly of mechanical parts** that can each rotate, providing the user with multiple rotation capabilities.
  - The orientation of the linkages is computed from the various linkage angles measured with incremental encoders or potentiometers.
  - **Other types of mechanical linkages are wire**s that are rolled in coils.
  - A spring system ensures that the wires are tensed in order to measure the distance accurately.

○ **Phase difference**

- Phase difference systems measure the shift in phase of an incoming signal from an emitter on a moving target compared to the phase of an incoming signal from a reference emitter.
- With this the relative motion of the emitter with respect to the receiver can be calculated.

○ **Direct field sensing**

- Direct field sensing systems use a known field to derive orientation or position:
  - **A simple compass** uses the Earth's magnetic field to know its orientation in two directions.
  - **An inclinometer** uses the earth's gravitational field to know its orientation in the remaining third direction.

■ The field used for positioning does not need to originate from nature.

○ **Optical systems**

■ Optical positioning systems are based on optics components, such as in total stations.

○ **Magnetic positioning**

■ Magnetic positioning is an IPS (Indoor positioning system) solution that takes advantage of the magnetic field anomalies typical of indoor settings by using them as distinctive place recognition signatures.

○ **Hybrid systems**

■ Because every technology has its pros and cons, most systems use more than one technology.

■ A system based on relative position changes like the inertial system needs periodic calibration against a system with absolute position measurement.

■ Systems combining two or more technologies are called hybrid positioning systems.

5.3 SUMMARY

- This chapter has set out to demonstrate the spatial position element of GIS.
- Many complexities and gross errors may occur unless some fundamental principles are understood by the user of the system.
- Thus care in the selection and use of referencing and coordinate systems is always essential.
- The most common difficulties arise when information derived by the use of GPS is combined with that from maps produced using different datums.
- The combined effects of the use of different geodetic reference systems (including different datums), projection change, grid shifts, and any embedded errors in the maps can cause great practical problems.
- As indicated in the chapter maps are the basis for much current and most historical data in GIS.

5.4 EXERCISE

1. What is the Geographic Coordinate System?
2. Write a short note on Datum.4.
3. What is Map Projection? List and explain types of Map Projections.5.
4. Explain the term false origin, false easting and false northing with the help of diagrams.

5. List and explain commonly used map projections
6. Explain different Coordinate systems used in GIS.
7. Explain Spatial framework for mapping locations.

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6

DATA ENTRY AND PREPARATION

Unit Structure :

6.0 OBJECTIVE

- The most important component of a GIS is the data.
- Geographic data or Spatial data and related tabular data can be collected in-house or bought from a commercial data provider.
- Spatial data can be in the form of a map/remotely-sensed data such as satellite imagery and aerial photography.
- These data forms must be properly georeferenced (latitude/longitude).
- Tabular data can be in the form of attribute data that is in some way related to spatial data.
- Most GIS software comes with inbuilt Database Management Systems (DBMS) to create and maintain a database to help organize and manage data.
- Input of relevant data required for Analysis and modeling in a GIS.

- In this chapter we will see,
  - What is Data?
  - how data is prepared and entered in the system?
  - Why is it important to see the quality of data?
  - What is data transformation and how is it implemented?
  - In this section we outline four techniques as:

  1. Trend surface fitting using regression,
  2. Triangulation,
  3. Spatial moving averages using inverse distance weighting,
  4. Kriging.

6.1 SPATIAL DATA INPUT

- Spatial data is any type of data that directly or indirectly references a specific geographical area or location.
- It is also known as geospatial data or geographic information, spatial data can also numerically represent a physical object in a geographic coordinate system.
- However, spatial data is much more than a spatial component of a map.
- **The data** consist of two types:
  - representing geographic features like points,lines and areas and
  - representing attribute data i.e. descriptive information.
- Data input should be done with utmost care, as the results of analyses heavily depend on the quality of the input data.

Type of spatial data:

In a GISThe two primary types of spatial data are:

1) Vector data and
2) raster data.

Let's discuss each in more detail:

Vector data model:

- Vector data is not made up of a grid of pixels.
- Instead, vector graphics are composed of vertices and paths.
- The three basic symbol types for vector data are:

- **Points:**
  - Vector points are simply XY coordinates.
  - Generally, they are latitude and longitude with a spatial reference frame.
  - When features are too small to be represented as polygons, points are used.
  - For example, you can't see city boundary lines on a global scale. In this case, maps often use points to display cities.
- **Lines:**
  - Vector lines connect each vertex with paths.
  - Basically, you're connecting the dots in a set order and it becomes a vector line with each dot representing a vertex.
  - Lines usually represent features that are linear in nature.
  - For example, maps show rivers, roads, and pipelines as vector lines. Often, busier highways have thicker lines than abandoned roads.
- **Polygons or areas:**
  - When you join a set of vertices in a particular order and close it, this is now a vector polygon feature.
  - When you create a polygon, the first and last coordinate pairs are the same.
  - Cartographers use polygons to show boundaries and they all have an area.
  - For example, a building footprint has square footage, and agricultural fields have acreage.

Raster data model:

- Raster data is made up of pixels (also referred to as grid cells).
- They are usually regularly spaced and square but they don't have to be.
- Rasters often look pixelated because each pixel has its own value or class.
- Raster data models consist of two categories –

- **Discrete:**
  - Discrete rasters have distinct themes or categories.
  - For example, one grid cell represents a land cover class or a soil type.

- In other words, each land cover cell is definable and it fills the entire area of the cell.
- Discrete data usually consists of integers to represent classes.
- For example, the value 1 might represent urban areas, the value 2 represents forest, and so on.

○ **Continuous:**

- Continuous rasters (non-discrete) are grid cells with gradually changing data such as elevation, temperature, or an aerial photograph.
- A continuous raster surface can be derived from a fixed registration point.
- For example, digital elevation models use sea level as a registration point.

Spatial data can be obtained from various sources. It can be collected from scratch, using direct spatial-data acquisition techniques, or indirectly, by making use of existing spatial data collected by others.

6.1.1 Direct spatial data capture:

- We can obtain spatial data by direct observation of relevant geographic phenomena.
- This can be done through ground-based field surveys or by using remote sensors on satellites or aircraft.
- Many Earth science disciplines have developed specific survey techniques as ground-based approaches remain the most important source of reliable data in many cases.
- ***Data that are captured directly from the environment are called primary data***.
- With primary data, the core concern in knowing their properties is to know the process by which they were captured, the parameters of any instruments used, and the rigor with which quality requirements were observed.
- In practice, it is not always feasible to obtain spatial data by direct capture.
- Factors of cost and available time may be a hindrance, and sometimes previous projects have acquired data that may fit a current project's purpose.

6.1.2 Indirect spatial data capture:

- The other way to get spatial data is sourced indirectly.
- This includes data derived by:
  - ○ scanning existing printed maps,

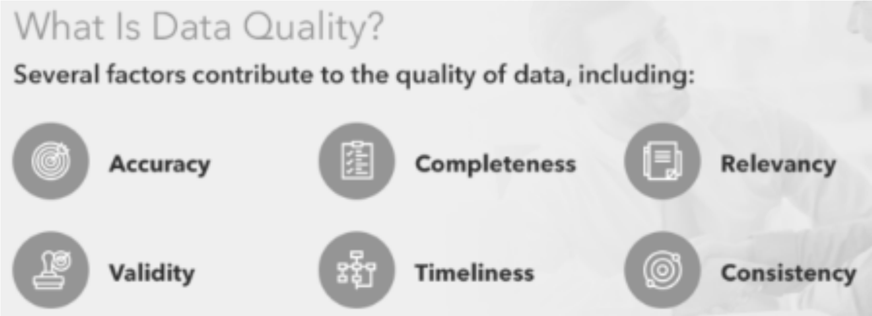
  - data digitized from a satellite image
  - processed data purchased from data-capture firms or international agencies, and so on.

- ***This type of data is known as secondary data.***
- Secondary data are derived from existing sources and have been collected for other purposes, often not connected with the investigation at hand.
- Spatial data have been collected in digital form at an increasing rate and stored in various databases by the individual producers for their own use and for commercial purposes.
- More and more of these data are being shared among GIS users.
- There are several reasons for this such as,
  - Some data are freely available,
  - Other data are only available commercially, as is the case for most satellite imagery.
  - High quality data remains both costly and time consuming to collect and verify.

6.1.3 Obtaining spatial data elsewhere:

- New technologies have played a key role in the increasing availability of geospatial data.
- As a result of this availability of various data has increased,
- Though we have to be more careful that the data we have acquired are of sufficient quality to be used in analyses and decision-making.
- There are several related initiatives in the world to supply base data sets at national, regional and global levels, as well as those aiming to harmonize data models and definitions of existing data sets.
- Global initiatives include, for example,
  - the Global Map,
  - the USGS Global GIS database and
  - the Second Administrative Level Boundaries (SALB) project.
- SALB, for instance, is a UN project aiming at improving the availability of information about administrative boundaries in developing countries.

6.2 DATA QUALITY



- Data quality is a measure of the condition of data based on factors such as,

  - **Accuracy:**

    - This can be termed as the discrepancy between the actual attributes value and coded attribute value.
    - **Positional accuracy** is the quantifiable value that represents the positional difference between two geospatial layers or between a geospatial layer and reality.
    - **Attribute accuracy** indicates the attribute attached to the points, lines and polygons features of the spatial database, which are reliable and reasonably correct or free from bias.
    - **Temporal Accuracy** occurs if the GIS data set has a temporal dimension and thus the spatial information data type results in the form of: x,y,z,t. The temporal accuracy refers to data that has a time component.

  - **Completeness:**

    - It is basically the measure of totality of features.
    - A data set with minimal amount of missing features can be termed as Complete-Data.

  - **Relevancy:**

    - You must consider whether you really need this information, or whether you're collecting it just for the sake of it.
    - Why does relevance matter as a data quality characteristic?
    - If you're gathering irrelevant information, you're wasting time as well as money. Your analyses won't be as valuable.

  - **Validity:**

    - Validity means that a piece of information doesn't contradict another piece of information in a different source or system.

    - When pieces of information contradict themselves, you can't trust the data. You could make a mistake that could cost your firm money and reputational damage.

- **Timeliness:**
    - Timeliness refers to the time expectation for accessibility and availability of information.
    - Timeliness can be measured as the time between when information is expected and when it is readily available for use.

- **Consistency:**
    - Data consistency can be termed as the absence of conflicts in a particular database.
    - **Logical consistency** describes the fidelity of relationships encoded in the data structure of the digital spatial data.
    - For example, a street arc that does not have a street name should not have a street type.

Characteristic	**How it's measured**
Accuracy	Is the information correct in every detail?
Completeness	How comprehensive is the information?
Validity	Does the information contradict other trusted resources?
Relevance	Do you really need this information?
Timeliness	How up- to-date is information? Can it be used for real-time reporting?

- Data created from different channels with different techniques can have discrepancies in terms of resolution, orientation and displacements.
- Improved data quality leads to better decision-making across an organization.
- Good data decreases risk and can result in consistent improvements in results.
- Data quality is the degree of data excellency that satisfies the given objective.

Data lineage:

- It is the process of understanding, recording, and visualizing data as it flows from data sources to consumption.
- This includes all transformations the data underwent along the way how the data was transformed, what changed, and why.
- Data lineage process describes ,
  - the history of the spatial data,
  - including descriptions of the source material from which the data were derived, and
  - the methods of derivation.
  - it also contains the dates of the source material, and
  - all transformations involved in producing the final digital files or map products.

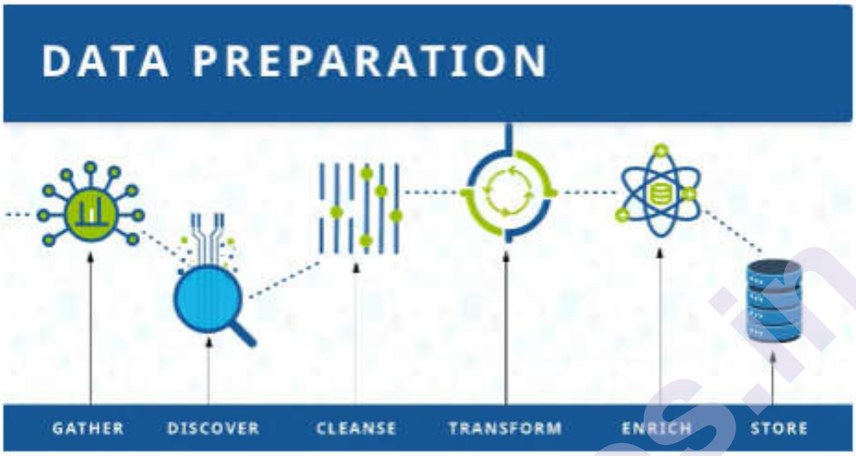
6.3 DATA PREPARATION

- Data preparation is the process of cleaning and transforming raw data prior to processing and analysis.
- It is an important step prior to processing and often involves reformatting data, making corrections to data and the combining of data sets to enrich data.
- Data preparation is often a lengthy undertaking for data professionals or business users, but it is essential as a prerequisite to put data in context in order to turn it into insights and eliminate bias resulting from poor data quality.
- For example, the data preparation process usually includes standardizing data formats, enriching source data, and/or removing outliers.
- Data preparation helps:
  - **Fix errors quickly**
    - Data preparation helps catch errors before processing.
    - After data has been removed from its original source, these errors become more difficult to understand and correct.
  - **Produce top-quality data**
    - Cleaning and reformatting datasets ensures that all data used in analysis will be high quality.

- **Make better business decisions**
  - Higher quality data that can be processed and analyzed more quickly and efficiently leads to more timely, efficient and high-quality business decisions.

Data Preparation Steps

The specifics of the data preparation process vary by industry, organization and need, but the framework remains largely the same.



1. Gather data

- The data preparation process begins with finding the right data.
- This can come from an existing data catalog or can be added ad-hoc.

2. Discover and assess data

- After collecting the data, it is important to discover each dataset.
- This step is about getting to know the data and understanding what has to be done before the data becomes useful in a particular context.

3. Cleanse and validate data

- Cleaning up the data is traditionally the most time consuming part of the data preparation process, but it's crucial for removing faulty data and filling in gaps.
- Important tasks here include:
  - Removing extraneous data and outliers.
  - Filling in missing values.
  - Conforming data to a standardized pattern.
  - Masking private or sensitive data entries.

- Once data has been cleansed, it must be validated by testing for errors in the data preparation process up to this point.
- Oftentimes, an error in the system will become apparent during this step and will need to be resolved before moving forward.

4. Transform and enrich data

- Transforming data is the process of updating the format or value entries in order to reach a well-defined outcome, or to make the data more easily understood by a wider audience.
- Enriching data refers to adding and connecting data with other related information to provide deeper insights.

5. Store data

- Once prepared, the data can be stored.
- Or it can be channeled into a third party application such as, a business intelligence tool clearing the way for processing and analysis to take place.

6.3.1 Data checks and repairs:

- **Data checks and repairs** refers to the step when acquired data sets must be checked for quality in terms of the accuracy, consistency and completeness.
- **Errors** can be identified automatically, after which manual editing methods can be used to correct the errors.
- Alternatively, some software may identify and automatically correct certain types of errors.
- The geometric, topological, and attribute components of spatial data can be distinguished.
- Errors can be injected at many points in a GIS analysis, and one of the largest sources of error is the data collected.
- Each time a new dataset is used in a GIS analysis, new error possibilities are also introduced.
- One of the feature benefits of GIS is the ability to use information from many sources, so the need to have an understanding of the quality of the data is extremely important.
- Accuracy in GIS is the degree to which information on a map matches real-world values. It is an issue that pertains both to the quality of the data collected and the number of errors contained in a dataset or a map.
- Precision refers to the level of measurement and exactness of description in a GIS database. Precise location data may measure position to a fraction of a unit (meters, feet, inches, etc.).

