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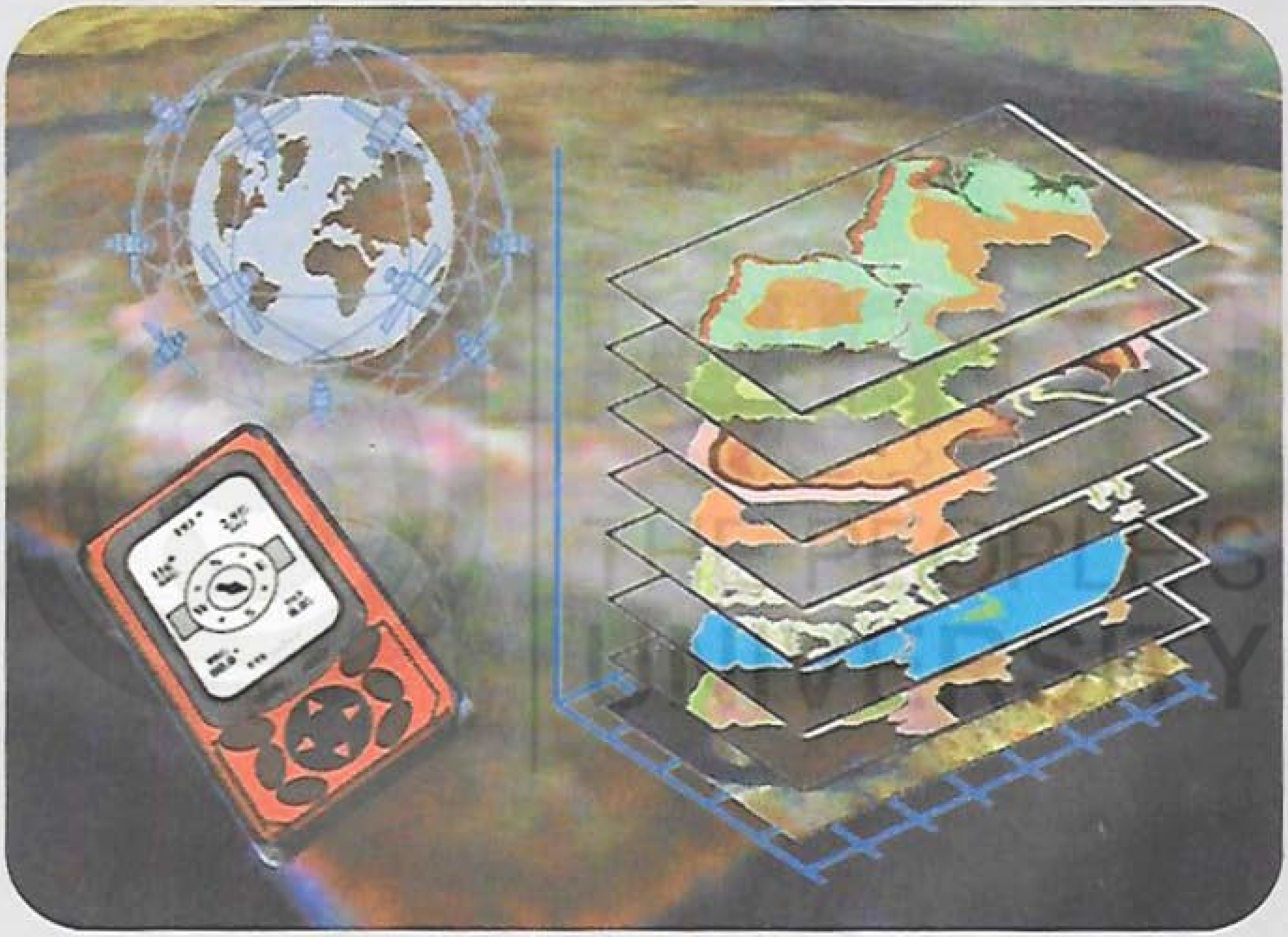
# MGY - 003
# GLOBAL NAVIGATION SATELLITE SYSTEM AND GEOGRAPHIC INFORMATION SYSTEM



## GIS Analysis, Output and Project Design

## 4

Indira Gandhi
National Open University
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# MGY-003
# GLOBAL NAVIGATION SATELLITE SYSTEM AND GEOGRAPHIC INFORMATION SYSTEM

Block

# 4

## GIS ANALYSIS, OUTPUT AND PROJECT DESIGN

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# BLOCK 4 GIS ANALYSIS, OUTPUT AND PROJECT DESIGN

GIS analysis relates to the use of the technological inputs in collecting, storing, retrieving, displaying, manipulating, managing and analysing the spatial information and data. It is an amalgamation of remote sensing, GPS, GIS, digital cartography and database management systems. Spatial analysis allows us to study real-world processes including the present day situation in specific areas. Thus, the spatial analysis is a process that involves looking at geographic patterns in the data and their relationships. GIS allows the user to display spatial and tabular data as maps, tables and charts. Therefore, a strong GIS platform must contain powerful tools for different types of outputs. The careful design of a GIS Project and its implementation is also very important for developing a successful GIS application. GIS design makes use of state-of-the-art techniques and modeling tools suitable for database development with mainstream software packages. Thus, the ability of GIS to manage geospatial data establishes GIS as an important tool for a wide variety of applications in management of natural resources, crime analysis, emergency planning, transportation planning, land resource management, market analysis, etc.

**Unit 11** introduces you to the methods of spatial analysis that allow us to solve specific problems which are used to support important decisions, using the capabilities of hardware, software and data.

**Unit 12** discusses about the various GIS outputs and the changing nature of maps and cartographic methods in GIS.

**Unit 13** focuses on the GIS Project design and its successful implementation, using the knowledge of spatial analysis and GIS outputs that you have gained from the previous units. You shall also read about the various aspects of GIS design that will help you in preparing a successful GIS.

**Objectives**

After studying this block you should be able to:

- discuss the possibilities and methods in vector analysis and raster analysis;
- describe different types of GIS outputs;
- evaluate the significance of Spatial Decision Support System (SDSS);
- identify various components, approaches and models of GIS design; and
- recognise the influence of GIS information products.

We wish you all the best and hope you will enjoy reading this course.

# UNIT 11 SPATIAL ANALYSIS

## Structure



## 11.1 INTRODUCTION

You have been provided with conceptual and historical framework of GIS in the Block 2 *Fundamentals of GIS* and Block 3 *GIS Database Creation* of this course. You have learnt about the types of geographic data, data conversion techniques, data input methods, data quality issues, data integration types and methods. Now we shall discuss about converting the spatial data into useful information. The GIS software can perform data analysis and modelling and their results can be used to reveal patterns and trends in data that are not apparent. In this unit you will learn about the real core of GIS i.e., spatial analysis. We will learn about the methods of analysis and modelling that allow us to solve specific problems which are used to support important decisions, using the capabilities of hardware, software and data.

In Unit 4 *Introduction* Block 2 of MGY-001, we have discussed various terms such as data, information, spatial and geospatial.

### Objectives

After studying this unit you should be able to:

- define spatial analysis;
- list out the spatial elements;

- discuss the possibilities in vector analysis;
- describe the methods used in raster analysis; and
- explain the significance of optimisation and design.

## 11.2 WHAT IS SPATIAL ANALYSIS?

An intelligent user and powerful computer are the prerequisites for effective spatial analysis.

You have read that various methods of geospatial analysis and modelling devised over the years. Many of them date before the advent of GIS, when calculations and measurements were performed manually. Numbers of methods have been provided by the developers of GIS software, specialised companies and individuals. Spatial analysis is the heart of GIS.

GIS provides tools that are far more powerful than the map in suggesting economic status of the residents in a locality.