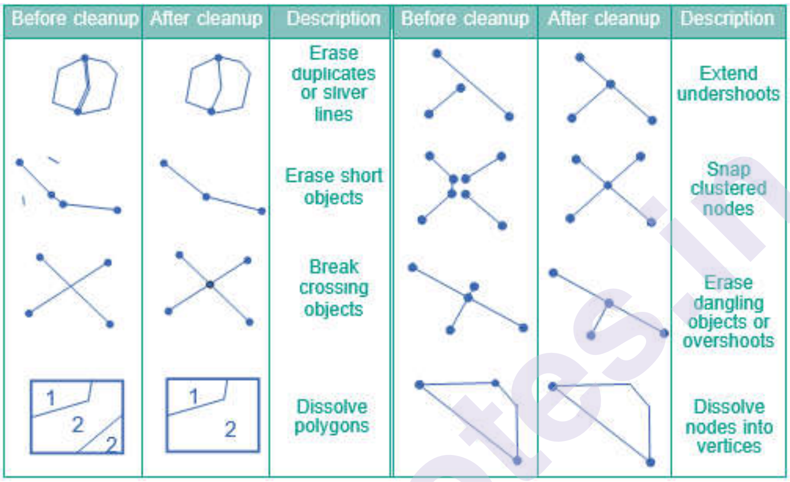
- The more accurate and precise the data, the higher the cost to obtain and store it because it can be very difficult to obtain and will require larger data files.

- Highly precise data does not necessarily correlate to highly accurate data nor does highly accurate data imply high precision data.

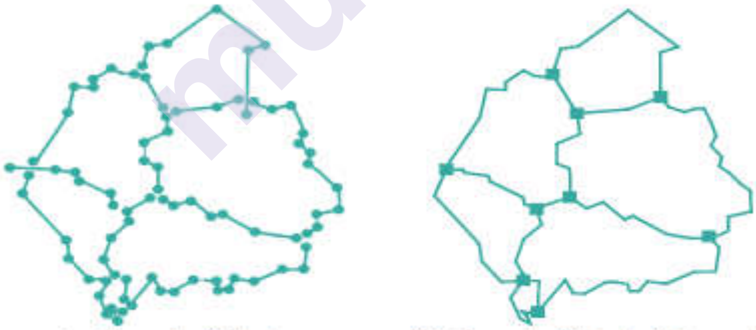
- **Clean-up** operations are often performed in a standard sequence.

- For example, crossing lines are split before dangling lines are erased, and nodes are created at intersections before polygons are generated.

- These are illustrated in below diagram:



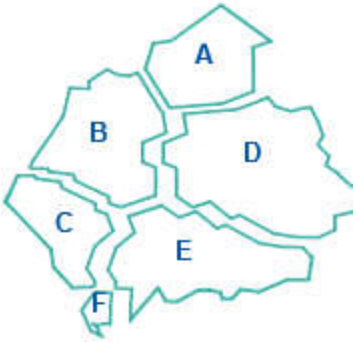
- With polygon data, one usually starts with many polylines, in an unwieldy format known as spaghetti data.



1. Spaghetti data (b) Spaghetti data (cleaned)

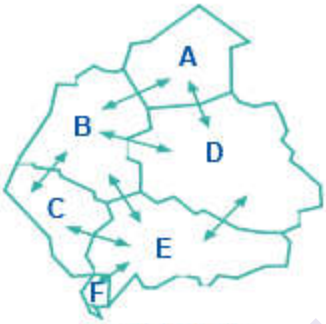
- This results in fewer polylines with more internal vertices.

- Then, polygons can be identified .



(c) Polygons

- Sometimes, polylines that should connect to form closed boundaries do not, and therefore must be connected; this step is not indicated in the figure.



(d) Topology

- In a final step, the elementary topology of the polygons can be derived (d).

Associating attributes

Attributes may be automatically associated with features that have unique identifiers.

In the case of vector data, attributes are assigned directly to the features, while in a raster the attributes are assigned to all cells that represent a feature.

Rasterization or vectorization

- **Vectorization** produces a vector data set from a raster.
- Another form of vectorization takes place when we want to identify features or patterns in remotely sensed imagery.
- The keywords here are feature extraction and pattern recognition, which are dealt with Remote Sensing .
- **Rasterization** is a process of converting vector data sets to raster data when some or all of the subsequent spatial data analysis is to be carried out on raster data.
- It involves assigning point, line and polygon attribute values to raster cells that overlap with the respective point, line or polygon.

- A cell size which is too large may result in cells that cover parts of multiple vector features.

- Rasterization itself could be seen as a '**backwards step**':

  - Firstly, raster boundaries are only an approximation of the objects' original boundary.

  - Secondly, the original 'objects' can no longer be treated as such, as they have lost their topological properties.

- An alternative to rasterization is to not perform it during the data preparation phase, but to use GIS rasterization functions on- the-fly, that is when the computations call for it.

- This allows keeping the vector data and generating raster data from them when needed. Obviously, the issue of performance trade-off must be looked into.

Topology generation

- We have already discussed derivation of topology from vectorized data sources.

- However, more topological relations may sometimes be needed, for instance in networks, e.g. the questions of line connectivity, flow direction, and which lines have over- and underpasses.

6.3.2 Combining data from multiple sources:

- A GIS project usually involves multiple data sets

- Hence it is important to see integration of these multiple sets related to each other.

- There are four fundamental cases to be considered in the combination of data from different sources:

  - They may be about the same area, but differ in accuracy,

  - They may be about the same area, but differ in choice of representation,

  - They may be about adjacent areas, and have to be merged into a single data set.

  - They may be about the same or adjacent areas, but referenced in different coordinate systems.

Differences in accuracy:

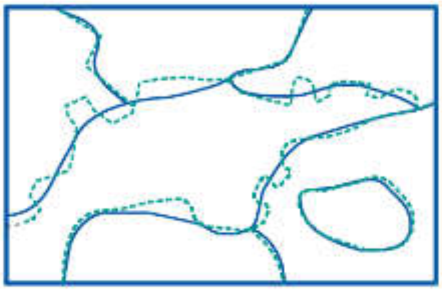


Figure: The integration of two vector datasets, which represent the same phenomenon, may lead to sliver polygons

- In the above Figure the polygons of two digitized maps at different scales are overlaid.
- Due to scale differences in the sources, the resulting polygons do not perfectly coincide, and polygon boundaries cross each other.
- This causes small,artefact polygons in the overlay known as sliver polygons.
- If the map scales in- Sliver polygons volved differ significantly, the polygon boundaries of the large-scale map should probably take priority, but when the differences are slight, we need interactive techniques to resolve the issues.

Differences in representation

- When points need to be translated into rasters, we need to perform something known as point data transformation.
- Some advanced GIS applications require the possibility of representing the same geographic phenomenon in different ways. These are called multirepresentation systems.
- The commonality is that phenomena must sometimes be Multi-scale and viewed as points, and at other times as polygons.
- For example, a small-scale multirepresentation systems national road network analysis may represent villages as point objects, but a nation-wide urban population density study should regard all municipalities as represented by polygons.
- The links between various representations for the same object maintained by the system allows switching between them, and many fancy applications of their use seem possible.

- A comparison is illustrated in below Figure:

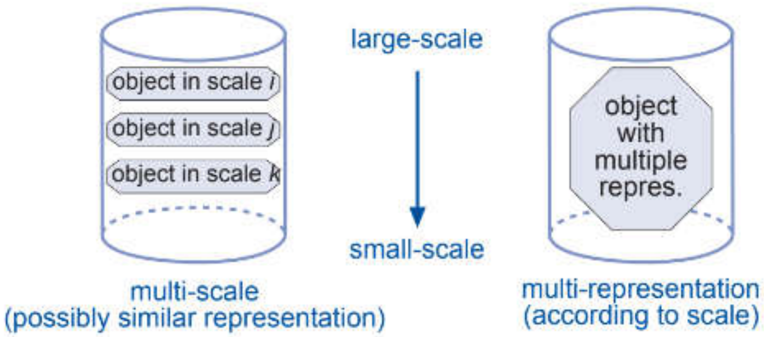


Figure: Multi-scale and multi-representation systems compared; the main difference is that multi-representation systems have a built-in 'understanding' that different representations belong together.

Merging data sets of adjacent areas:

- Sometimes data sets have to be matched into a single 'seamless' data set, ensuring that the appearance of the integrated geometry is as homogeneous as possible.
- **Edge matching** is the process of joining two or more map sheets.
- Merging adjacent data sets can be a major problem.
- Some GIS functions, such as line smoothing and data clean-up (removing duplicate lines) may have to be performed.
- Following Figure illustrates a typical situation.

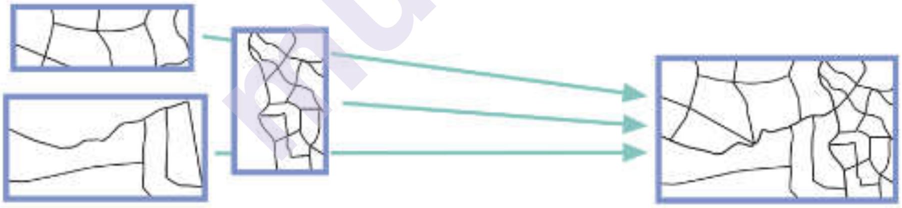


Figure: Multiple adjacent data sets, after cleaning, can be matched and merged into a single one.

- Some GISs have merge or edge-matching functions to solve the problem arising from merging adjacent data.
- At the map sheet edges, feature representations have to be matched in order for them to be combined.
- Coordinates of the objects along shared borders are adjusted to match those in the neighboring data sets.
- Mismatches may still occur, so a visual check, and interactive editing is likely to be required.

Differences in coordinate systems:

- Map projections provide means to map geographic coordinates onto a flat surface and vice versa.
- It may be the case that data layers which are to be combined or merged in some way are referenced in different coordinate systems, or are based upon different datums.
- As a result, data Transformations may need **coordinate transformation**, or **both a coordinate transformation and datum transformation**.
- It may also be the case that data has been digitized from an existing map or data layer .
- In this case, geometric transformations help to transform device coordinates (coordinates from digitizing tablets or screen coordinates) into world coordinates (geographic coordinates, meters, etc.).

Other data preparation functions:

A range of other data preparation functions exist that support conversion or adjustment of the acquired data to format requirements that have been defined for data storage purposes.

These include:

- Format transformation functions
  - These convert between data formats of different systems or representations, e.g. reading a DXF file into a GIS.
  - The user should be warned that conversions from one format to another may cause problems.
  - The reason is that not all formats can capture the same information, and therefore conversions often mean loss of information.
- Graphic element editing
  - Manual editing of digitized features so as to correct errors, and to prepare a clean data set for topology building.
- Coordinate thinning
  - A process that is often applied to remove redundant or excess vertices from line representations, as obtained from digitizing.

6.4 POINT DATA TRANSFORMATION

We will see several methods of transforming point data in a GIS:

Interpolation

- We may want to transform our points into other representations in order to facilitate interpretation and/or integration with other data.
- Examples include defining homogeneous areas (polygons) from our point data, or deriving contour lines.
- This is generally referred to as **interpolation**,
- The calculation of an Interpolation value from 'surrounding' observations.
- The principle of spatial autocorrelation plays a central part in the process of interpolation

Nearest-neighbour interpolation

- In order to predict the value of a point for a given (x, y) location, we could simply find the 'nearest' known value to the point, and assign that value.
- This is the simplest form of interpolation, known as **nearest-neighbour interpolation**.
- We might instead choose to use the distance that points are away from (x, y) to weight their importance in our calculation.

Discrete and continuous fields

- How we represent a field constructed from point measurements in the GIS also depends on the above distinction.
- A **discrete field** can either be represented as a classified raster or as a polygon data layer, in which each polygon has been assigned a (constant) field value.
- A **continuous field** can be represented as an un-Discrete and continuous classified raster, as an isoline (thus, vector) data layer, or perhaps as a TIN.
- Some field GIS software only provides the option of generating raster output, requiring an intermediate step of raster to vector conversion.
- The choice of representation depends on what will be done with the data in the analysis phase.

6.4.1 Interpolating discrete data

- If we are dealing with discrete data, we are effectively restricted to using nearest-neighbour interpolation.
- In a nearest-neighbour interpolation, each location is assigned the value of the closest measured point.

- Effectively, this technique will construct **'zones'** around interpolation of the points of measurement, with each point belonging to a zone assigned the same value.
- Effectively, this represents an assignment of an existing value to a location.
- If the desired output was a polygon layer, we could construct **Thiessen polygons** around the points of measurement.
- The boundaries of such polygons, by definition, are the locations for which more than one point of measurement is the closest point.
- If the desired output was in the form of a raster layer, we could rasterize the Thiessen polygons.

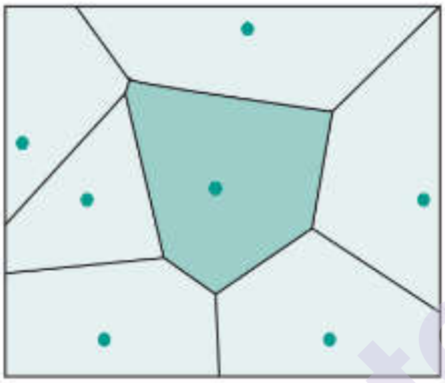


Figure: Generation of Thiessen polygons for qualitative point measurements. The measured

points are indicated in dark green; the darker area indicates all locations assigned with the measurement value of the central point.

6.4.2 Interpolating continuous data

There are many continuous geographic field elevation, temperature and groundwater salinity are just a few examples.

Commonly, continuous fields are represented as rasters, and we will almost by default assume that they are.

The main alternative for continuous field representation is a polyline vector layer, in which the lines are isolines.

The aim is to use measurements to obtain a representation of the entire field using point samples.

In this section we outline four techniques to do so:

1. Trend surface fitting using regression,

2. Triangulation,

3. Spatial moving averages using inverse distance weighting,

4. Kriging.

1. Trend surface fitting using regression,

- A surface interpolation method that fits a polynomial surface by least-squares regression through the sample data points.
- This method results in a surface that minimizes the variance of the surface in relation to the input values.
- The resulting surface rarely goes through the sample data points.

2. Triangulation,

- Triangulation refers to the use of multiple methods or data sources in qualitative research to develop a comprehensive understanding of phenomena (Patton, 1999).
- Triangulation also has been viewed as a qualitative research strategy to test validity through the convergence of information from different sources.

3. Spatial moving averages using inverse distance weighting,

- Inverse distance weighted (IDW) interpolation determines cell values using a linearly weighted combination of a set of sample points.
- The weight is a function of inverse distance. The surface being interpolated should be that of a locationally dependent variable.

4. Kriging.

- Kriging is a multistep process; it includes exploratory statistical analysis of the data, variogram modeling, creating the surface, and (optionally) exploring a variance surface.
- Kriging is most appropriate when you know there is a spatially correlated distance or directional bias in the data.
- Kriging predicts the value of a function at a given point by computing a weighted average of the known values of the function in the neighborhood of the point.
- The method is closely related to regression analysis.

6.5 SUMMARY

- GIS will help to ascertain the ground level realities with the help of spatial data obtained from various resources.
- In GIS one can integrate data from various sources such as Remote Sensing Data and
- Image with that of data of land records and agricultural census.
- It would be more appropriate to use GIS applications in agro-based enterprise to ascertain the scope of activities and monitoring of activities.

- Digital data can be obtained directly from spatial data providers, or from pre-
- existing GIS application projects.
- Sometimes, however, the data must be obtained from non-digital sources such as paper maps. In all of these cases, data quality is a key consideration.
- Data cleaning and preparation involves checking for errors, inconsistencies, and simplification and merging existing spatial data sets.
- The problems that one may encounter may be caused by differences in resolution and differences in representation.
- We have discussed various methods to address these issues in this chapter.

6.6 EXERCISE

1. Distinguish between primary and secondary data and give examples of each.

   In what circumstances is this distinction difficult to maintain?
2. Rasterization of vector data is sometimes required in data preparation. What reasons may exist for this?
3. What is secondary data in GIS? Explain any two ways to brain secondary data in GIS.
4. List the four issues in obtaining data from multiple sources. Explain any two of them.

Reference :

1) https://www.techtarget.com/searchdatamanagement/definition/spatial-data

2) https://gisgeography.com/spatial-data-types-vector-raster/#:~:text=The%20two%20primary%20types%20of,raster%20data%20in%20a%20GIS.