You have already been introduced to concepts of spatial data in Block 2 *Fundamentals of GIS* of MGY-003. The strength of the GIS lies in its analytical capabilities i.e., spatial analysis.

Spatial analysis deals with adding significance to the geographic data and converting the data into useful information. Spatial analysis allows us to study real-world processes including the present situation of specific areas and features or the change in situation or the trends e.g. decreasing or increasing urbanisation in Delhi and NCR (National Capital Region)? Thus the spatial analysis is a process that involves looking at geographic patterns in the data and their relationships. The actual methods for spatial analysis can be very simple such as just by making a map of the theme you are analysing or more complex, involving models that mimic the real world by combining many data layers.

Thus the spatial analysis relates to the use of the technological inputs in collecting, storing, retrieving, displaying, manipulating, managing and analysing the spatial information. It is an amalgamation of remote sensing, GPS, GIS, digital cartography and database management systems. You can consider spatial analysis as the collaboration between the computer and the human, in which both play vital roles. Thus spatial analysis essentially requires an intelligent user, not just a powerful computer. In all of these cases GIS is the engine that performs the necessary operations, under the guidance of the user issuing the necessary instructions. Spatial analysis can reveal things that might otherwise be invisible or hidden.

You have read and found that all the possible definitions of spatial analysis express the basic idea that information on locations is essential and also that the analysis carried out without knowledge of location is not spatial analysis. Spatial analysis is a set of methods whose results change when the locations of the objects being analysed change. For example analysis of the average savings for a group of people is in no way spatial analysis because it is not concerned with the location of the people.

*Planimeter* is the mechanical device used to measure length and areas on analog maps.

Later in this unit you will learn about simplest capabilities of GIS: counting and locating objects. These sets of techniques resemble the descriptive work by early explorers. This old approach should not be discounted, as it provides the basis for later analytical techniques. However, we will discuss about replacing the devices like dots, grids, distances wheels and planimeters traditionally used for measuring the sizes, lengths and areas of objects with computer algorithm that perform the same techniques.

Let us say for example, you are interested to represent a road. It can be represented by recording an appropriate value in a swath of cells in a raster representation. With a cell size of 1m, the swath corresponding to a major four-lane highway might be as much as 50 or even 100 cells wide (Fig. 11.1a). Alternatively, the road might be represented as a single line, or centerline (Fig. 11.1b) in a vector database. In this case its location would be recorded by specifying the coordinates of a series of points aligned along the road's center. Finally, the road might be represented as an area, encased by its edges (Fig.11.1c).

*Centerline* databases are commonly used in applications like vehicle routing and scheduling. Websites such as www.mapquest.com offer to find the best routes between pairs of places and are used daily by millions of people.

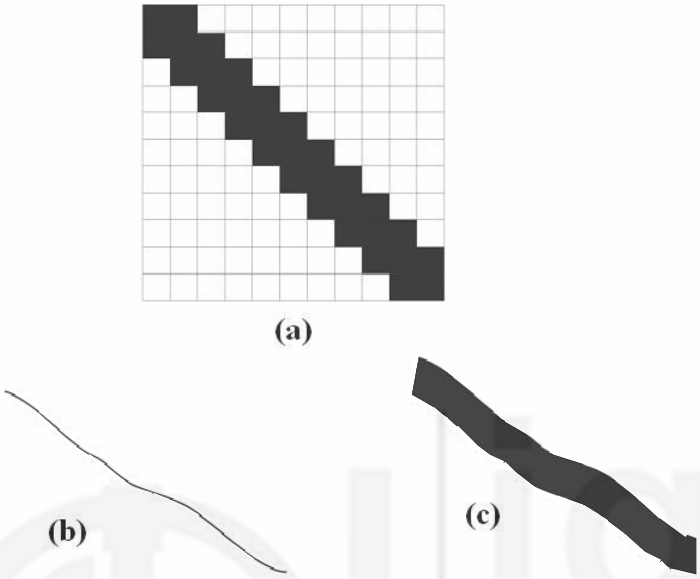



**Fig. 11.1: Three alternative representations of the same road, as: a) swath of raster pixels, b) a vector centerline, c) a vector area**

However, spatial analysis is also the most misused subsystem of the GIS. Much of the abuse of the GIS analysis is the result of lack of understanding of the nature of the spatial data contained in the system.

## 11.3 SPATIAL ELEMENTS

Spatial objects identified in the real world are easily identifiable into four types: *Points, Lines, Areas,* and *Surfaces* (Fig. 11.2). Collectively they are known as *spatial elements.* You have already been introduced to the spatial elements in Block 3 of MGY-003. The spatial elements can represent most of the substantial natural and human phenomena that we come across on everyday basis. In general, points, lines, and areas are used to explicitly represent real-world objects, where as surfaces are mostly used for volumetric representation, such as to represent hills, valleys.

*Point features* are spatial phenomena each of which occurs at one location in space. Each feature is said to be discrete in that it can occupy only a given point in space at any time and considered to have *no spatial dimension* – no width or length. Example of such feature would be a house or a village.

*Line features* are conceptualised as occupying only a *single dimension* in coordinate space. Roads, rivers, are the examples of linear features.

*Area features* have *two dimensions* both length and width dimensions. Area is composed of series of lines that begin and end at the same location.

*Surface,* add the third dimension of height to area features. Surfaces have three dimensions – length, width, and height. For instance, hills, valleys, and ridges can be described by citing their locations, amount of area they occupy, how they are oriented and by noting their heights.

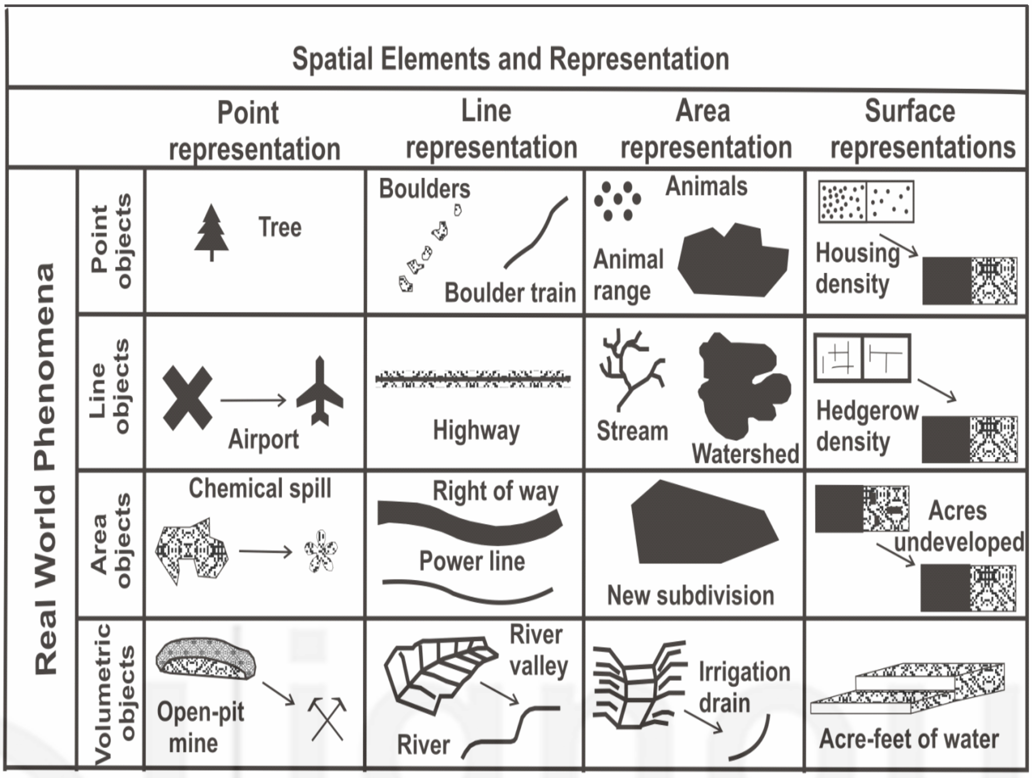



**Fig. 11.2: Spatial Elements and their representation (DeMers, 2000)**

## 11.4 VECTOR ANALYSIS

You have read about data conversion in Unit 9 *Attribute Data Linkages and Data Conversion* of MGY-003.

The operational models of the real world are built by making use of spatial datasets, based upon field and object. The vector data may be transformed into raster representation and vice versa. The transformation in most cases will result in the loss of information (e.g. resolution) and therefore such transformations may not be reversible. It is possible to separate methods of analysis of vector data sets from those that operate on raster data sets at a level. Since, there are very few instances of operations that require input of both kinds. There are so many possibilities, it is important to understand the ones that are used most often and to leave the less popular ones. Each method is described in terms of the problem it attempts to solve, the inputs required and the outputs that it generates.

We shall examine methods for optimisation and design, where our objective will be to use GIS to find the best solution to problems in Unit 13, *GIS Project Design and Implementation* of MGY-003.

### 11.4.1 Methods of Analysis for Points

*Geocoding* is the process of inputting spatial data into GIS database by assigning geographical coordinates to each point, line and area entity.

*Address matching* is the process of defining exact addresses and linking them to specific locations along linear objects.

You will begin here with the simplest kinds of geographic objects. Suppose you have records of each of the customers of an insurance agent, including each customer's location. Perhaps these originated in an address list and were subsequently converted to coordinates using the process known as *geocoding* or *address matching*. Dynamic segregation plots linearly referenced data on a coordinate system. Plotted on a map they might look something like Fig. 11.3. The two techniques are similar because both can locate data source that lacks x-, y- coordinates and both use linear features (e.g. streets, highways) as reference data. The data generated from geocoding and dynamic segregation is necessary for inputs for certain data analysis. Geocoded data are crucial for crime mapping and analysis, and dynamic segregation layers are useful for managing and analysing highway related data.

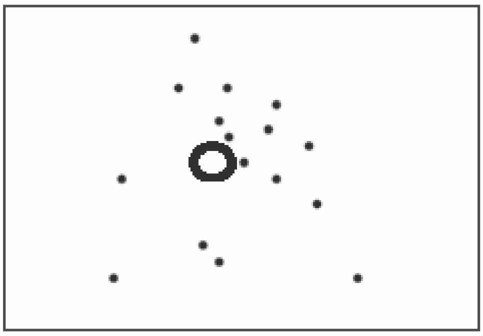


**Fig. 11.3: Locations of the customers of an insurance agent, shown in relation to the agent's office location and is ready for analysis**

## 11.4.2 Measurement of Distance

Now in the next instance we might ask how far each customer is located from the agent's location. The agent might be interested in knowing how many customers do their business with the agent rather than with some other agent. What is the average distance between each of the customers and the agent and are there areas near the agent where advertising might increase the agent's market share? All of these questions require the ability to measure the distance between points, a commonly used function of a GIS. Distance measurement calculates distance between spatial features. To measure the distance between two points we need to know their locations in ($x$,$y$) coordinates. Coordinate systems were introduced to you in Unit 8, *Datums, Map Projections and Coordinate Systems* of MGY-001. You have read that the UTM (universal transverse Mercator) coordinate system is based on measurements of coordinates in meters, so distances calculated in this coordinate system are easily understood. In these cases the distance between two points ($x_A$,$y_A$) and ($x_C$,$y_C$), representing the locations of the agent and a customer, are given by:

$$D = \sqrt{(x_A - x_C)^2 + (y_A - y_C)^2}$$

This equation is derived from Pythagoras's famous theorem, so it is also known as the Pythagorean distance or the length of a straight line between the two points. Pythagorean distance applies to points located on a plane not on the curved surface of the Earth. Therefore they should be used only when the points are close together. It is important to recognise that this problem of the Earth's curvature is not resolved by using latitude and longitude coordinates. Suppose we record location using latitude and longitude and plug these values into the Pythagorean equation as if they were $y$ and $x$ respectively. In this case the coordinates are measured in degrees, so the value of $D$ will also be in degrees. There are many other bases for measuring distance because it is often necessary to allow for travel that must follow streets or avoid barriers of one kind or another.

## 11.4.3 Measurement of Area

The use of GIS is strongly supported with the argument that computers make it easier to take measurements from maps, as compared with manual methods of analysis of information shown on maps. Let us demonstrate this by the measurement of an area. Suppose we want to measure the areas occupied by industry in a particular city and we are given a map showing the industrial locations in coloured areas. Manually, we have to use one of two traditional methods, known as dot counting and planimetry.

*Dot counting* proceeds by overlaying a transparent sheet covered by dots at a known *density* and counting the number of such dots falling within the area of interest. In order to get a reliable estimate, the high density of dots and smaller size is required. The process is tedious and may produce erroneous results.

*Planimetry* is a crude mechanical device to trace the outline of the area and the result is read off on the dial of the instrument. Again the process is tedious and error prone. Thus manual methods are frustrating and expensive in terms of the time required to obtain even a poor level of accuracy.

However this operation becomes simple if the measurement of area is represented in the digital form as polygons. A simple calculation is made for each straight edge of the polygon, using the coordinates of its endpoints and the calculations are summed around the polygon. Any vector GIS is able to do this quickly and accurately. The accuracy of the final result is limited only by the resolution of the original digitiser. The world's first GIS, the Canada Geographic Information System were developed in the mid 1960s precisely for this reason. It would have taken decades even after employing a large workforce, to produce the promised measurements manually. The results would have been of disappointing accuracy. Instead, a GIS was developed and all of the maps were digitised.

### 11.4.4 Buffer Operation

It might be interesting to outline on a map the area that is within 1km of the agent's location. Instead of ascertaining the distance of one customer from another in Fig. 11.3, you might in turn identify all of the points within a certain distance, taking a reference point. In GIS the term *buffer* is used and we say that the circle created by this operation constitutes the 1km buffer around the agent. Buffers can be created for any kind of object such as points, lines, or areas and are very widely used in GIS analysis. Fig. 11.4 shows buffers for each of these types of objects. *Buffering* creates buffer zone by measuring straight line distances from selected features.

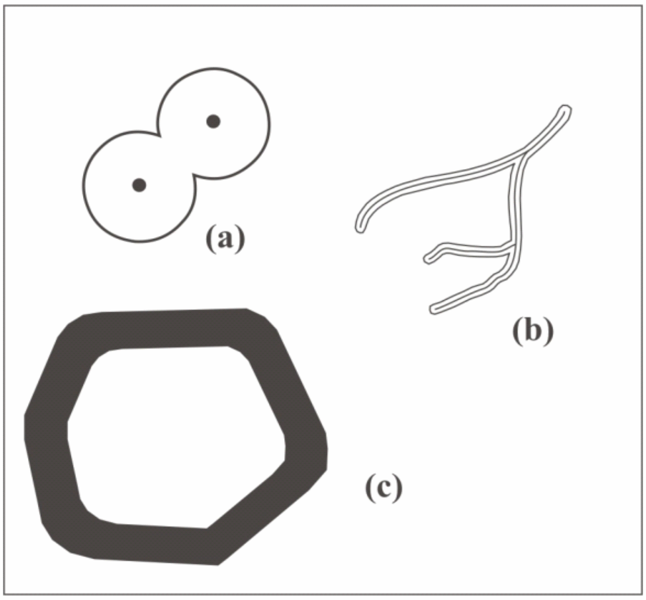



**Fig. 11.4: Buffers for (a) point, (b) line and (c) area objects**

Buffer operation is important spatial analysis function in GIS. Let us read about the applications of buffering as mentioned below:

- A buffer zone is often treated as a protection zone and is used for planning and regulatory purposes.
- It is useful in locating the areas/population benefitted or denied of the facilities and essential services such as hospitals, post office, roads etc.
- It can also be used to undertake population and environmental studies. This kind of analysis is called *Proximity Analysis* wherein the buffer operation will generate polygon feature types.
- It helps in determining the spatial proximity or nearness of various geographic features.