3) https://www.talend.com/resources/what-is-data-preparation/

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7

SPATIAL DATA ANALYSIS

Unit Structure :

7.0 OBJECTIVES

After going through this chapter ,you will be able to

- How analytical functions that can form the building blocks for application models.
- It will hopefully become clear to the reader that these operations can be combined in various ways for increasingly complex analyses.
- Overview of different types of analytical models and related concepts .

7.1 INTRODUCTION

The discussion up until this point has sought to prepare the reader for the 'data analysis' phase. So far, we have discussed the nature of spatial data, georeferencing, notions of data acquisition and preparation, and issues relating to data quality and error.

Before we move on to discuss a range of analytical operations, we should begin with some clarifications. We know from preceding discussions that the analytical capabilities of a GIS use spatial and non-spatial (attribute) data to answer questions and solve problems that are of spatial relevance. It is important to make a distinction between analysis. By analysis we mean only a subset of what is usually implied by the term: we do not specifically deal with statistical analysis

7.2 CLASSIFICATION OF ANALYTICAL GIS CAPABILITIES

There are many ways to classify the analytical functions of a GIS. The classification used for this chapter, is essentially the one put forward by Aronoff [3]. Itmakes the following distinctions, which are addressed in subsequent sections of the chapter:

1. Classification, retrieval, and measurement functions. All functions in this category are performed on a single (vector or raster) data layer, often usingthe associated attribute data.

- Classification allows the assignment of features to a class on the basisof attribute values or attribute ranges (definition of data patterns). Onthe basis of reflectance characteristics found in a raster, pixels may beclassified as representing different crops, such as potato and maize.

- Retrieval functions allow the selective search of data. We might thusretrieve all agricultural fields where potato is grown.

- Generalization is a function that joins different classes of objects withcommon characteristics to a higher level (generalized) class.

Measurement functions allow the calculation of distances, lengths, orareas.

2. Overlay functions. These belong to the most frequently used functionsin a GISapplication. They allow the combination of two (or more) spa-tial data layers comparing them position by position, and treating areas ofoverlap—and of non-overlap—in distinct ways. Many GISs support over-lays through an algebraic language, expressing an overlay function as aformula in which the data layers are the arguments. In this way, we can find

- The potato fields on clay soils (select the 'potato' cover in the cropdata layer and the 'clay' cover in the soil data layer and perform anintersection of the two areas found),

- The fields where potato or maize is the crop (select both areas of‘potato’ and ‘maize’ cover in the crop data layer and take their union),

- The potato fields not on clay soils (perform a difference operator ofareas with ‘potato’ cover with the areas having clay soil),

- The fields that do not have potato as crop (take the complement of the potato areas).

3. Neighbourhood functions. Whereas overlays combine features at the samelocation, neighbourhood functions evaluate the characteristics of an areasurrounding a feature’s location. A neighbourhood function ‘scans’ theneighbourhood of the given feature(s), and performs a computation on it.

- Search functions allow the retrieval of features that fall within a givensearch window. This window may be a rectangle, circle, or polygon.

- Buffer zone generation (or buffering) is one of the best known neighbourhood functions. It determines a spatial envelope (buffer) around(a) given feature(s). The created buffer may have a fixed width, or avariable width that depends on characteristics of the area.

- Interpolation functions predict unknown values using the known values at nearby locations. This typically occurs for continuous fields, like elevation, when the data actually stored does not provide the direct answer for the location(s) of interest. Interpolation of continuousdata was discussed in Section 5.4.2.

- Topographic functions determine characteristics of an area by lookingat the immediate neighbourhood as well. Typical examples are slopecomputations on digital terrain models (i.e. continuous spatial fields).The slope in a location is defined as the plane tangent to the topography in that location. Various computations can be performed, such as:

– determination of slope angle,

– determination of slope aspect,

– determination of slope length,

4. Connectivity functions. These functions work on the basis of networks, including road networks, water courses in coastal zones, and communication lines in mobile telephony. These networks represent spatial linkagesbetween features. Main functions of this type include:

- Contiguity functions evaluate a characteristic of a set of connected spatial units. One can think of the search for a contiguous area of forestof certain size and shape in a satellite image.

- Network analytic functions are used to compute over connected line features that make up a network. The network may consist of roads, public transport routes, high voltage lines or other forms of transportation infrastructure. Analysis of such networks may entail shortest path computations (in terms of distance or travel time) between two points in a network for routing purposes. Other forms are to find all pointsreachable within a given distance or duration from a start point forallocation purposes, or determination of the capacity of the networkfor transportation between an indicated source location and sink lo - cation.

- Visibility functions also fit in this list as they are used to compute thepoints visible from a given location (viewshed modelling or viewshed mapping) using a digital terrain model

7.3 RETRIEVAL, CLASSIFICATION AND MEASUREMENT

7.3.1 Measurement

Geometric measurement on spatial features includes counting, distance and area size computations. For the sake of simplicity, this section discusses such measurements in a planar spatial reference system. We limit ourselves to geometric measurements, and do not include attribute data measurement. In general, Measurement types measurements on vector data are more advanced, thus, also more complex, than those on raster data. We discuss each group.

Measurements on vector data.The primitives of vector data sets are point, (poly)line and polygon. Related geometric measurements are location, length, distance and area size. Some of these are geometric properties of a feature in isolation (location, length, area size); others (distance) require two features to be identified. The location property of a vector feature is always stored by the GIS: a single coordinate pair for a point, or a list of pairs for a polyline or polygon boundary. Occasionally, there is a need to obtain the location of the centroid of a polygon; some GISs store these also, others compute them 'on-the-fly'. Length is a geometric property associated with polylines, by themselves, or in their function as polygon boundary. It can obviously be computed by the GIS— as the sum of lengths of the constituent line segments—but it quite often is also stored with the polyline. Area size is associated with polygon features. Again, it can be computed, butusually is stored with the polygon as an extra attribute value. This speeds upthe computation of other functions that require area size values. The attentive reader will have noted that all of the above 'measurements' do notactually require computation, but only retrieval of stored data.Measuring distance between two features is another important function. If both features are points, say p and q, the computation in a Cartesian spatial reference system are given by the well-known Pythagorean distance function.

7.3.2 Spatial selection queries

Interactive spatial selection In interactive spatial selection, one defines the selection condition by pointing at or drawing spatial objects on the screen display, after having indicated the spa- tial data layer(s) from which to select features. The interactively defined objects are called the selection objects; they can be points, lines, or polygons. The GIS Selection objects then selects the features in the indicated data layer(s) that overlap (i.e. intersect, meet, contain, or are contained in.

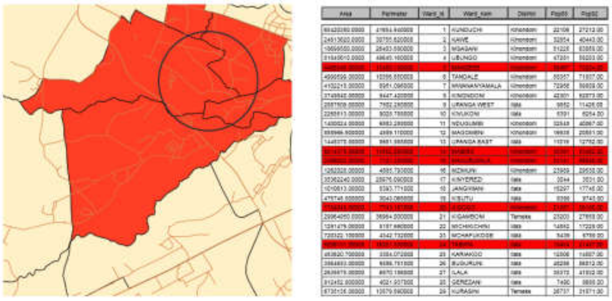
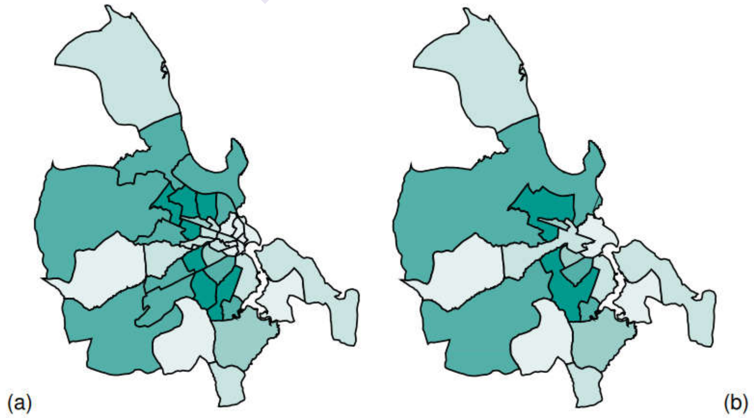


Figure 6.2: All city wards that overlap with the selection object—here a circle—are selected (left), and their corresponding attribute records are highlighted (right, only part of the table is shown). Data from an urban application in Dar es Salaam, Tanzania. Data source: Dept. of Urban & Regional Planning and Geo-information Management, ITC.

7.3.3 Classification

Classification is a technique of purposefully removing detail from an input data set, in the hope of revealing important patterns (of spatial distribution). In the process, we produce an output data set, so that the input set can be left intact. We do so by assigning a characteristic value to each element in the input set, which is usually a collection of spatial features that can be raster cells or points, lines or polygons. If the number of characteristic values is small in comparison to the size of the input set, we have classified the input set. The pattern that we look for may be the distribution of household income in a city. Household income is called the classification parameter. If we know for each ward in the city the associated average income, we have many different values. Subsequently, we could define five different categories (or: classes) of Classification parameter income: 'low', 'below average', 'average', 'above average' and 'high', and pro- vide value ranges for each category. If these five categories are mapped in a sensible colour scheme, this may reveal interesting information. The input data set may have itself been the result of a classification, and in such a case we call it a reclassification. For example, we may have a soil map that shows different soil type units and we would like to show the suitability of units for a specific crop. In this case, it is better to assign to the soil units an attribute Reclassification of suitability for the crop. Since different soil types may have the same crop suitability, a classification may merge soil units of different type into the same category of crop suitability.



In classification of vector data, there are two possible results. In the first, theinput features may become the output features in a new data layer, with an additional category assigned. In other words, nothing changes with respect to the spatial extents of the original features. Is an illustration of this first type of output. A second type of output is obtained when adjacent features with the same category are merged into one bigger feature. Such post-processing functions are called spatial merging, aggregation or dissolving. An illustration of this second type is found . Observe that this type of merging is only an option in vector data, as merging cells in an output raster on the basis of a classification makes little sense. Vector data classification can be performed on point sets, line sets or polygon sets; the optional merge phase is sensibleonly for lines and polygons.

Automatic classification

User-controlled classifications require a classification table or user interaction. GIS software can also perform automatic classification, in which a user only specifies the number of classes in the output data set. The system automatically determines the class break points. Two main techniques of determining break points are in use.

1. Equal interval technique: The minimum and maximum values vmin and vmax of the classification parameter are determined and the (constant) interval size for each category is calculated as (vmax − vmin)/n, where n is the number of classes chosen by the user. This classification is useful in revealing the distribution patterns as it determines the number of features in each category.

2. Equal frequency technique: This technique is also known as quantile classification. The objective is to create categories with roughly equal numbers of features per category. The total number of features is determined first and by the required number of categories, the number of features per category is calculated. The class break points are then determined by counting off the features in order of classification parameter value.

1	1	1	2	8
4	4	5	4	9
4	3	3	2	10
4	5	6	8	8
4	2	1	1	1

(a) original raster

1	1	1	1	4
2	2	3	2	5
2	2	2	1	5
2	3	3	4	4
2	1	1	1	1

(b) equal interval classification

1	1	1	2	5
3	3	4	3	5
3	2	2	2	5
3	4	4	5	5
3	2	1	1	1

(c) equal frequency classification

original value	new value	# cells
1,2	1	9
3,4	2	8
5,6	3	3
7,8	4	3
9,10	5	2

original value	new value	# cells
1	1	6
2,3	2	5
4	3	6
5,6	4	3
8,9,10	5	5

7.4 OVERLAY FUNCTIONS

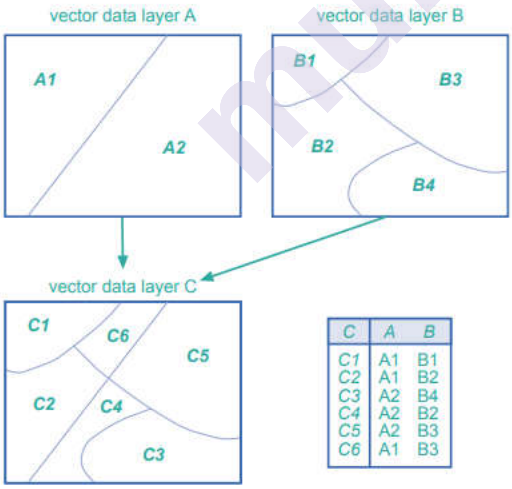
In the previous section, we saw various techniques of measuring and selecting spatial data. We also discussed the generation of a new spatial data layer from an old one, using classification. In this section, we look at techniques of combining two spatial data layers and producing a third from them. The binary operators that we discuss are known as spatial overlay operators. We will firstly discuss vector overlay operators, and then focus on the raster case.

Standard overlay operators take two input data layers, and assume they are georeferenced in the same system, and overlap in study area. If either of these requirements is not met, the use of an overlay operator is senseless. The principle of spatial overlay is to compare the characteristics of the same location in both data layers, and to produce a result for each location in the output data layer. The specific result to produce is determined by the user. It might involve a calculation, or some other logical function to be applied to every area or location.

In raster data, as we shall see, these comparisons are carried out between pairs of cells, one from each input raster. In vector data, the same principle of comparing locations applies, but the underlying computations rely on determining the spatial intersections of features from each input layer.

7.4.1 Vector overlay operators

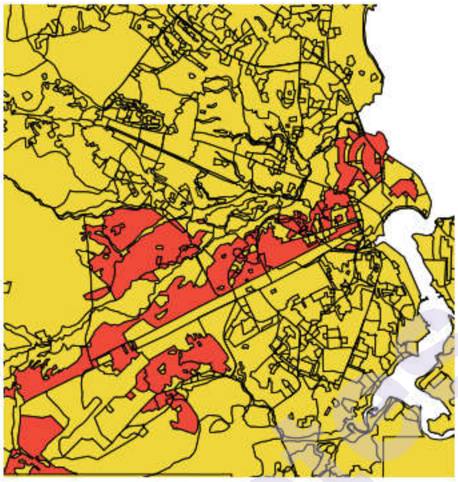
In the vector domain, overlay is computationally more demanding than in the raster domain. Here we will only discuss overlays from polygon data layers, but we note that most of the ideas also apply to overlay operations with point or line data layers



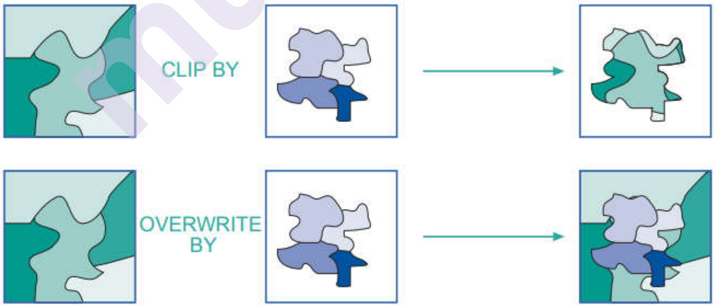
C	A	B
C1	A1	B1
C2	A1	B2
C3	A2	B4
C4	A2	B2
C5	A2	B3
C6	A1	B3

The standard overlay operator for two layers of polygons is the polygon intersection operator. It is fundamental, as many other overlay operators proposed in the literature or implemented in systems can be defined in terms of it. The result of this operator is the collection of all possible polygon intersections; the attribute table result is a join—in the relational database sense .

This outputattribute table only contains one tuple for each intersection polygon found, and this explains why we call this operator a spatial join. A more practical example is provided in Figure which was produced by polygon intersection of the ward polygons with land use polygons classified as in Figure . This has allowed us to select the residential areas in Ilala District. Two more polygon overlay operators are illustrated in Figure . The first is known as the polygon clipping operator. It takes a polygon data layer and restricts its spatial extent to the generalized outer boundary obtained from all (selected) Polygon clipping polygons in a second input layer. Besides this generalized outer boundary, no other polygon boundaries from the second layer play a role in the result.



Attribute table only contains one tuple for each intersection polygon found, and this explains why we call this operator a spatial joi.