### 11.4.5 Overlay

The major advantage of a GIS is that it allows to identify spatial relationships between map features and to create new relationships by integration of map layers on various themes. It is performed under the *Map Overlay*, which is a spatial analysis involving two or more maps. Each map can be thought of as a layer containing information on a particular theme. These maps can be integrated to produce an output map on the basis of some logical and / or arithmetic operation. An overlay operation combines the geometries and attributes of two feature layers to create the output. The geometry of the output represents the geometric intersection of the features from the input layers.

Overlay processes involves two (or more) layers. Merging is a simple overlay process that combines two or more layers into one. It leaves overlapping regions and does not create new attributed polygons where there is overlap. In contrast to a simple merge, each of these operations will produce a new layer with unique combinations of the input database polygons.

You will read here about the two overlay methods:

- Union
- Intersection

*Union* is the laying one GIS database on another to produce a combination of the two. The resulting GIS database will extend as far as both input GIS databases extend (Fig. 11.5). Thus union preserves all features from the inputs.

The area extent of the output combines the area extents of both input layers. Union requires that both input layers be polygon layers.

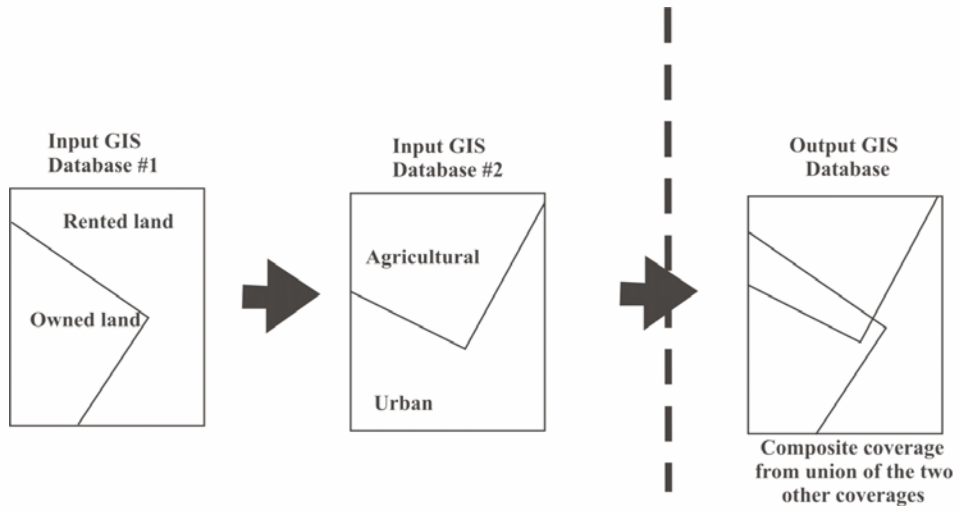



**Fig. 11.5: Union overlay: The union operation is used in a vector overlay of two coverages: the first is a map of land ownership versus renting and the second is a landuse map showing agricultural versus urban. The result of this operation is a map of the entire study area, indicating agricultural and urban as well as owned versus rented land (source: modified from DeMers, 2000)**

*Intersection* is the laying one GIS database on another to produce a combination of the two and finding the overlapping areas between two GIS databases (Fig. 11.6)**.** Thus intersection preserves only those features that fall within the area extent common to the inputs.

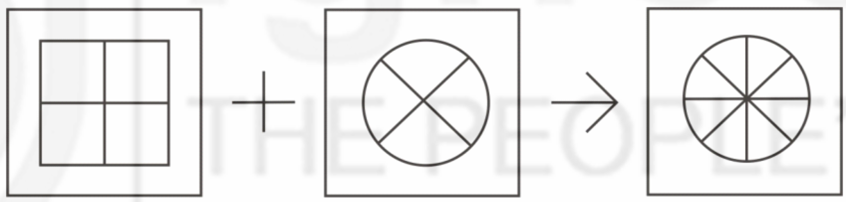


**Fig. 11.6: Intersection between two GIS databases shows common area produced from the combination**

Intersection is the most preferred method of overlay because any feature on its output has the attribute data from both of its inputs**.**

Overlay operations can be classified into the following:

1) Points-in-Polygon

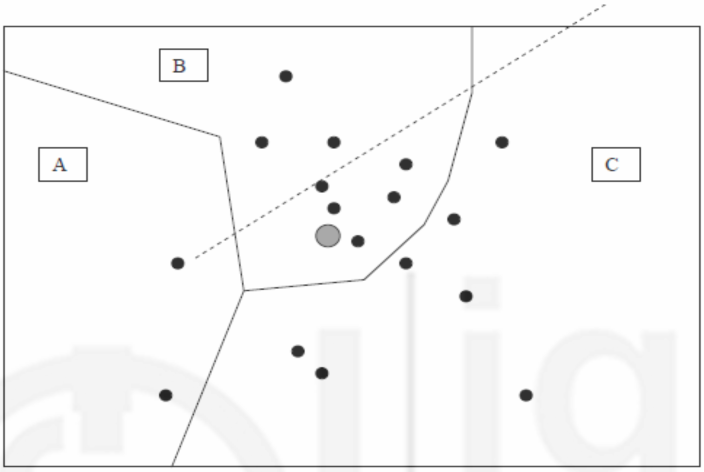
2) Line-in-Polygon

3) Polygon Overlay

1) **Points-in-Polygon**

A point-in-polygon operation is a key feature of GIS analysis. Point features of one layer can be overlaid on polygon features of another layer to identify the polygons within which each point falls. For example, if well sites are represented as points in a layer and land holdings as polygons in another layer. Point-in-Polygon overlay could be used to determine the well sites contained within each land holding.

The point-in-polygon operation is actually very simple to execute and you will read about this method briefly. One of the points in the Fig.11.7 will be used as an example. A line is drawn from the point, in this case diagonally upwards. The number of intersections between this line and the boundaries of each polygon is counted. In the example, there is one intersection with the boundary of Polygon A, second with the boundary of Polygon B and third with the boundary of Polygon C. The polygon that contains the point is the only one with an odd number of boundary intersections (and it will always be true that exactly one polygon has an odd number - all other polygons will have an even number). One useful way to think about the result of the point in polygon operation is in terms of tables. The result of the point in polygon operation could be expressed in terms of an additional column for the census tract table shown in Fig. 11.7, recording the number of points found to lie in that polygon, as a preliminary to computing the local market penetration.




| Census Tract | Number of Customers | Total households |
|---|---|---|
| 1 | 2 | 249 |
| 2 | 8 | 377 |
| 3 | 7 | 401 |

**Fig: 11.7: By using the point-in-polygon operation to identify the census tract containing each of the customer locations, it is possible to compare customer counts to other attributes of the tracts, such as the total number of households**

2) **Line-in-Polygon**

In a line-in-polygon overlay operation, the output contains the same line features as in the input layer but each line feature is dissected by the polygon boundaries on an overlay layer. Part of line may also fall directly on a polygon boundary instead of within a polygon. Thus the output has more line segments than does the input layer. Each line segment on the output combines attributes from the input layer and the underlying polygon. For example, roads stored as line in one layer can be merged with country polygons from another layer using a Line-in-Polygon overlay. The result can be used to determine the number and type of roads that fall within the Country or State.

3) **Polygon Overlay**

Polygon Overlay is an important operation for vector GIS, but it has two distinct versions. You will read about the examples in this section, such that each point on the map lies exactly in one polygon and overlay produces a similar map. Overlay in this version is conducted on an entire map or layer or coverage at a time.

Fig. 11.8 shows a typical application of polygon overlay. Let us take two input maps, e.g. a map of land use and a map of district boundaries. A reasonable question to ask of a GIS in a case like this is: "how much land in district A is in agricultural use?" To answer the question we must somehow compare the two maps, identifying the areas common both in district A and in agricultural land use and measure this area. You can do this using polygon overlay. The history of this method dates back to the 1960s, though efficient software to perform this operation on vector data sets was not developed until the late 1970s.

Fig. 11.8 shows the result of the polygon overlay operation, in the form of a new data set. Each of the polygons in the new data set represents a unique combination of the inputs and the boundaries. The resulting polygons are combinations of the lines from the two inputs.

Polygon overlay has a numerous uses, of which landuse is the simplest. Another popular use is population statistics.

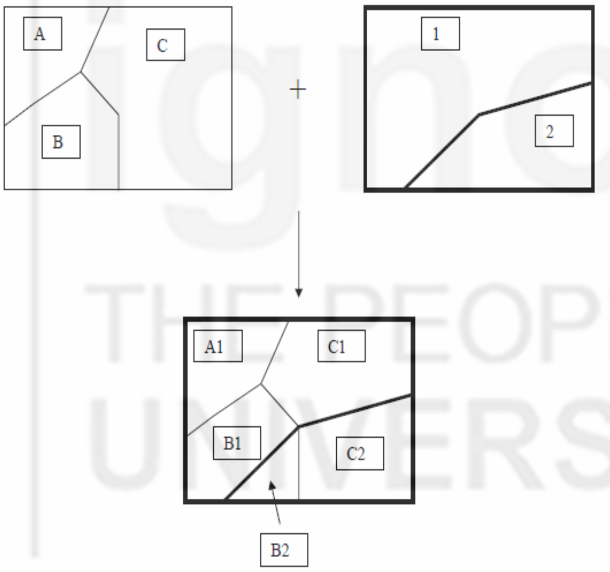



**Fig. 11.8: Polygon overlay, combining a map with three polygons and a map with two polygons to create a map with five polygons. The attributes of the new map combine the relevant attributes of the input maps**

## 11.4.6 Reclassification

Reclassification can be applied to both vector and raster data.

You know that before conducting any kind of study or survey it is necessary to classify them. Similar classification framework has long been extended for the analysis of Earth surface features by cartographers. Thousands of classification schemes produced has one thing in common; they all have a target audience or end user in mind. They enable you to explore your data, without making changes to the location of spatial elements and without creating new spatial elements. You can store data with GIS before they are classified and later on manipulate them within the GIS depending on your needs. A GIS provides a wide variety of ways to classify and reclassify the stored attribute data to achieve the result. The nature of working and applicability of the user can actually be called one of *reclassification*, because the data that are input to GIS have already been classified. Thus the GIS operator either displays the existing classification (a data storage and data retrieval operation) or manipulates the existing attributes to create a classification more appropriate to the questions being asked and decisions to be made. Data retrieval involves the selective search of data.

Reclassification involves the (re)assignment of thematic values to categories of an existing map. *Reclassification* can be defined as repackaging of exiting information based on initial values, locations, size, shape, contiguity.

Let us read this with an example of data for household income from a town 'A', ranges from ₹ 0 to more than ₹ 75,000. Now you can reclassify this data into seven slabs and further into three major groups, as you can read below:

| | | |
|---|---|---|
| 1. | 0 – 5000 | |
| 2. | 5000 – 10,000 | Low Income Group |
| 3. | 10,000 – 20,000 | |
| 4. | 20,000 – 40,000 | Medium Income Group |
| 5. | 40,000 – 60,000 | |
| 6. | 50,000 – 75,000 | High Income Group |
| 7. | > 75,000 | |

### 11.4.7 Query

The fundamental purpose of any Geographic Information System is to allow retrieval of desired information. This retrieval in GIS is achieved through 'Query' function. We will read about various types of queries mentioned below:

- **Spatial Query:** It includes queries made on the spatial properties of the geographic object. You can read about some spatial queries as mentioned below:

  *Query a location* is represented by a Point. Locational query provides the record number, or point-ID number coordinates specific to spatial data model, latitude-longitude of the point and the projection coordinates.

  *Query Distance* computes both the current and cumulative distances. There are several ways to provide the distance information, viz. the longitude and latitude of the interactive cursor location, the pixel resolution of the current window, great circle distance between two points etc.

  *Circular/Rectangular/Polygon Area Search* are useful for querying a data layer and select only those entities that fall within a user specific radius / rectangular /polygon area.

- **Non-spatial (attribute) Query:** It refers to the characteristics of any feature or phenomenon which are stored in form of a table in a database with a unique identifier key. This 'attribute' table can be queried to locate row or column that satisfies the search conditions. The data linkage is established between the spatial elements and their corresponding attribute tables through the common feature identifier key.

  *Exact Matching* is most often employed. Here the attribute table has a corresponding record entered for each of the spatial elements. Sometimes, few attribute information are collected in more detail than the other attributes; in that case *Non-exact Matching* is carried out. It is of two types, *Hierarchical Matching* includes e.g., finance, unemployment data and population data; *Fuzzy Matching* comprises crop boundaries usually define the field edges that rarely match the boundary between the soil types

- **Topological query:** It is defined as the inter-relationship amongst the features that are dependent of distance or direction. The key topological relationships are connectivity, adjacency and containment.
- **Spatio-temporal query:** This query provides ready answers to simple questions of feature, areal histories and attributes for the past moments in time.
- **SQL based query formulation:** A Structured Query Language (SQL) is a tool to extract data from a database and present result in a useful manner. SQL is used extensively in many database applications and has become a standard for relational DBMS.

*Spend 5 mins*

**Check Your Progress I**

1. What is the advantage of geocoding?

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   ........................................................................................................

2. Define Buffer.

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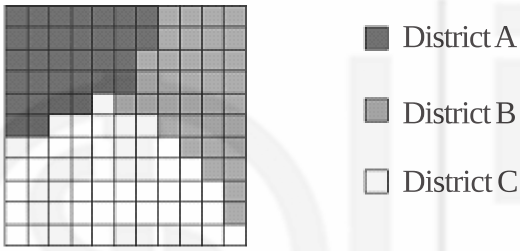
## 11.5 RASTER ANALYSIS

Spatial analysis consists of getting information using geospatial datasets. Here you will read about the spatial analysis with raster data. Raster GIS provides a very powerful basis for analysis, which is similar in many respects to the capabilities of other software that also relies on raster representations. For example, some of the raster operations described here will be familiar in concept to people who regularly use software for processing digital photographs or scanned documents, or for processing the images captured by remote sensing satellites. Vector data sets are similar in form to those used in computer-assisted design software (CAD) and in drawing software. In raster GIS the world is represented as a series of *layers*, each layer divides the same project area into the same set of rectangular or square cells or *pixels***.**

This makes it very easy to compare layers, since the pixels in each layer exactly coincide. But it also means that the ability to represent detail is limited by a pixel size, since no feature on the Earth's surface is smaller than a single pixel that cannot be represented. Smaller features can be represented by reducing the pixel size, but only at the cost of rapidly increasing data volume. Each layer records the values of one variable or attribute, such as land use or county name, for each pixel. The recorded value might be the average value over the pixel, or the value at the exact centre of the pixel, or the commonest value found in the pixel.