7.4.2 Raster overlay operators

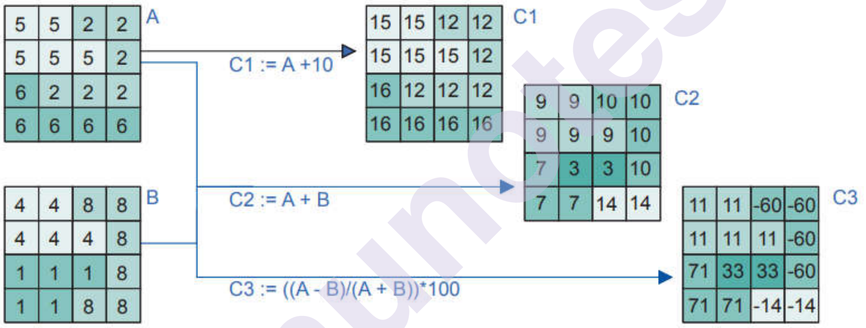
Vector overlay operators are useful, but geometrically complicated, and this sometimes results in poor operator performance. Raster overlays do not suffer from this disadvantage, as most of them perform their computations cell by cell, and thus they are fast. GISs that support raster processing—as most do—usually have a language to express operations on rasters. These languages are generally referred to as map algebra , or sometimes raster calculus. They allow a GIS to compute new rasters from existing ones, using a range of functions and operators. Unfortunately, not all implementations of map algebra offer the same functionality. The discussion below is to a large extent based on general terminology, and attempts to illustrate the key operations using a logical, structured language. Again, the syntax often differs for different GIS software packages. When producing a new raster we must provide a name for it, and define how it is computed. This is done in an assignment statement of the following format:

Output raster name := Map algebra expression

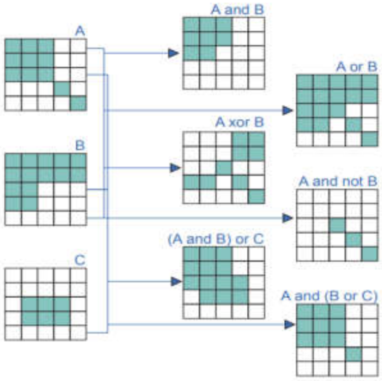
Arithmetic operators

Various arithmetic operators are supported. The standard ones are multiplication (×), division (/), subtraction (−) and addition (+). Obviously, these arithmetic operators should only be used on appropriate data values, and for instance, not on classification values. Other arithmetic operators may include modulo division (MOD) and integer division (DIV).

Modulo division returns the remainder of division: for instance, 10 MOD 3 will return 1 as 10 − 3 × 3 = 1. Similarly, 10 DIV 3 will return 3. More operators are goniometric: sine (sin), cosine (cos), tangent (tan), and their inverse functions asin, acos, and atan, which return radian angles as real values.

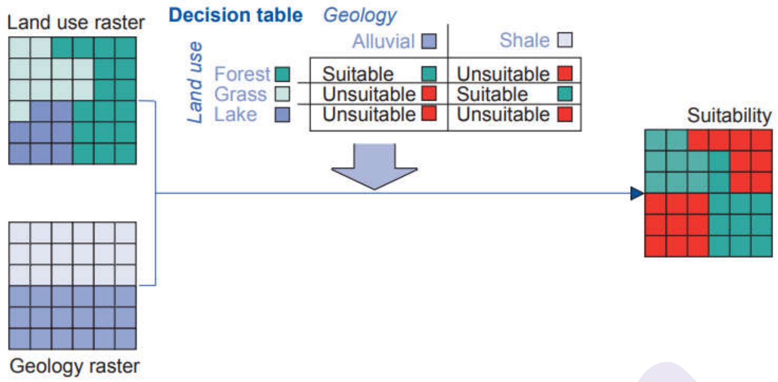


Comparison and logical operators



7.4.3 Overlays using a decision table

Conditional expressions are powerful tools in cases where multiple criteria must be taken into account. A small size example may illustrate this. Consider a suitability study in which a land use classification and a geological classification must be used. The respective rasters are illustrated in Figure on the left. Domain expertise dictates that some combinations of land use and geology result in suitable areas, whereas other combinations do not. In our example, forests on alluvial terrain and grassland on shale are considered suitable combinations, while the others are not.



7.5 NEIGHBOURHOOD FUNCTIONS

In our section on overlay operators, the guiding principle was to compare or combine the characteristic value of a location from two data layers, and to do so for all locations. This is what map algebra, for instance, gave us: cell by cell calculations, with the results stored in a new raster. There is another guiding principle in spatial analysis that can be equally useful. The principle here is to find out the characteristics of the vicinity, here called neighbourhood, of a location. After all, many suitability questions, for instance, depend not only on what is at the location, but also on what is near the location.

Thus, the GIS must allow us 'to look around locally'. To perform neighbourhood analysis, we must:

1. State which target locations are of interest to us, and define their spatial extent,
2. Define how to determine the neighbourhood for each target,
3. Define which characteristic(s) must be computed for each neighbourhood.

For instance, our target might be a medical clinic. Its neighbourhood could be defined as:

- An area within 2 km distance as the crow flies, or
- An area within 2 km travel distance, or
- All roads within 500 m travel distance, or
- All other clinics within 10 minutes travel time, or
- All residential areas, for which the clinic is the closest clinic. The alert reader will note the increasingly complex definitions of 'neighbourhood'

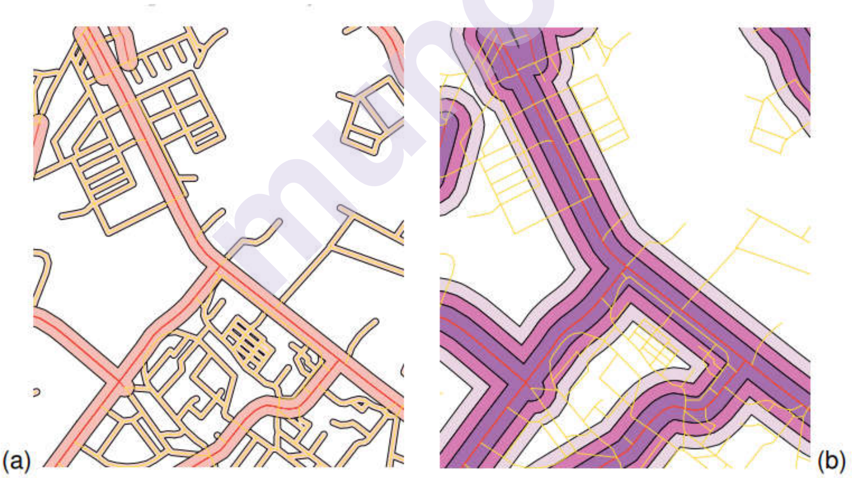
used here. This is to illustrate that different ways of measuring neighbourhoods exist, and some are better (or more representative of real neighbourhoods) than others, depending on the purpose of the analysis. Then, in the third step we indicate what it is we want to discover about the phenomena that exist or occur in the neighbourhood. This might simply be its spatial extent, but it might also be statistical information like:

- The total population of the area,
- Average household income, or
- The distribution of high-risk industries located in the neighbourhood.

7.5.1 Proximity computations

In proximity computations, we use geometric distance to define the neighbourhood of one or more target locations. The most common and useful technique is buffer zone generation. Another technique based on geometric distance that we discuss is Thiessen polygon generationBuffer zone generation

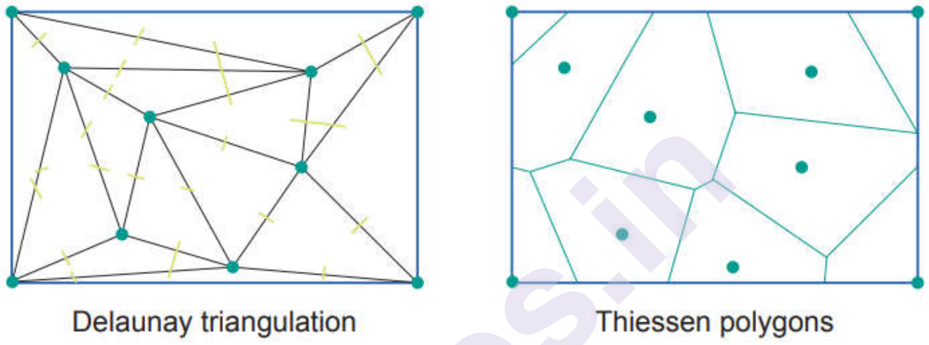
The principle of buffer zone generation is simple: we select one or more target locations, and then determine the area around them, within a certain distance. In Figure a number of main and minor roads were selected as targets, and a 75 m (resp., 25 m) buffer was computed from them. In some case studies, zonated buffers must be determined, for instance in assessments of traffic noise effects. Most GISs support this type of zonated buffer computation. An illustration is provided in Figure



In vector-based buffer generation, the buffers themselves become polygon features, usually in a separate data layer, that can be used in further spatial analysis.Buffer generation on rasters is a fairly simple function. The target location or locations are always represented by a selection of the raster's cells, and geometric distance is defined, using cell resolution as the unit. The distance function applied is the Pythagorean distance between the cell centres. The distance from a non-target cell to the target is the minimal distance one can find between that non-target cell and any target cell.

Thiessen polygon generation

Thiessen polygon partitions make use of geometric distance for determining neighbourhoods. This is useful if we have a spatially distributed set of points as target locations, and we want to know for each location in the study to which target it is closest. This technique will generate a polygon around each target location that identifies all those locations that 'belong to' that target. We have already seen the use of Thiessen polygons in the context of interpolation of point data, as discussed in Section . Given an input point set that will be the polygon's midpoints, it is not difficult to construct such a partition. It is even much easier to construct if we already have a Delaunay triangulation for the same input point set .



7.5.2 Computation of diffusion

The determination of neighbourhood of one or more target locations may depend not only on distance—cases which we discussed above—but also on direction and differences in the terrain in different directions. This typically is the case when the target location contains a 'source material' that spreads over time, referred to as diffusion. This 'source material' may be air, water or soil pollution, exiting a train station, people from an opened-up refugee camp, a water spring uphill, or the radio waves emitted from a radio relay station. In all these cases, one will not expect the spread to occur evenly in all directions. There will be local terrain factors that influence the spread, making it easier or more difficult. Many GISs provide support for this type of computation, and we discuss some of its principles here, in the context of raster data. Diffusion computation involves one or more target locations, which are better called source locations in this context. They are the locations of the source of whatever spreads.

The computation also involves a local resistance raster, which for each cell provides a value that indicates how difficult it is for the 'source - material' to pass by that cell. The value in the cell must be normalized: i.e. valid Resistance for a standardized length (usually the cell's width) of spread path.

From the source location(s) and the local resistance raster, the GIS will be able to compute a new raster that indicates how much minimal total resistance the spread has witnessed for reaching a raster cell. This process is illustrated in Figure. While computing total resistances, the GIS takes proper care of the path lengths. Obviously, the diffusion from a cell csrc to its neighbour cell to the east is shorter than to the cell that is its northeast neighbour. The distance ratio between these two cases is 1 : √ 2. If val(c) indicates the local resistance value

1	1	1	2	8
4	4	5	4	9
4	3	3	2	10
4	5	6	8	8
4	2	1	1	1

(a)

14.50	14.95	15.95	17.45	22.45
12.00	12.45	14.61	16.66	21.44
8.00	8.95	11.95	13.66	19.66
4.00	6.36	8.00	10.00	11.00
0.00	3.00	4.50	5.50	6.50

(b)

7.5.3 Flow computation

Flow computations determine how a phenomenon spreads over the area, in principle in all directions, though with varying difficulty or resistance. There are also cases where a phenomenon does not spread in all directions, but moves or 'flows' along a given, least-cost path, determined again by local terrain characteristics. The typical case arises when we want to determine the drainage patterns in a catchment: the rainfall water 'chooses' a way to leave the area. This principle is illustrated with a simple elevation raster, in Figure .For each cell in that raster, the steepest downward slope to a neighbour cell is computed, and its direction is stored in a new raster. This computation determines the elevation difference between the cell and a neighbour cell, and takes into account cell distance—1 for neighbour cells in N–S or W–E direction, √ 2 for cells in NE–SW or NW-SE direction.

Among its eight neighbour Determining flow direction cells, it picks the one with the steepest path to it. The directions in raster (b), thus obtained, are encoded in integer values, and we have 'decoded' them for the sake of illustration. Raster (b) can be called the flow direction raster. From raster (b), the GIS can compute the accumulated flow count raster, a raster that for each cell indicates how many cells have their water flow into the cell.

156	144	138	142	116	98
148	134	112	98	92	100
138	106	88	74	76	96
128	116	110	44	62	48
136	122	94	42	32	38
148	106	68	24	22	24

(a)

↘	↘	↘	↓	↓	↙
↘	↘	↘	↓	↓	↙
→	→	↘	↓	↙	↓
↗	↗	→	↘	↓	↙
↘	↘	→	↓	↓	↓
→	→	→	→	↓	←

(b)

0	0	0	0	0	0
0	1	1	2	2	0
0	3	7	5	4	0
0	0	0	20	0	1
0	0	0	1	24	0
0	2	4	7	35	1

(c)

7.5.4 Raster based surface analysis

Continuous fields have a number of characteristics not shared by discrete fields. Since the field changes continuously, we can talk about slope angle, slope aspect and concavity/convexity of the slope. These notions are not applicable to discrete fields.

The discussions in this section use terrain elevation as the prototypical example of a continuous field, but all issues discussed are equally applicable to other types of continuous fields. Nonetheless, we regularly refer to the continuous field representation as a DEM, to conform with the most common situation. Throughout the section we will assume that the DEM is represented as a raster

Applications There are numerous examples where more advanced computations on continuous field representations are needed. A short list is provided below.

- Slope angle calculation The calculation of the slope steepness, expressed as an angle in degrees or percentages, for any or all locations.
- Slope aspect calculation The calculation of the aspect (or orientation) of the slope in degrees (between 0 and 360 degrees), for any or all locations.
- Slope convexity/concavity calculation Slope convexity—defined as the change of the slope (negative when the slope is concave and positive when the slope is convex)—can be derived as the second derivative of the field.
- Slope length calculation With the use of neighbourhood operations, it is possible to calculate for each cell the nearest distance to a watershed boundary (the upslope length) and to the nearest stream (the downslope length). This information is useful for hydrological modelling.
- Hillshading is used to portray relief difference and terrain morphology in hilly and mountainous areas. The application of a special filter to a DEM produces hillshading. Filters are discussed on page 6.4.4. The colour tones in a hillshading raster represent the amount of reflected light in each location, depending on its orientation relative to the illumination source. This illumination source is usually chosen at an angle of 45◦ above the horizon in the north-west.
- Three-dimensional map display With GIS software, three-dimensional views of a DEM can be constructed, in which the location of the viewer, the angle under which s/he is looking, the zoom angle, and the amplification factor of relief exaggeration can be specified. Three-dimensional views can be constructed using only a predefined mesh, covering the surface, or using other rasters (e.g. a hillshading raster) or images (e.g. satellite images) which are draped over the DEM.
- Determination of change in elevation through time The cut-and-fill volume of soil to be removed or to be brought in to make a site ready for construction can be computed by overlaying the DEM of the site before the work begins with the DEM of the expected modified topography. It is also

possible to determine landslide effects by comparing DEMs of before and after the landslide event.

- Automatic catchment delineation Catchment boundaries or drainage lines can be automatically generated from a good quality DEM with the use of neighbourhood functions. The system will determine the lowest point in the DEM, which is considered the outlet of the catchment. From there, it will repeatedly search the neighbouring pixels with the highest altitude. This process is continued until the highest location (i.e. cell with highest value) is found, and the path followed determines the catchment boundary. For delineating the drainage network, the process is reversed. Now, the system will work from the watershed downwards, each time looking for the lowest neighbouring cells, which determines the direction of water flow.

- Dynamic modelling Apart from the applications mentioned above, DEM sare increasingly used in GIS-based dynamic modelling, such as the computation of surface run-off and erosion, groundwater flow, the delineation of areas affected by pollution, the computation of areas that will be covered by processes such as debris flows and lava flows.

- Visibility analysis A viewshed is the area that can be 'seen'—i.e. is in the direct line-of-sight—from a specified target location. Visibility analysis determines the area visible from a scenic lookout, the area that can be reached by a radar antenna, or assesses how effectively a road or quarry will be hidden from view.