If there are many attributes to record (the census, for example, reports hundreds of attributes for each county in India), then separate layers must be created for each attribute. However, some raster GIS allows more efficient solution to this particular problem, in which a single layer is used to record district ID for each pixel. Fig. 11.9 gives the many attributes corresponding to that ID. Raster operations include four basic types of operations:

- *local operations* processes the contents of data sets pixel by pixel, performing operations on each pixel or comparing the contents of the same pixel on each layer;
- *focal operations* compares the contents of a pixel with those of neighbouring pixels, using a fixed neighbourhood (often the pixel's eight immediate neighbours);
- *zonal operations* performs operations on zones or contiguous blocks of pixels having the same values;
- *global operations* are performed for all pixels. Examples of each type of operation are given in the following sections.




| Districts | Population | Tax Rate |
|---|---|---|
| A | 2019 | 6 |
| B | 4511 | 6.5% |
| C | 7633 | 6.8% |

**Fig. 11.9: By using raster cells to store the IDs of polygons with multiple attributes in a related table it is possible to store many attributes in a single raster layer**

You will read about them in details in the following sections. Often a raster data operation relates the input to the output with mathematical functions.

## 11.5.1 Local Operations

The local operations can compute the average of the input rasters on a cell by cell basis. The simplest kind of local operations occur when a single raster layer is processed. This is often done in order to apply a simple reclassification, such as: "All areas of Soil Classes 1, 3, and 5 are suitable building sites for residential development; all other areas are not." This could be operationalised by reclassifying the soil class layer, assigning 1 to all pixels that currently have Soil Class 1, 3, or 5, and 0 to all other pixels.

GIS software with well-developed raster capabilities, such as IDRISI software, allows the user to access a wide range of operations of this type that create a new layer through a local operation on an existing layer.

### 11.5.2 Focal Operations

Focal operations produce results by analysing each pixel in relation to its immediate neighbours. Some of these operations work on all eight immediate neighbours, but others focus only on the four neighbours that share a common edge and ignore the four diagonal neighbours. Sometimes we distinguish these options by referring to moves in the game of chess - the eight-neighbour case is called the queen’s case, and the four-neighbour case is called the rook’s case (Fig. 11.10).

**Fig. 11.10: Two definitions of a raster cell’s neighbourhood. In the rooks case only the four cells that share an edge are neighbours, but in the queen’s case the neighbourhood includes the four diagonal neighbours**

Among the most useful focal operations are the so-called *convolutions*, in which the output is similar to an averaging over the immediate neighbourhood. For example, we might produce a new layer in which each pixel’s value is the average over the values of the pixel and its 8 queen’s case neighbours. Fig. 11.10 shows a simple instance of this. The result of this operation produce an output layer that is smoother than the input, by reducing gradients, lowering peaks and filling valleys. In effect, the layer has been filtered to remove some of the variation between pixels and to expose more general trends. Repeated application of the convolution will eventually smooth the data completely.

Convolutions are very useful in remote sensing, where they are used to remove noise from images. Averaging can only be used if the values in each pixel are numeric and measured on continuous scales, so this operation would make no sense if the values represent classes of land, such as soil classes. But in this case it is possible to filter by selecting the commonest class in the neighbourhood, rather than by averaging (Fig. 11.11).

| | | | | |
|---|---|---|---|---|
| **10** | **9** | **7** | **4** | **5** |
| **9** | **6** | **5** | **3** | **4** |
| **6** | **3** | **2** | **2** | **3** |

| | | | | |
|---|---|---|---|---|
| **8.5** | **7.5** | **5.7** | **4.7** | **4.0** |
| **7.2** | **6.3** | **4.6** | **3.9** | **3.5** |
| **6.0** | **5.2** | **3.5** | **3.2** | **3.0** |

**Fig. 11.11: Application of a convolution filter. Each pixel’s value in the new layer is the average of its queen’s case neighbourhood in the input layer. The result is smoother, picking up more of the general trend. At the edge, where part of the neighbourhood is missing, averages are over fewer than nine pixels**

*Digital Elevation data*, also referred to as digital elevation models (DEMs), or digital terrain data are digital representations of the shape of the Earth's surface. Typically digital elevation data consist of arrays of values that represent topographic elevations measured at equal intervals on the Earth's surface. Such data can be considered analogous to digital remote sensing images except that each pixel represents an elevation measurement rather than a brightness value. Digital elevation data can be manipulated, classified and analysed in many of the same ways that digital remote sensing data can be displayed as pictorial images.

Slope and aspect can also be used to estimate the pattern of surface water flow over a DEM (digital elevation model), a very useful operation in determining watershed boundaries and other aspects of surface hydrology. Each pixel's elevation is compared to those of its eight neighbours. If at least one of the neighbours is lower, then the GIS infers that water will flow to the lowest neighbour. If no neighbour is lower, the pixel is inferred to be a pit, in which a shallow lake will form. If this rule is applied to every pixel in a DEM, the result is a tree-like network of flow directions (Fig. 11.12), with associated watersheds.

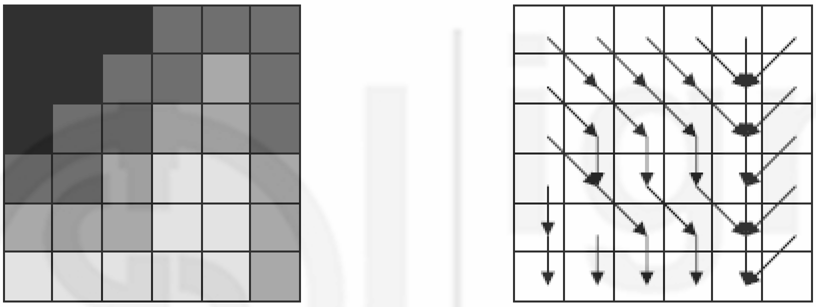


**Fig. 11.12: A digital elevation model, and the result of inferring drainage directions using the simple rule "If at least one neighbour is lower, flow goes to the lowest neighbour"**

If the input layer is a digital elevation model, with pixel values equal to terrain elevation, a form of local operation can be used to calculate slope and aspect. This is normally done by comparing each pixel's elevation with those of its eight neighbours, and applying simple formulae (Burrough and McDonnell, 1998). The result is not the actual slope and aspect at each pixel's central point, but an average over the neighbourhood. Because of this, slope and aspect estimates always depend on the pixel size (often called the distance between adjacent postings) and will change if the pixel size changes. For this reason it is always best to quote the pixel size when dealing with slope or aspect in a GIS.

Another powerful form of local operation forms the raster equivalent of the buffer operation and also supports a range of other operations concerned with finding routes across surfaces. To determine a buffer on a raster, it is necessary only to determine which pixels lie within the buffer distance of the object. Fig. 11.13 shows how this works in the cases of a point and a line. But suppose we make the problem a little more complex, by asking for pixels that are within a certain travel time of a given point, and allowing travel speed to be determined by a new layer. Fig. 11.14 shows such a layer and the result of determining how far it is possible to travel in given numbers of minutes. The operation is also known as *spreading.* Of course this assumes that travel is possible in all directions, but this would be appropriate in the case of an aircraft looking for the best route across the Atlantic or a ship in the open ocean.

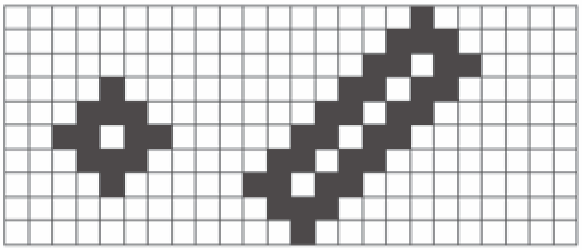


Fig. 11.13: **The buffer operation in its raster form, for a point and a line (indicated by the white cells)**

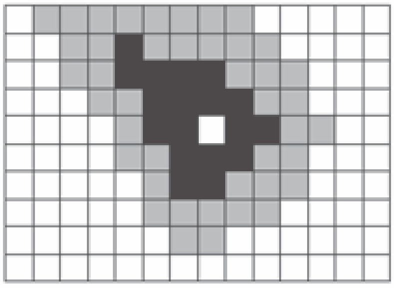


**Fig. 11.14: Illustration of a spreading operation over a variable friction layer. From the central white cell, all cells in the black area can be reached in 10 minutes, and all cells in the grey area can be reached in 20 minutes**

This method is used very frequently to find the best routes for power transmission lines, highways, pipelines, and military vehicles such as tanks — in all of these cases; the assumption of travel in all directions is reasonably accurate. Origin and destination points for the route are defined. A raster GIS is used to create a layer of travel speed, or friction. Because this is not uniform, the best route between the origin and destination is not necessarily a straight line. Instead, the best route is modelled as a series of moves in the raster from each cell to the most appropriate of its eight neighbours, until a complete route of least total time or least total cost is found (Fig. 11.15). There have been many applications of this GIS method over the past three decades by highway departments, power utilities, and pipeline companies.

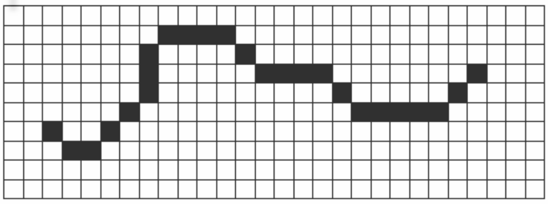


**Fig. 11.15: Finding the least-cost path across a variable-cost layer from a given origin to a given destination, using queen's case moves between raster cells. This form of analysis is often applied to find routes for power lines, pipelines, or new highways**

The final operation considered here is the so-called *viewshed operation*. This also works on a DEM and is used to compute the area that can be seen from a specified point, by a person at that point. When more than one point is specified, the GIS could be used to determine the area visible from at least one point, or in some military applications it might be useful to determine the area invisible from all points. The viewshed operation is often used in planning. For example, if a new clearcut is proposed by a forest management agency it might be useful to determine whether the scar will be visible from certain key locations, such as public roads.

### 11.5.3 Zonal Operations

Raster data is represented in pixels, so the line objects and the area objects are the modeled as collections of pixel values with no clear linkage between them. If we simply count the pixels assigned to Class 1 on a soil layer, for example, we get the total area of Class 1, not the separate areas of the individual patches of Class 1. Zonal operations attempt to address this by focusing on operations that examine a layer as a collection of zones, each zone being defined by contiguous pixels of the same class. Zonal operations can be used to measure the areas of patches or their perimeter lengths and the results are returned as new layers in which each pixel is given the appropriate measure.

### 11.5.4 Global Operations

Finally, global operations apply a simple manipulation to an entire layer, usually returning a single value. Examples include operations to determine the average of all pixel values or the number of pixels having a specific value, or the numbers of pixels having each unique value, or the total area having each unique value. For example, a global measurement of area on a a soil layer with six classes might return six areas, plus the total area. Global operations produce summary statistics, so they are often the last operation in a sequence.

**Check Your Progress II**

***Spend 5 mins***

1. What are the operations of overlay?

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2. Mention the four basic operations in raster analysis.

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## 11.6 OPTIMISATION AND DESIGN

Many applications of GIS analysis provide information that can be used to make decisions, but some methods come much closer to recommending decisions directly. These are the methods that focus on optimisation, by finding the answers that best address a problem and methods that focus on design. Today, there are many methods of optimisation and design available in GIS. Many are concerned with optimum routing and scheduling of vehicles operating on a road network, a type of problem that is almost always implemented in vector GIS. In the simplest instance, the GIS are used to find the shortest path through a road and street network between a user-specified origin and destination. Millions of people use this kind of analysis daily when the access Websites such as www.mapquest.com to request driving directions between two street addresses. The same kind of analysis is possible in the in-vehicle navigation systems that are becoming increasingly common, especially in vehicles from car rental agencies. Much more sophisticated versions of the same basic idea are used by school bus authorities to design the best routes to pick up children and take them to school, by parcel delivery companies to design routes for their drivers, and by utility companies that schedule daily work orders for their maintenance staff. The term logistics is often used to describe this application of GIS. Another class of optimisation problems is termed *location-allocation.*

Here the issue is to find sites for activities that serve geographically distributed demand. Examples are retail stores which must locate centrally with respect to their customers, schools and hospitals, fire stations and ambulance depots, and a host of other services. In all cases the objective is to find locations that are best able to serve a dispersed population. The problem is known as location-allocation because the best solution involves both the location of one or more central facilities, and the allocation of demand to it, in the form of service areas.

## 11.7 SUMMARY

The vast number of options is available in the form of methods of spatial analysis and modelling implemented in GIS. Any good GIS software provides many of these and more are available in the form of add-ons from other vendors, agencies, or individuals. Let us sum up about what we have learnt in this unit:

- All of the options for spatial analysis have greatly extended the power of GIS to solve problems and to provide the kinds of information people need to make effective decisions.
- Certain aspects should be considered in any application of analysis and modelling using GIS. First, is the analysis more suited to a raster or a vector approach? Many operations are possible in both.
- Spatial or geospatial analysis is the process by which you can convert raw data into useful information, in search of scientific discovery or decision making. The analysis functions use the spatial and non-spatial attributes in the database to answer questions about the real world.
- Spatial objects in the real world identified can be of four easily identifiable types: Points, Lines, Areas, and Surfaces
- The methods of analysis of points and area have been discussed in addition to processes in overlay.
- Buffer operation is important spatial analysis function in GIS.
- Reclassification can be defined as repackaging of exiting information based on initial values, locations, size, shape, contiguity.
- You have learnt about query and its types, i.e. spatial, spatio-temporal, topological etc.
- Raster operations include four basic types of operations, viz., local operations, focal operations, zonal operations and global operations.

- Finally, how should the results should be presented? GIS is fundamentally a graphic tool and the images and pictures it produces can have enormous impact if they are well designed.

## 11.8 UNIT END QUESTIONS

*Spend 30 mins*

1. What is spatial analysis?
2. Discuss in brief various operations in raster and vector analysis.

## 11.9 REFERENCES


- Burrough, P. A. and McDonnell, R. A. (1998), *Principles of geographical information systems*. New York: Oxford University Press. 332p.
- DeMers, M. N. (2000), Fundamentals of Geographic Information Systems. 2nd Ed., John Wiley & Sons, INC., 498p.


## 11.10 FURTHER/SUGGESTED READING


- Chang, Kang-tsung, (2010), Introduction to Geographic Information Systems. 4th Ed., Tata McGraw Hill Education Pvt. Ltd. 450p.
- DeMers, Michael N., (2000) Fundamentals of Geographic Information Systems. 2nd Ed., John Wiley & Sons, INC., 498p.


## 11.11 ANSWERS

**Check Your Progress I**

1. Refer to subsection 11.4.1.
2. Refer to subsection 11.4.4

**Check Your Progress II**

1. Refer to subsection 11.4.5
2. Local operations, focal operations, zonal operations, global operations

**Unit End Questions**

1. Refer to section 11.2
2. Refer to sections 11.4 and 11.5

# UNIT 12 GIS OUTPUTS

## Structure



## 12.1 INTRODUCTION

You have already been introduced to the fundamentals of geographical information system and GIS database creation in the Block 2 and 3 of MGY-003. GIS was conceived as an application based tool that aimed primarily to automate the management and creation of the resource maps. The production of map is one of the basic functions of GIS. Historically, the paper map was the only available interface between the map-maker and the user. The fixed array of attributes severely limited the usefulness of the paper map in today's application environment. Digital maps are now generated directly from a geospatial database instead of using the conventional cartographic process. The conventions and constraints in depicting the world by a paper map could easily be overcome, when GIS is used for mapping. In this unit you shall learn about the various outputs of geographical information system. This would explain the changing nature of maps and cartographic methods in GIS.