7.6 SUMMARY

Spatial analysis allows you to solve complex location-oriented problems and better understand where and what is occurring in your world. It goes beyond mere mapping to let you study the characteristics of places and the relationships between them. Spatial analysis lends new perspectives to your decision-making.

Spatial analysis is the most intriguing and remarkable aspect of GIS. Using spatial analysis, you can combine information from many independent sources and derive new sets of information (results) by applying a sophisticated set of spatial operators. This comprehensive collection of spatial analysis tools extends your ability to answer complex spatial questions.

Statistical analysis can determine if the patterns that you see are significant. You can analyze various layers to calculate the suitability of a place for a particular activity. And by employing image analysis, you can detect change over time. These tools and many others, which are part of ArcGIS, enable you to address critically important questions and decisions that are beyond the scope of simple visual analysis. Here are some of the foundational spatial analyses and examples of how they are applied in the real

7.7 REFERENCES

1. www.esri.com

2. www.nationalgeographic.org

3. Principle of grographic Information system(Reference book)

7. 8 UNIT END QUESTIONS

1. What is overlay functions?

2. Explain neighbourhood functions?

3. Explain spatial queries?

4. Explain difference between raster and vector overlay

❖❖❖❖

8

GIS APPLICATION MODELS

Unit Structure :

8.0 OBJECTIVES

After going through this chapter ,you will be able to

1. Different application of GIS models

2. Analyzing of error and there propogation

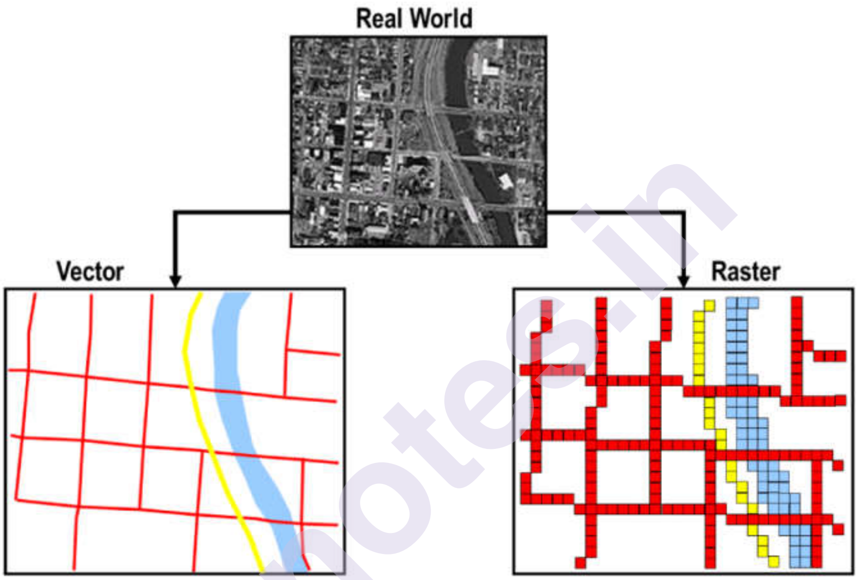
8.1 INTRODUCTION

Geographic Information Systems is a vast field in Information Technology and, like any other booming technology, also has various applications in multiple domains. GIS is used to create awareness and to share knowledge regarding the environment, natural resources, potential disasters and risks and planned urban routes. Organizations like ESRI, Here Maps, and Leidos group are working on various models concerning natural resources, advanced driving systems, and even defense systems of the nations. Applications of GIS allow people and organizations to do geological observations and analyze the spatial data in a granular format.

We have discussed the notion that real world processes are often highly complex. Models are simplified abstractions of reality representing or describing its most important elements and their interactions.

Modelling and GIS are more or less inseparable, as GIS is itself a tool for modelling 'the real world' (or al least some part of it). The solution to a (spatial) problem usually depends on a (large) number of parameters. Since these parameters are often interrelated, their interaction is made more precise in an application model.

8.2 APPLICATIONS



GIS Data Models

Representing the "real world" in a data model has been a challenge for GIS since their inception in the 1960s. A GIS data model enables a computer to represent real geographical elements as graphical elements. Two representational models are dominant; raster (grid-based) and vector (line-based):

- **Raster**. Based on a cellular organization that divides space into a series of units. Each unit is generally similar in size to another. Grid cells are the most common raster representation. Features are divided into cellular arrays and a coordinate (X,Y) is assigned to each cell, as well as a value. This allows for registration with a geographic reference system. A raster representation also relies on **tessellation**: geometric shapes that can completely cover an area. Although many shapes are possible (e.g. triangles and hexagons), the square is the most commonly used. Resolution is an important concern in raster representations. For a small grid, the resolution is coarse but the required storage space is limited. For a large grid the resolution is fine, but at the expense of a much larger storage space. On the above figure, the real world (shown as an aerial photograph) is simplified as a grid where the color of each cell relates to an entity such as road, highway or river.

- **Vector**. The concept assumes that space is continuous, rather than discrete, which gives an infinite (in theory) set of coordinates. A vector representation is composed of three main elements: points, lines and polygons. **Points** are spatial objects with no area but can have attached attributes since they are a single set of coordinates (X and Y) in a coordinate space. **Lines** are spatial objects made up of connected points (nodes) that have no width. **Polygons** are closed areas that can be made up of a circuit of line segments. On the above figure, the real world is represented by a series of lines (roads and highway) and one polygon (the river). A real-world entity could be represented by different types of vector features depending on the map scale used in an application (e.g. a road can be represented as a line at a smaller scale or as a polygon at a larger scale.)

Application models to include any kind of GIS based model (including so-called analytical and process models) for a specific real-world application. Such a model, in one way or other, describes as faithfully as possible how the relevant geographic phenomena behave, and it does so in terms of the parameters.

The nature of application models varies enormously. GIS applications for famine relief programs, for instance, are very different from earthquake risk assessment applications, though both can make use of GIS to derive a solution. Many kinds of application models exist, and they can be classified in many different ways.

Here we identify five characteristics of GIS-based application models:

1. The purpose of the model,

2. The methodology underlying the model,

3. The scale at which the model works,

4. Its dimensionality - i.e. whether the model includes spatial, temporal or spatial and temporal dimensions, and

5. Its implementation logic - i.e. the extent to which the model uses existing knowledge about the implementation context. It is important to note that the categories above are merely different characteristics of any given application model.

8.2.1 Purpose of the model

It refers to whether the model is descriptive, prescriptive or predictive in nature. Descriptive models attempt to answer the “what is” - question. Prescriptive models usually answer the “what should be” question by determining the best solution from a given set of conditions. models for planning and site selection are usually prescriptive, in that they quantify environmental, economic and social factors to determine ‘best’ or optimal locations. So-called Predictive models focus upon the “what is likely to be” questions, and predict outcomes based upon a set of input conditions. Examples of predictive models include forecasting models, such as those attempting to predict landslides or sea–level rise.

8.2.2 Methodology

It refers to the operational components of the model. Stochastic models use statistical or probability functions to represent random or semi-random behaviour of phenomena. In contrast, deterministic models are based upon a well-defined cause and effect relationship.

Examples of deterministic modelsinclude hydrological flow and pollution models, where the 'effect' can often be described by numerical methods and differential equations.

1.Rule-based models attempt to model processes by using local (spatial) rules. Cellular Automata (CA) are examples of models in this category. These are often used to understand systems which are generally not well understood, but for which their local processes are well known. For example, the characteristics of neighbourhood cells (such as wind direction and vegetation type) in a rasterbased CA model might be used to model the direction of spread of a fire over several time steps.

2.Agent-based models (ABM) attempt to model movement and development of multiple interacting agents (which might represent individuals), often using sets of decision-rules about what the agent can and cannot do. Complex agent-based models have been developed to understand aspects of travel behaviour and crowd interactions which also incorporate stochastic components.

8.2.3 Scale

It refers to whether the components of the model are individual or aggregate in nature. Essentially this refers to the 'level' at which the model operates. Individual-based models are based on individual entities, such as the agent-based models described above, whereas aggregate models deal with 'grouped' data, such as population census data. Aggregate models may operate on data at the level of a city block (for example, using population census data for particular social groups), at the regional, or even at a global scale.

8.2.4 Dimensions

It is the term chosen to refer to whether a model is static or dynamic, and spatial or aspatial. Some models are explicitly spatial, meaning theoperate in some geographically defined space. Some models are aspatial, meaning they have no direct spatial reference. Models can also be static, meaning they do not incorporate a notion of time or change. In dynamic models, time is an essential parameter .Dynamic models include various types of models referred to as process models or simulations. These types of models aim to generate future scenarios from existing scenarios, and might include deterministic or stochastic components, or some kind of local rule (for example, to drive a simulation of urban growth and spread). The fire spread example given above is a good example of an explicitly spatial, dynamic model which might incorporate both local rules and stochastic components.

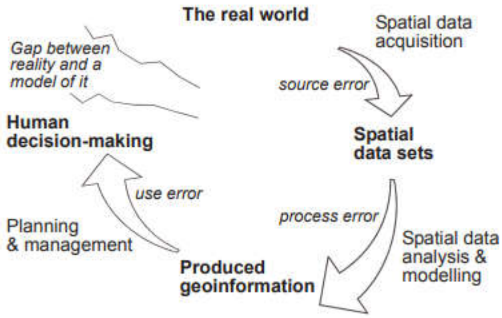
8.2.4 Implementation logic

It refers to how the model uses existing theory or knowledge to create new knowledge. Deductive approaches use knowledge of the overall situation in order to predict outcome conditions. This includes models that have some kind of formalized set of criteria, often with known weightings for the inputs, and existing algorithms are used to derive outcomes. Inductive approaches, on the other hand, are less straightforward, in that they try to gener- approaches alize (often based upon samples of a specific data set) in order to derive more general models. While an inductive approach is useful if we do not know the general conditions or rules which apply in a given domain, it is typically a trialand-error approach which requires empirical testing to determine the parameters of each input variable.

Most GIS only come equipped with a limited range of tools for modelling. For complex models, or functions which are not natively supported in our GIS, external software environments are frequently used. In some cases, GIS and models can be fully integrated (known as embedded coupling) or linked through data andinterface (known as tight coupling). If neither of these is possible, the external model might be run independently of our GIS, and the output exported from our model into the GIS for further analysis and visualization. This is known as loose coupling.It is important to compare our model results with previous experiments and to examine the possible causes of inconsistency between the output of our models and the expected results.

8.3 ERROR PROPAGATION IN SPATIAL DATA PROCESSING

number of sources of error that may be present in source data. It is important to note that the acquisition of base data to a high standard of quality still does not guarantee that the results of further, complex processing can be treated with certainty. As the number of processing steps increases, it becomes difficult to predict the behaviour of error propagation. These various errors may affect the outcome of spatial data manipulations. In addition, further errors may be introduced during the various processing steps discussed earlier in this chapter, as illustrated in Figure.



One of the most commonly applied operations in geographic information systems is analysis by overlaying two or more spatial data layers. As discussed above, each such layer will contain errors, due to both inherent inaccuracies in the source data and errors arising from some form of computer processing, for example, rasterization.

During the process of spatial overlay, all the errors in the individual data layers contribute to the final error of the output. The amount of error in the output depends on the type of overlay operation applied. For example, errors in the results of overlay using the logical operator AND are not the same as those created using the OR operator.

Table contains lists common sources of error introduced into GIS analyses. Note that these are from a wide range of sources, and include various common tasks relating to both data preparation and data analysis. It is the combination of different errors that are generated at each stage of preparation and analysis which may bring about various errors and uncertainties in the eventual outputs.

Consider another example. A land use planning agency is faced with the problem of identifying areas of agricultural land that are highly susceptible to erosion. Such areas occur on steep slopes in areas of high rainfall. The spatial data used in a GIS to obtain this information might include:

- A land use map produced five years previously from 1 : 25, 000 scale aerial photographs,
- A DEM produced by interpolating contours from a 1 : 50, 000 scale topographic map, and
- Annual rainfall statistics collected at two rainfall gauges.

8.4 SOME COMMON CAUSES OF ERROR PROPOGATION

Below are the list of some common causes of error in spatial data handling.

Coordinate adjustments	*Generalization*
rubber sheeting/transformations	linear alignment
projection changes	line simplification
datum conversions	addition/deletion of vertices
rescaling	linear displacement
Feature Editing	*Raster/Vector Conversions*
line snapping	raster cells to polygons
extension of lines to intersection	polygons to raster cells
reshaping	assignment of point attributes to raster cells
moving/copying	
elimination of spurious polygons	post-scanner line thinning
Attribute editing	*Data input and Management*
numeric calculation and change	digitizing
text value changes/substitution	scanning
re-definition of attributes	topological construction / spatial indexing
attribute value update	dissolving polygons with same attributes
Boolean Operations	*Surface modelling*
polygon on polygon	contour/lattice generation
polygon on line	TIN formation
polygon on point	Draping of data sets
line on line	Cross-section/profile generation
overlay and erase/update	Slope/aspect determination
Display and Analysis	*Display and Analysis*
cluster analysis	class intervals choice
calculation of surface lengths	areal interpolation
shortest route/path computation	perimeter/area size/volume computation
buffer creation	distance computation
display and query	spatial statistics
adjacency/contiguity	label/text placement

8.5 QUANTIFYING ERROR PROPAGATION

Chrisman noted that "the ultimate arbiter of cartographic error is the real world, not a mathematical formulation". It is an unavoidable fact that we will never be able to capture and represent everything that happens in the real world perfectly in a GIS. Hence there is much to recommend the use of testing procedures for accuracy assessment.

Various perspectives, motives and approaches to dealing with uncertainty have given rise to a wide range of conceptual models and indices for the description and measurement of error in spatial data. All these approaches have their origins in academic research and have strong theoretical bases in mathematics and statistics. Here we identify two main approaches for assessing the nature and amount of error propagation:

1. Testing the accuracy of each state by measurement against the real world, and
2. Modelling error propagation, either analytically or by means of simulation techniques.

Modelling of error propagation has been defined by Veregin as: "the application of formal mathematical models that describe the mechanisms whereby errors in source data layers are modified by particular data transformation operations." In other words, we would like to know how errors in the source data behave under manipulations that we subject them to in a GIS. If we are able to quantify the error in the source data as well as their behaviour under GIS manipulations, we have a means of judging the uncertainty of the results.

Error propagation models are very complex and valid only for certain data types (e.g. numerical attributes). Initially, they described only the propagation of attribute error .

More recent research has addressed the spatial aspects of error propagation and the development of models incorporating both attribute and locational components. These topics are outside the scope of this book, and readers are referred to for more detailed discussions. Rather than explicitly modelling error propagation, is often more practical to test the results of each step in the process against some independently measured reference data.

Looking at this robust system, its applications and uses are never-ending, just like its vast amount of geospatial data sets and databases. Day by day, analysts and researchers are innovating new applications of this technology. The count of the applications is never going to fall. Using GIS is not just limited to above 6 -7 applications, but it has around 1000+ uses and applications in various fields.

Archaeology, geology, Waste management, Natural Resources Management, Asset management and even Aviation and Banking. It seems that in the near future, GIS is going to get integrated with everything, and that's why companies like HERE Maps and GOOGLE are working on prototypic concepts like the Internet of Things, where everything will be interconnected.

8.6 SUMMARY

A GIS data model enables a computer to represent real geographical elements as graphical elements. Two representational models are dominant; raster (grid-based) and vector (line-based): Raster. Based on a cellular organization that divides space into a series of units.

Raster. Based on a cellular organization that divides space into a series of units. Each unit is generally similar in size to another. Grid cells are the most common raster representation. Features are divided into cellular arrays and a coordinate (X,Y) is assigned to each cell, as well as a value. This allows for registration with a geographic reference system. A raster representation also relies on tessellation: geometric shapes that can completely cover an area.

Vector. The concept assumes that space is continuous, rather than discrete, which gives an infinite (in theory) set of coordinates. A vector representation is composed of three main elements: points, lines and polygons. Points are spatial objects with no area but can have attached attributes since they are a single set of coordinates (X and Y) in a coordinate space. Lines are spatial objects made up of connected points (nodes) that have no width. Polygons are closed areas that can be made up of a circuit of line segments.

8.7 REFERENCES

1. www.esri.com

2. www.nationalgeographic.org

3. Principle of grographic Information system(Reference book)

8.6 UNIT END QUESTIONS

1. What are different GIS models?

2. What are different causes of error propogation?

3. HGow error propogates in spatial queries?

4. What is quantifying error propogation?

❖❖❖❖

9

DATA VISUALIZATION

Unit Strcture :

9.0 OBJECTIVES

After studying this chapter, the students will be able to,

- Understand the important of GIS map for spatial data.
- Describe the visualization process along with strategies.
- Summarize the cartographic toolbox.
- Infer the way to map quantitative data, qualitative data, terrain evaluation and time series data.
- Compare and contrast between map cosmetics and map dissemination.

9.1 INTRODUCTION

1. Visualization through maps is not only highly efficient way to transfer information to the audience but also it provides aesthetics to the information. It will make boring content to be eye catching.

2. So everyone nowadays use different maps to visualize information on data analysis reports, Geo based satellite image etc.

3. Doing visualization with map is easier to see the distribution or proportion of data in each region in order to mine deeper information and make better decisions about the data taken for understudy.

4. There are many types in map visualization such as administrative maps, heatmaps, statistical maps, trajectory maps, bubble maps etc.

5. Types of Maps are as follows

5.1 Point Map - Point maps are straightforward, especially for displaying data with a wide distribution of geographic information. For example some companies have a wide range of business located in different parts of country, it will be more complicated to implement with general maps, and with less accuracy, so for such type of problems, point map are suitable for precise and fast positioning. It can also be useful to track accident in certain geographic areas.

Fig 1 Point maps which shows dark blue circle representing company sales in different regions

5.2 Line Map - The line map sometimes contains not only space but also time required for the application where analysis of important scene is important. For eg Route distribution of riding or driving, bus or subway line distribution.

Fig 2 Line map which shows the taxi route of new York city

5.3 Regional Map -This map is also called a filling map. It can be displayed by country, province, city, district or even some customized maps. This map uses different shades of color on the map to show data of different sizes.

For eg To show the sales in different regions by drilling down the features of that region.

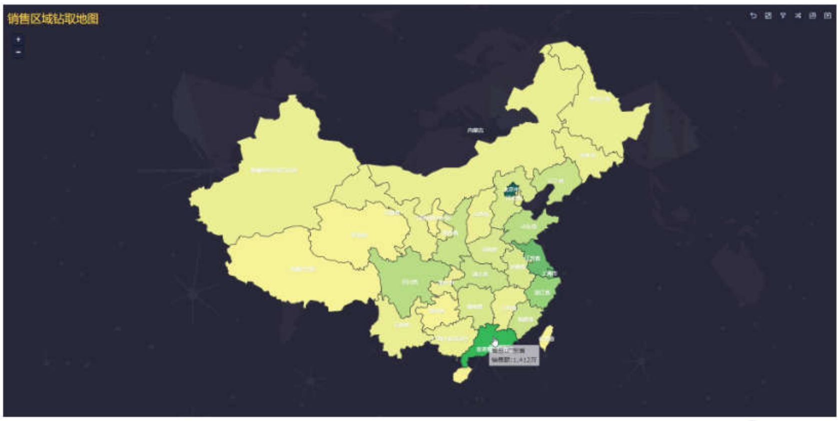


Fig 3 - Regional Map which shows the sales of each city in different shades of color, with larger the sales are, the darker the color is

5.4 Flow Map - In this type of map the interaction data between the origin and the destination is usually expressed by a line that connects the geometric center of gravity of the space unit. The flow direction value between the origin and the destination is determined by the width or the color of the line. This type of map is used in traffic flow analysis, population migration, shopping consumption behavior, communication information flow, aviation routes etc.

Fig 4 - Flow Map which shows the inter-regional trade between countries with the help of width and color line.

5.5 Time Space distribution Map - Such maps visualize the trajectory distribution with both temporal and spatial information. They can record time and spatial distribution of each point. This type of map is used in GPS geographic tracking etc.

5.6 Data Space Distribution Map - We Use a concrete example to explain this map. The picture below is a spatial distribution map of passenger flow in rail transit. Different colors identify different lines and the thickness of the line indicates the traffic volume of different stations. The thicker the line is, the larger the traffic is . It can also indicate the direction of the track line.

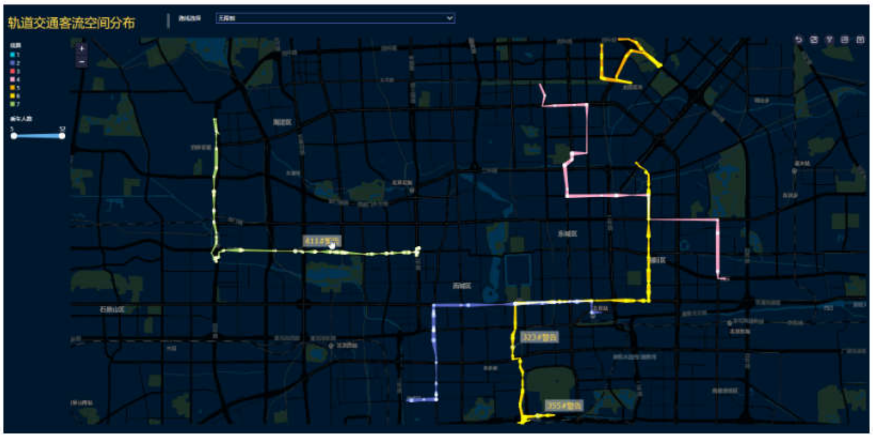


Fig 5 Data Space distribution map which shows the distribution of passenger flow in a certain period of time, so as to rationally arrange operations (such as the number of employees etc).

5.7 Other types of maps also exist such as heat map, heat point map, custom map, three dimensional rectangular map.

9.2 GIS AND MAPS

1. There is a strong relationship between maps and GIS. More specifically, maps can be used as input for a GIS.
2. As soon as a question contains a "Where?' question a map can often be the most suitable tool to solve the question and provide the answer. "Where do I find enschede?" and "where did ITC's students come from?" are both examples.
3. A map would put these answers in a spatial context. It could show where in the Netherlands Enschede is to be found and where it is located with respect to schirpol-amsterdam airport, where most students arrive. As shown in figure no 6

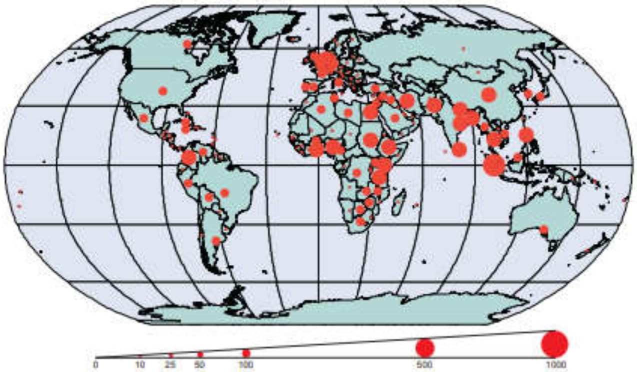


Fig no 6 This map reveals that most students arrive from Africa and Asia and only a few come from the Americas, Australia, and Europe.

4. As soon as the location of geographic objects("Where?") is involved, a map becomes useful. However, maps can do more than just providing information on location. They can also inform about the thematic attributes of the geographic objects located in the map. An example would be "what is the predominant land use in southeast Twentie?".

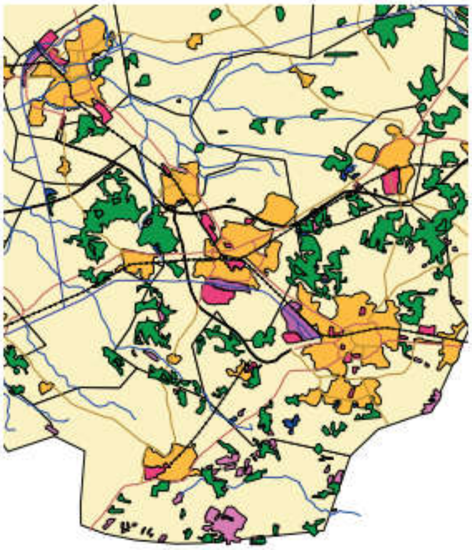


Fig 7 This map reveals a dominant northwest-southeast urban buffer about land use in southeast twente?

5. A third type of question that can be answered from maps is related to "when?" for instance, "When did the Netherlands have its longest coastline?". The answer might be "1600", and this will probably be satisfactory to most people. As shown in figure below

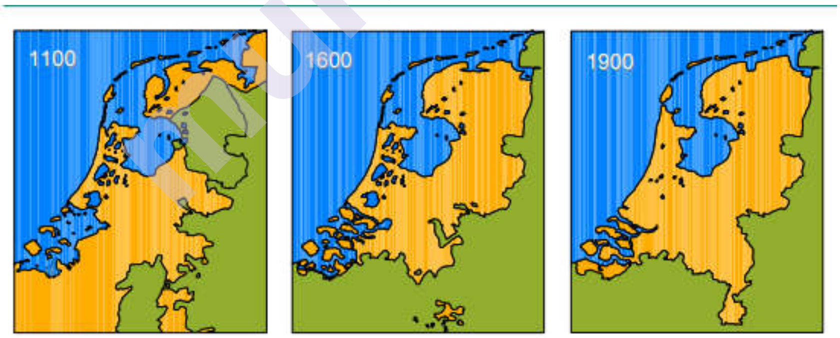


Fig 8 This map depicts about the coastline covered by netherlands

6. Maps can deal with questions/answers related to the basic components of spatial or geographic data: location(geometry), characteristics (thematic attributes) and time and their combination.

7. As such, maps are the most efficient and effective means to transfer spatial information. The map user can locate geographic objects, while the shape and colour of signs and symbols representing the objects inform about their characteristics. Onscreen maps are often interactive and have a link to a database and as such allow for more complex queries.

8. Below figure shows an aerial photograph of the ITC building and a map of the same area. The photographs show all visible objects, including parked cars, and small temporary buildings.

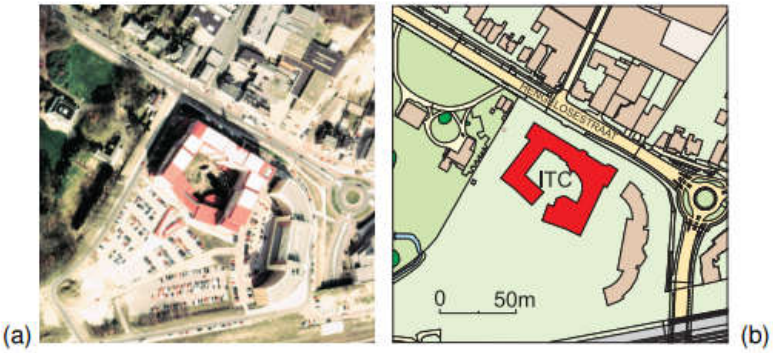


Fig 9 Comparing aerial photograph in photo a and b

9. The map scale is the ratio between a distance on the map and the corresponding distance in reality. Maps that show much detail of a small area called large-scale maps. Broad definition of map is – " A representation or abstraction of geographic reality. A tool for presenting geographic information in a way that is visual, digital or tactile.

10. Traditionally maps are divided in to topographic maps and thematic maps. A topographic map visualizes, limited by its scale, the earth's surface are accurately as possible. This may include infrastructure (eg railroads and roads), land use (eg vegetation and built-up area), relief, hydrology, geographic names and a reference grid.

Fig 10 A topographic map of the province of overijssel. Geographic names and a reference grid have been omitted for reasons of clarity.

11. Thematic maps represent the distribution of particular themes. One can distinguish between socio-economic themes and physical themes. The map in below figure a) shows population density in overjissel, is an example of the first and the map in figure b) displaying the province's drainage areas, is an example of the second.

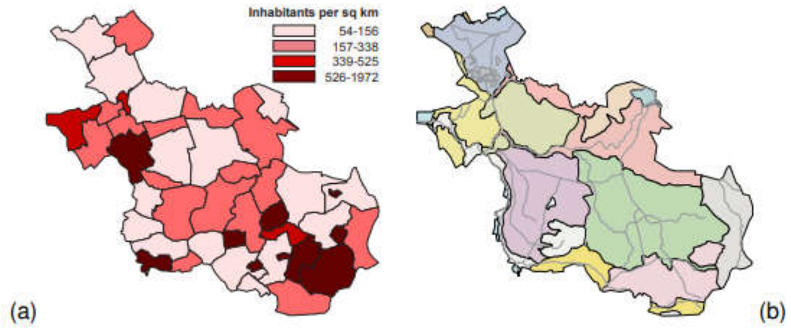


Fig 11 a) Socio-economic thematic map, showing population density of the province density of the province of overijissel (higher densities in darker tints), b) physical thematic map showing watershed areas of overijissel.

9.3 THE VISUALIZATION PROCESS

1. The cartographic visualization process is considered to be the translation or conversion of spatial data from a database in to graphics.

2. During the visualization process, cartographic methods and techniques are applied. These can be considered to form a kind of grammar that allows for the optimal design and production for the use of maps, depending on the application. The process is described in figure below

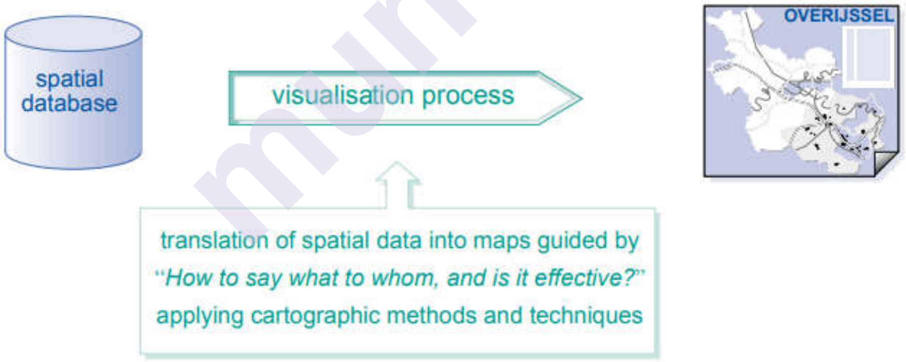


Fig 12 The cartographic visualization process

3. The producer of these visual products may be a professional cartographer, but may also be a discipline expert, for instance mapping vegetation stands using remote sensing images or health statistics in the slums of a city.

4. The visualization process can vary greatly depending on where in the spatial data handling process it takes place and the purpose for which it is needed. The process can be simple or complex while the production time can be short or long.

5. Some examples includes such as creation of full traditional topographic map sheet, a newspaper map, a sketch map, a map from an electronic atlas, an animation showing the growth of a city, a three dimensional view of a building or a mountain or even a real-time map display of traffic conditions.

6. Visualization can also be used for checking the consistency of the acquisition process or even the database structure. The environment in which the visualization process is executed can vary considerably. It can be done on a stand alone personal computer, a network computer connected to network or the WWW/ internet.

7. The visualization process is guided by the question "how do I say what to whom?" "how" refers to cartographic methods and the techniques. "I" refers to the cartographer or map maker, "say" deals with communicating in graphics the semantics of the spatial data. "what" refers to the spatial data and its characteristics. "Whom" refers to the map audience and the purpose of the map- for instance a map for scientists requires a different approach than a map on the same topic aimed at children.

8. In the past, the cartographer was often solely responsible for the whole map compilation process. During this process, incomplete and uncertain data often still resulted in an authoritative map.

9. The visualization process should also be tested on its effectiveness. To the proposition "how do is say what to whom" we have to add and its effective? Based on feedback from map users or knowledge about the effectiveness of cartographic solutions, it is to be decide whether improvements are needed and derive recommendations for future application of these solutions.

10. The visualization process is always influenced by several factors. Some of these questions can be answered by just looking at the content of the spatial database:

    10.1 What will be the scale of the map: large, small other?. This introduces the problem of generalization. Generalization addresses the meaningful reduction of the map content during scale reduction.

    10.2 Are we dealing with topographic or thematic data? These two categories traditionally resulted in different design approaches.

    10.3 Whether the data to be represented are of a quantitative of qualitative nature.

11. One should understand that the impact of these factors may increase, since the compilation of maps by spatial data handling is often the result of combining different data sets of different quality and from different data sources, collected at different scales and stored in different map projections.

9.4 VISUALIZATION STRATEGIES : PRESENT OR EXPLORE?

1. The main function of maps is to communicate geographic information, i.e to inform the map user about location and nature of geographic phenomena and spatial patterns. Well trained cartographers are designing and producing maps with a well designed cartographic tools.

2. The widespread use of GIS has increased the number of maps tremendously. Even the spreadsheet software used commonly in office today has mapping capabilities, but many of these maps are not produced as final products, rather act as intermediaries to support the user in her/his work dealing with spatial data.

3. The map has started to play a completely new role: it is not only a communication tool, but also has become an aid in the user's (visual) thinking process.

4. This thinking process is accelerated by the continued developments in hard and software. Media like DVD-ROMS and the WWW allow dynamic presentation and also user interaction.

5. Users now expect immediate and real time access to the data, data that have become abundant in many sectors of the geoinformation world, due to lack of tools for processing user-friendly queries and retrieval when studying the massive amount of data produced by sensors, which is now available through the use of internet.

6. A new branch of science is currently evolving to deal with this problem of abundance in the base of geo-disciplines known as visual data mining.

7. Specific software toolboxes have been developed and their functionality is based on two key words as interaction and dynamics. A separate discipline called scientific visualization has developed around it and has also had an important impact on cartography. It offers the user the possibility of instantaneously changing the appearance of a map.

8. Interaction with the map will stimulate the user's thinking and will add a new function to the map. As well as communication, it will prompt thinking and decision making.

9. Developments in scientific visualization stimulated DiBiase to define a model for map-based scientific visualization also known as geovisualization. It covers both the presentation and exploration functions of the map. Where as presentation refers to representing public communication through maps and exploration refers to representing private maps through maps with unknown data.

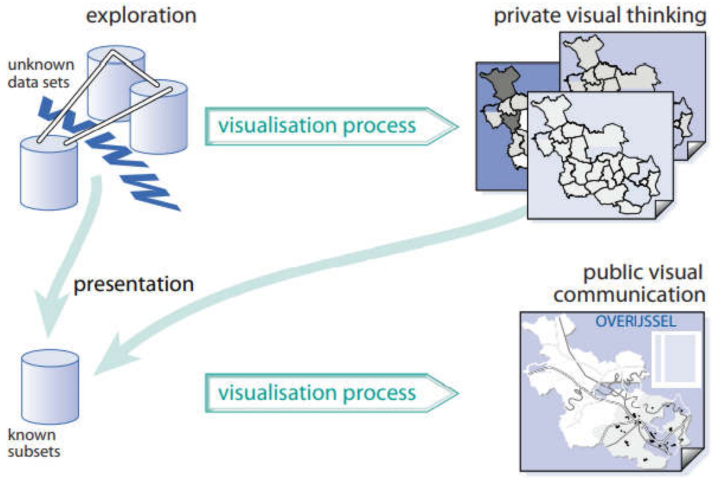


Fig 13 Private visual thinking and public visual communication.

10. The democratization of cartography by Morrison explains that "using electronic technology, no longer does the map user depend on what the cartographer decides to put on a map. Today the user is the cartographer, user are now able to produce analyses and visualizations at will to any accuracy standard that satisfies them.

11. Exploration means to search for spatial, temporal or spatio-temporal patterns, relationships between patterns or trends. A search for relationships between patterns could include: changes in vegetation indices and climatic parameters, location of deprived urban areas and their distance to educational facilities. A search for trends could, for example focus on the development in distribution and frequency of landslides.

12. Maps not only enable these types of searches, finding may also trigger new questions and lead to new visual exploration acts.

13. cartographic knowledge is incorporated in the program resulting in pre-designed maps. To create a map, one selects relevant geographic data and converts these in to meaningful symbols for the map. Paper maps had a dual function acted as a database of the objects selected from reality and communicated information about these geographic objects.

14. The sentence "How do I say what to whom and its effective?" guides the cartographic visualization process and summarizes the cartographic communication principle.

15. In 1967, the French cartographer bertin developed the basic concepts of the theory of map design with his publication semiology graphique. He provided guidelines for making good maps. If ten professional cartographers were given the same mapping task, and each would apply bertin's rule this would result in ten different maps with good quality.

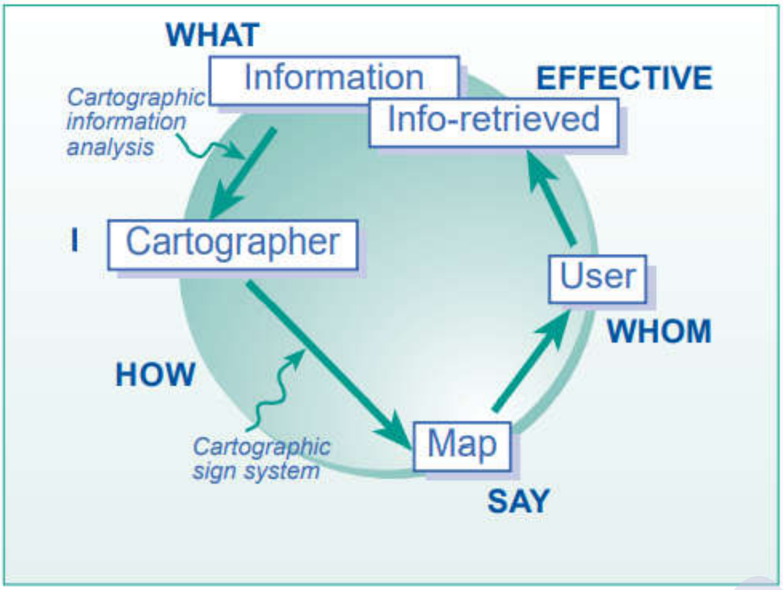


Fig 14 The cartographic communication process, based on "How do I say what to whom and is it effective?

16. From the above figure it is clear that the boxes with information and information retrieved do not overlap, which means the information derived by the map user is not the same as the information that the cartographic communication process started with. There may be several causes, possibly the original information was not used of additional information has been added during the process. Another reason that the map user did not fully understand the map, due to the cartographer who added extra information to strengthen the already available information. It is also possible that the map user has some prior knowledge on the topic or area, which allows them to combine this prior knowledge retrieved from the map.

9.5 THE CARTOGRAPHIC TOOLBOX

9.5.1 What kind of data do I have ?

1. To derive the proper symbology for a map one has to execute a cartographic data analysis. The core of this analysis process is to access the characteristics of the data to find out how they can be visualized, so that the map user properly interprets them. For example, if all the data are related to land use, collected in 2005, the title could be Landuse of 2005. Secondly the individual components such as landuse and probably relief should be analysed and their nature described. Later these components should be visible in the map legend.

2. Data will be of a qualitative or quantitative nature. Qualitative data is also called nominal or categorical data. This data exists as discrete, named values without a natural order amongst the values. Examples are the different languages (eg English, Swahili, Dutuch), the different soil types

(eg sand, clay,peat) or the different lanf use categories(eg arable land, pasture).

3. Quantitative data can be measured, either along an interval or ratio scale. For data measured on an interval scale, the exact distance between values is known but there is no absolute zero on the scale.

4. Temperature is an example : 40 degree Celsius is not twice as warm as 20 degree Celsius and 0 degree Celsius is not an absolute zero.

5. Quantitative data with a ratio scale does have a known absolute zero. An example is income: someone earning \$100 earns twice as much as someone with an income of \$50. In order to generate maps, quantitative data are often classified in to categories according to some mathematical method.

6. In between qualitative and quantitative data, one can distinguish ordinal data. These data are measured along a relative scale, based on hierarchies. For example one knows that one value is 'more' than another value such as warm versus cool. Another example is a hierarchy of road types: 'highway', 'main', 'road' and 'track'.

7. The different types of data are summarized as follow

Sr.No	Measurement Scale	Nature of Data
1	Nominal, Categorical	Data of different nature/ identity of things (Qualitative)
2	Ordinal	Data with a clear element of order, though not quantitatively determined (ordered)
3	Interval	Quantitative information with arbitrary zero
4	Ratio	Quantitative data with absolute zero

Table 1 Differences in the nature of data and their measurement scales

9.5.2 HOW TO MAP

1. Basic elements of a map, irrespective of the medium on which it is displayed are point symbols, line symbols , area symbols and text. The appearance of point, line and area symbols can vary depending on their nature.

2. Points can vary in form or colour to represent the location of shops or they can vary in size to represent aggregated values for an administrative areas.

3. Lines can vary in colour to distinguish between administrative boundaries and rivers or vary in shape to show the difference between railroads and roads. Areas follow the same principles: difference in colour distinguishes between different vegetation stands.

4. Although the variations in symbol appearance are only limited by the imagination they can be grouped together in a few categories. Bertin distinguished six categories which he called the visual variables and which may be applied to point, line and area symbols. As illustrated in given figure below they are Size, value(lightness), texture, colour, orientation and shape.

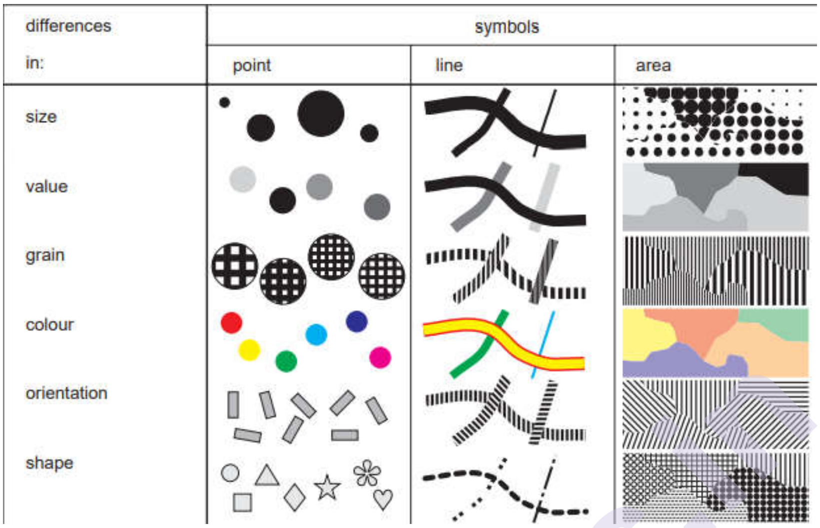


Fig 15 Bertin's Six visual variables

5. These visual variables can be used to make one symbol different from another. In doing this, map makers in principle have free choice, provided they do not violate the rules of cartographic grammar.

6. The symbol should be located where features belong. Visual variables influence the map user's perception in different ways. What is perceived depends on the human capacity to see or perceive.

   6.1 What is of equal importance (eg all red symbols represent danger)

   6.2 order (eg the population density varies from low to high- represented by light and dark colour tints, respectively).

   6.3 An instant overview of the mapped theme.

7. There is an obvious relationship between the nature of the data to be mapped and the 'perception properties' of visual variables. Dimensions of the plane is added to the list of visual variables, it is the basis used for the proper location of symbols on the plane (map).

perception properties	visual variables	measurement scales			
		nominal	ordinal	interval	ratio
	dimensions of the plane	x	x	x	x
order & quantities	size		x	x	x
order	(grey) value		x	x	
	grain/texture		x	x	
equal importance	colour hue	x			
	orientation	x			
	shape	x			

Table 2 Measurement scales linked to visual variables based on perception properties.

9.6 HOW TO MAP

1. This part deal with characteristics mapping problems. We first describe a problem and briefly discuss a solution based on cartographic rules and guidelines. The need to follow these rules and guidelines is illustrated by some maps that have been wrongly designed but are nevertheless commonly found.

9.6.1 How to map qualitative data

1. If, after a long fieldwork period, one has finally delineated the boundaries of a province's watersheds, one likely is interested in a map showing these areas. The geographic units in the map will have to represent the individual watersheds.

2. In such a map, each of the watersheds should get equal attention and none should stand out above the others.

3. The application of colour would be the best solution since it has characteristics that allow one of quickly differentiate between geographic units. However, since none of the watersheds is more important than the others, the colours used have to be of equal visual weight or brightness.

Fig 16 A good example of mapping qualitative data

4. The readability is influenced by the number of displayed geographic units. In the above example it is 15, but when it goes more than this number the scale displayed here will become too cluttered.

5. The map can also be made by filling the watershed areas by different forms(like small circles, squares, triangles) etc in one colour as an application of the visual variable shape.

6. In the figure 17 shows several tints of black as an application of the visual variable value. Looking at the map may cause perceptual confusion since the map image suggests differences in importance that are there in reality.

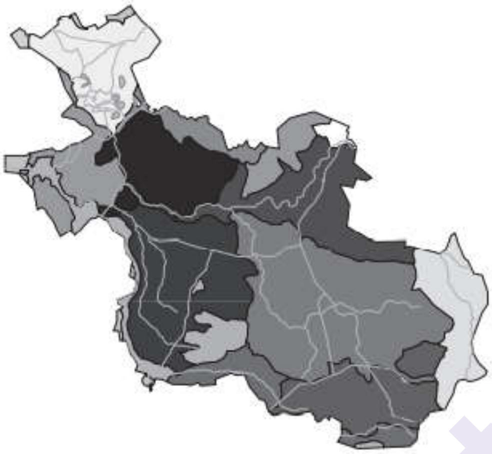


Fig 17 Misuse of tints of black

7. In the figure 18 different colours are used instead of black colour but watersheds are represented in pastel tints, one of them stands out by its bright colour. This gives the map an unbalanced look. The viewer's eye will be distracted by the bright colours, resulting in an unjustified weaker attention for other areas.

Fig 18 Misuse of bright colours

9.6.2 How to map quantitative data

1. One deals with absolute quantitative data, when after executing a census one would for example like to create a map with absolute quantitative data. The geographic units will logically be the municipalities. The final map should allow the user to determine the amount per municipality and also offer an overview of the geographic distribution of the phenomenon. Figure below shows the final map for the province of overjissel.

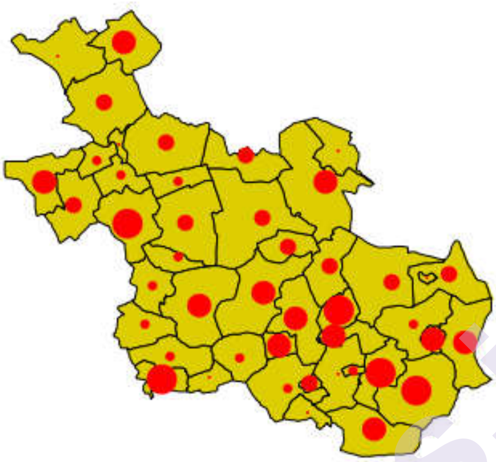


Fig 19 Mapping absolute quantitative data

2. Imagine a small and a large unit having the same number of inhabitants. The large unit would visually attract more attention, giving the impression there are more people than in the small unit.

3. Another issue is that the population is not necessarily homogeneously distributed within the geographic units. Colour has also been misused as shown in figure below.

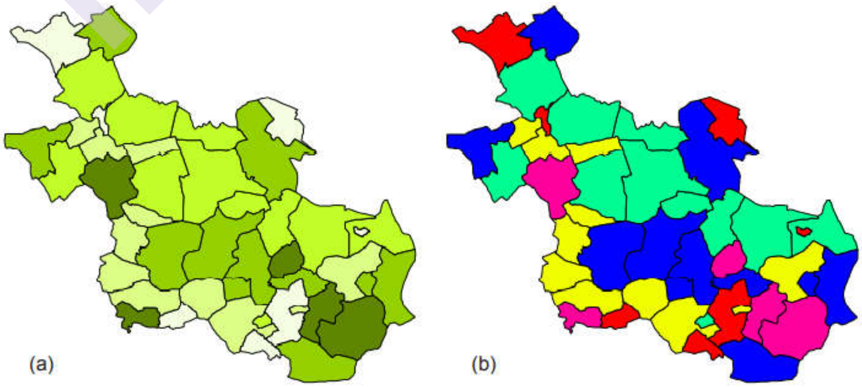


Fig 20 a) Poorly designed maps displaying absolute quantitative data: wrong use of green tints for absolute population b) incorrect use of colour.

4. On the basis of absolute population numbers per municipality and their geographic size, we can also generate a map that shows population density per municipality. We then deal with relative quantitative data.

5. The aim of the map is to give an overview of the distribution of the population density from low(light tints) to high (dark tints). The map reader automatically and in glance associate the dark colours with high density and the light values with low density as shown in figure below

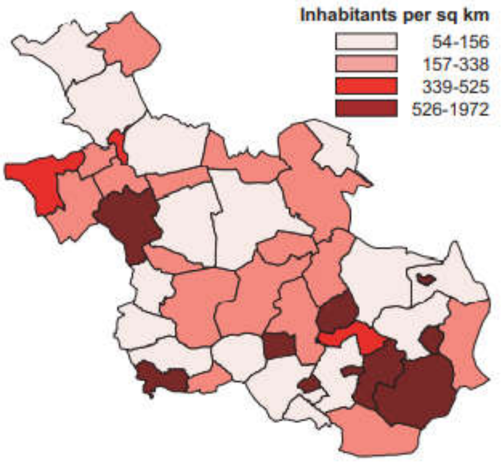


Fig 21 Mapping relative quantitative data

6. If one studies the badly designed maps carefully, the information can be derived, in one way or another, but it would take quite some effort. Proper application of cartographic guidelines will guarantee that this will go much more smoothly (eg faster and with less chance of misunderstanding).

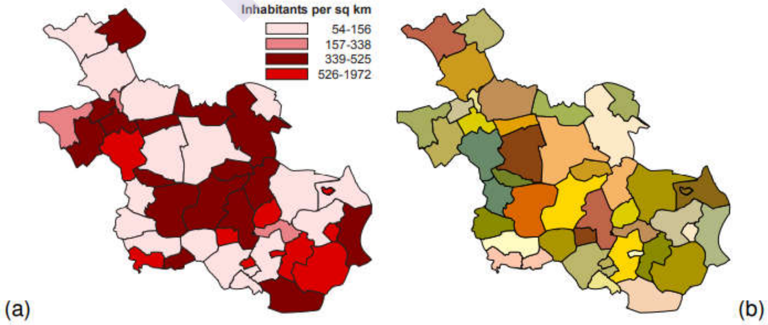


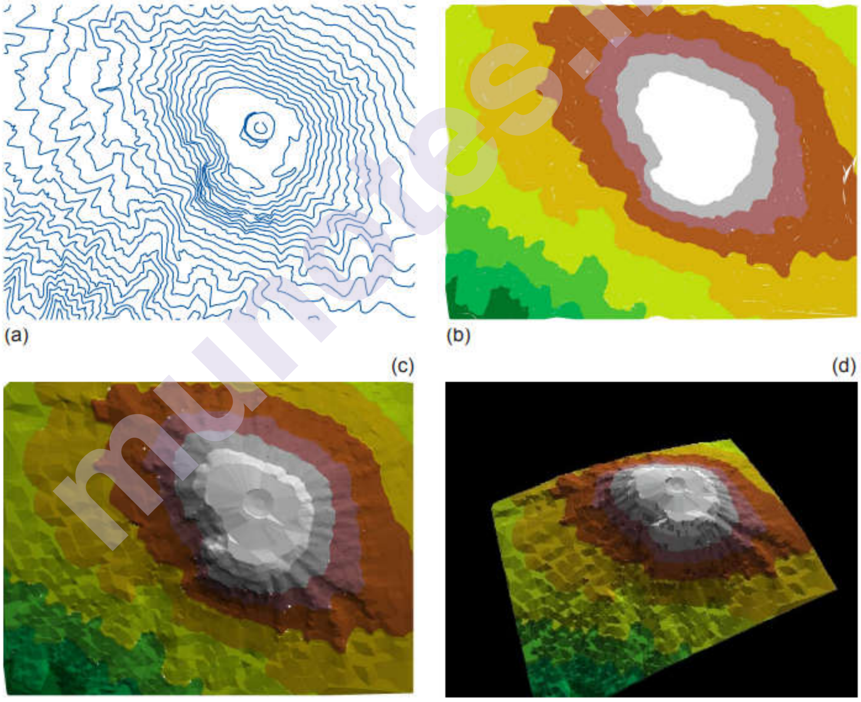
Fig 22 a) Badly designed maps representing relative quantitative data-lightness values used out of sequence b) Colour should not be used

9.6.3 How to map the terrain elevation

1. Terrain elevation can be mapped using different methods. Often one will have collected an elevation data set for individual points like peaks or other characteristic points in the terrain.

2. A contour map in which the lines connect points of equal elevation is generally used. To visually improve the information content of such a map the space between the contour lines can be filled with colour and value information following a convention eg green for low elevation and brown for high elevation areas. This technique is known as hypsometric or layer tinting.

3. The shaded relief map uses the full three dimensional information to create shading effects. This map represented on a two-dimensional surface can also be floated in three-dimensional space to give it a real three-dimensional appearance of a ‘virtual world’ as shown in figure below



a

Fig 23 a) Visualization of terrain elevation – Contour map b) Map with layer tints d) 3D view of the terrain

4. Interactive functions are required to manipulate the map in three-dimensional space in order to look behind some objects. These manipulations include pan-ning, zooming, rotating and scaling. Scaling is needed, particularly along the Z-axis since some maps require small-scale elevation resolution while others require large-scale resolution i.e vetical exaggeration.

5. of course one can also visualize objects below the surface in a similar way but this is more difficult because the data to describe underground objects are sparsely available.

9.6.4 How to map time series

1. Advances in spatial data handling have not only made the third dimension part of GIS routines. Nowadays, the handling of time-dependent data is also part of these routines. This has been caused by the increasing availability of data captured at different periods in time.

2. Mapping time means mapping change. This may be change in a feature's geometry, in its attributes or both. Examples of changing geometry are the evolving coastline of the Netherlands, the location of europe's national boundaries or the position of weather fonts.

3. The urban boundaries expand and simultaneously the land use shifts from rural to urban. If maps are to represent events like these, they should be suggestive of such change.

4. This implies the use of symbols that are perceived as representing change. Eg of such symbols are arrows that have an origin and a destination. They are used to show movement and their size can be an indication of the magnitude of change.

5. Specific point symbols such as crossed swords (battle) or lightning (riots) can be found to represent dynamics in historic maps. Another alternative is the use of the visual variable value.

6. In a map showing the development of a town, dark tints represent old built-up areas, while new built-up areas are represented by light tints. It is possible to distinguish between three temporal cartographic techniques

7 Types of Map

7.1 Single static map : Specific graphic variables and symbols are used to indicate change or represent an event.

7.2 Series of static maps : A single map in the series represents a 'snapshot' in time. Together, the maps depict a process of change. Change is perceived by the succession of individual maps depicting the situation in successive snapshots. It could be said that the temporal sequence is represented by a spatial sequence, which the user has to follow, to perceive the temporal variation. The number of images should be limited since it is difficult for the human eye to follow long series of maps.

7.3 Animated map : Change is perceived to happen in a single image by displaying several snapshots after each other just like a video cut with successive frames. The difference with the series of maps is that the variation can be deduced from real 'change' in the image itself, not from a spatial sequence

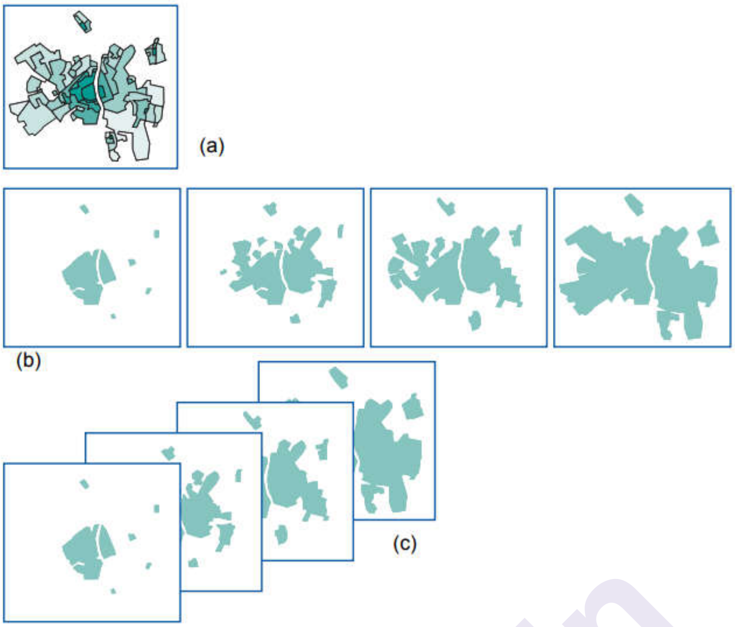


Fig 24 Mapping change, example of the urban growth of the city of Maastricht, the Netherlands a) Single map, in which tints represent age of the built-up area b) series of maps c) An animation.

9.7 MAP COSMETICS

1. Each map should have, next to the map image, a title, informing the user about the topic visualized. A legend is necessary to understand how the topic is depicted.

2. Additional marginal information to be found on a map is a scale indicator, a north arrow for orientation, the map datum and map projection used and some lineage information(such as data sources, dates of data collection, methods used etc).

3. Further information can be added that indicates when the map was issued and by whom (author/ publisher). All this information allows the user to obtain an impression of the quality of the map and is comparable with metadata describing the contents of a database or data layer.

4. On paper maps, these elements have to appear next to the map and is comparable with metadata describing the contents of a database or data layer.

5. Maps presented on screen often go without marginal information, partly because of space constraints. How-ever on-screen maps are often interactive and clicking on a map element may reveal additional information from the database. Legends and titles are often available on demand as well.

6. Text is used to transfer information in addition to the symbols used. This can be done by the application of the visual variables to the text as well.

7. Common example is the use of colour to differentiate between hydrographic names(in blue) and other names(in black). The text should also be placed in a proper position with respect to the object to which it refers.

8. The design aspect of creating appealing maps also has to be included in the visualization process. 'Appealing' does not only mean having nice colours. One of the keywords here is 'contrast'.

9. Contrast will increase the communicative role of the map since it creates a hierarchy in the map contents, assuming that not all information has equal importance. This design trick is known as visual hierarchy or the figure-ground concept. The need for visual hierarchy in map is best understood when looking at the map as shown in figure below.

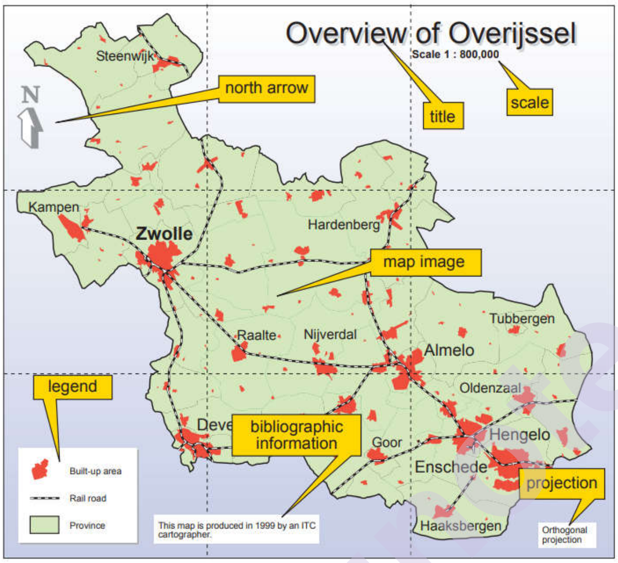


Fig 24 The paper map and its(marginal) information.

Fig 25 visual hierarchy and the location of the ITC building a)hierarchy not applied b) hierarchy applied

9.8 MAP DISSEMINATION

1. The map design will not only be influenced by the nature of the data to be mapped or the intended audience (the 'what' and 'whom' from "how do I say what to whom and its effective"), the output medium also plays a role. Traditionally, maps were produced on paper and many still are.

2. Compared to maps on paper, on-screen maps have to be smaller and therefore their contents should be carefully selected. This might seem a disadvantage, but presenting maps on-screen offers very interesting alternatives.

3. A mouse click could also open the link to a database and reveal much more information than a paper map could ever offer. Links to other than tabular or map data could also be made available.

4. Maps and multimedia(photography, sound, video, animation) can be integrated. Some of today's electronic atlases such as the Encarta world atlas are good examples of how multimedia elements can be integrated with the map.

5. Pointing to a country on a world map starts the national anthem of the country or shows its flag. It can be used to explore a country's language, moving the mouse would start a short sentence in the region's dialects.

6. The WWW is nowadays a common medium used to present and disseminate spatial data. Here maps can play their traditional role, for instance to show the location of objects or provide insight in to spatial patterns, but because of the nature of the internet, the map can also function as an interface to additional information.

7. Maps can also be used as 'previews' of spatial data products to be acquired through a spatial data clearing house that is part of a spatial data infrastructure. For that purpose we can make use of geo-webservices which can provide interactive map views as intermediate between data and web browser.

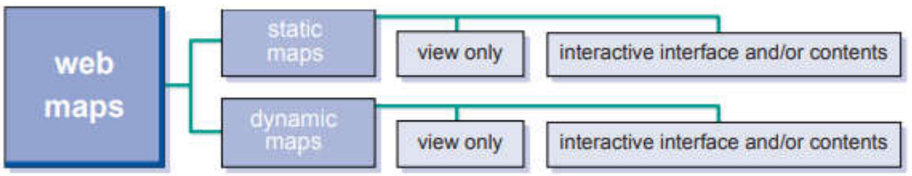


Fig 26 classification of maps on the WWW.

8. An important distinction is the one between static and dynamic maps. Many static maps on the web are view-only. Organizations such as map libraries or tourist information providers often make their maps available in this way.

9. An important distinction is the one between static and dynamic maps. Many static maps on the web are view-only. Organizations such as map

libraries or tourist information providers often make their maps available in this way. Static, view-only maps can also serve to give web surfers a preview of the products that are available from organizations such as national mapping agencies.

10. When static maps offers more than view-only functionality, they may present an interactive view to the user by offering zooming, panning or hyperlinking to other information. Clicking on geographic objects may lead the user to quantitative data, photographs, sound or video or other information sources on the web.

11. Dynamic maps are about change; change in one or more of the spatial data components. On the WWW, several options to play animations are available. The so-called animated GIF can be seen as a view-only version of a dynamic map. A sequence of bitmaps, each representing a frame of an animation, are positioned one after another and the WWW browser will continuously repeat the animation. This can be used for example to show the change of weather over the last day.

12. More interactive versions of this type of map are those to be played by media players for instance those in quick time format or as a flash movie. Plug-ins to the web browser define the interaction options which are often limited to simple pause, backward and forward play.

13. The WWW also allows for the fully interactive presentation of 3D models. The virtual reality markup language (VRML). For instance can be used for this purpose. It stores a true 3D model of the objects not just a series of 3D views.

9.9 SUMMARY

In this chapter we studied about

1. Maps are the most efficient and effective means to inform us about spatial information. They locate geographic objects, while the shape and colour of signs and symbols representing the objects, inform about their characteristics.

2. Maps are the result of the visualization process. Their design is guided by "how do I say what to whom and is it effective?". Executing the sentence will inform the map maker about the characteristics of the data to be mapped as well the purpose of the map.

3. Map design will not only depend on the nature of the data to be mapped or the intended audience but also on the output medium.

9.10 REFERENCES

[1] Principles of Geographic Information Systems, An introductory textbook by Otto Huisman and Rolf A. de published by The International Institute for Geo-Information Science and Earth observation (ITC).

9.11 QUESTIONS

1. Suppose one has two maps, one at scale 1:10,000 and another at scale 1:1,000,000. Which of the two maps can be called a large-scale map and which is a small scale map?
2. Describe the difference between a topographic map and a thematic map.
3. Describe in one sentence or in one question, the main problem of the cartographic visualization process.
4. Which four main types of thematic data can be distinguished on the basis of their measurement scales?
5. Which are the six visual variables that allow to distinguish cartographic symbols from each other?
6. Describe a number of ways in which a three-dimensional terrain can be represented on a flat map display.
7. Describe different techniques of cartographic output from the user's perspective.
8. Explain the difference between static maps and dynamic maps.

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