Difference between a map and GIS is the same as the difference between the "seeing" and "understanding".

### Objectives

After studying this unit you should be able to:

- discuss the different types of GIS outputs;
- explain the geovisualisation;
- differentiate between cartographic and non-cartographic outputs;
- identify the process of map generalisation and symbolisation; and
- know the significance of Spatial Decision Support System (SDSS).

## 12.2 TYPES OF GIS OUTPUT

GIS allows user to display spatial and tabular data as maps, tables and charts. This helps in visualising information, in the ways that reveal new relationships, patterns, trends that are not visible with text files, spreadsheets and databases. All the functions a GIS culminate in the output it produces. So a strong GIS platform must contain powerful tools for different types of outputs. There are four major types of outputs one can expect from a GIS as mentioned below:

- text - tables, lists, numbers or text in response to query
- graphic outputs - maps, screen displays, graphs, perspective plots
- hardcopy outputs
- digital data - on disk, tape or transmitted across a network

### 12.2.1 Texts and Tables

The texts sometimes are more important than maps for reporting results of analysis. Tables may be attribute table of objects in GIS which can consider a list of hospitals located in a metropolitan city or a list of wells in a village or driving directions for a milk distribution route. The text outputs may include the results which might be a list or table of selected objects with attributes.

You will find that though the tables list all areas of forest, timber giving area, species, age, estimate of yield in board feet. But they are not of great value without an accompanying map to identify each object in the list. The queries might result in numerical results, e.g. totals, distances, areas, counts. The text output might be delivered by voice generator, e.g. navigation instructions like & U- turn left at next traffic signal.

### 12.2.2 Graphic Outputs

You have already read about raster and vector data models in Unit 1, *Overview of Geoinformatics* of MGY-001 and Unit 4, *Concept of GIS* of MGY-003.

Graphic outputs are the strength of any GIS. For graphics to display it requires a display system. In most of the GIS, this is affected through monitors. Graphics provide graphic input and output of maps, diagrams and charts. The interactive graphic devices allow users to point to objects and identify them in their correct spatial context. You shall read about the devices for graphic output and the ways their development has influenced GIS later in this unit. Further the quality of the graphic output is determined by type of graphic files being used for display and hence there are two major types of graphic output devices viz., raster and vector groups.

A raster device may be driven by vector commands, which can be converted for display and vice versa. The conversion between raster and vector may thus occur at several points in a GIS between input and output.

### 12.2.3 Hardcopy Outputs

There are different types of printers which are useful for hardcopy outputs. These mostly include hard copy maps taken as printouts from GIS system. Let us read about them:

- **Drum plotter** facilitates the printing of a simple or a complex system of the maps (Fig 12.1).

**Fig. 12.1: GIS Output device-Drum plotter**

- **Line printers** are the first common device for computer output that was used as the output device for SYMAP (the earliest mapping package released in 1967). They were most useful for repeated mapping of statistics on a constant base, e.g. census atlas, weekly reports of crime statistics.
- **Dot matrix printers/plotters** are image composed of rows of dots - often printed in blocks.
- **Pen plotters** create images by moving a pen under computer control. They are most incremental - draw a line using large numbers of movements of fixed size in fixed directions.
- **Optical scanners** provide the output on photographic paper which is mounted on inside of a rotating drum. It is a common output device for remote sensing and image processing outputs.

Other hardcopy output devices are CRTs (cathode ray tubes), storage tube technology and refresh image technology

### 12.2.4 Digital Data

Digital data consists of discrete, discontinuous binary digits. In comparison, analog data consists of continuous waves that vary (fluctuate) infinitely within a range. In GIS, to process geographic information, the existing hard copy maps should be digitised. The result of such digitisation or tracing of hard copy maps through electronic interfaces produce *Digital Line Graphs (DLG)* a term generally used by USGS (United States Geological Survey). DLG are digital representations of cartographic information. DLG's of map features are digital vectors converted from maps and related sources. You will find that these DLGs are always paired with attribute tables. Attribute tables contain data or code that describes DLGs. Attribute data are used with vector data to describe the physical and cultural characteristics of node, line, and area elements. Each attribute data identifies the major category or unit to which a data element belongs, as well as the specific nature of the element. Attribute data may also provide additional descriptive information, numerical values, or identifiers. Many elements are uniquely described by a single attribute data, but some may require two or more codes for a complete description.

You have read about DLG data formats in Unit 7, *Data Analysis Tools* MGY-001.

You would understand with this example- a line in a DLG may be a road or a transmission line. If it is a road then the attribute table may contain details regarding the length of the road segment the category which it belongs, such as state highway or national highway and the associated symbolisation details.

The digital data standardisation effort is currently being directed at this area, where DLGs are involved. It is a unique set of data format that requires special

You have read about COTS software in Unit 7, *Data Analysis Tools* of MGY-001.

software for display. Similarly, the data exchange formats of DLGs are more cumbersome, as many of the software are COTS and have royalty bindings. However, there are some exchange formats available for data transfer and migration to other software, for example, DXF (data exchange format) for CAD drawings and ESRI E00 format (for the transfer of Arc Info Coverages). Many systems including open sources GIS software now has the permission to access ESRI shape file for accessing Geographic Information.

The following are some of the common DLG data formats:

- **.**shp (ESRI Shape)
- .dwg,dxf (Autodesk drawing and exchange format)
- .dgn (Micro station design files)
- .kml/kmz (Key hole markup language – Google Earth)

***Spend 5 mins***

**Check Your Progress I**

1. Enumerate different types of GIS outputs.

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2. Give two examples for raster and vector devices.

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3. Expand DLG and name few common DLG data formats.

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## 12.3 GEOVISUALISATION

You have seen that once the geographic data is analysed, for a particular purpose, the results of the analysis should be retrieved in the form of an analysis output. The output from GIS does not always have to be a map. Many of the GIS software produce beautiful and informative graphic displays. You can see the results of the geographic analysis are seen in the monitor of the computer. The display of GIS is not simple but a complex process in which many fields of expertise such as cartography, computer science, image processing and information processing are involved. Most of the GIS software has specific modules for showing the output, such as showing a result in three dimensions. There are many GIS software capable of generating 3D models and specific hardware tools are also available to see these specific outputs. This complex procedure of looking at GIS outputs is collectively called as *Geographic-Visualisation or Geovisualisation.*

You know that the basic idea of visual data exploration is to present the data in some visual form which allows the user to gain insight into the data, draw conclusions and directly interact with the data. Visual data mining techniques have proven to be of high value in exploratory data analysis and have a high potential for exploring large databases. Visual data exploration is especially useful when little is known about the data and the exploration goals are vague. Since the user is directly involved in the exploration process, shifting and adjusting the exploration goals is automatically done, if necessary. Here you would read about more recently, faster processing hardware and more sophisticated computer graphics, including animation. The term *Visualisation in Scientific Computing (ViSC)* describes the use of new technology and media to convey the multi-faceted messages of today's mapping. This computing provides an altogether more flexible, sophisticated and interactive window on the world than the paper maps of the past.

The *ViSC* entails more than a one-way transfer of geographic information from machine to user. It not only supports the visual interpretation of spatial distributions, but also data quality assessment and data exploration (Longley et al., 2001).

Visual data exploration can be seen as a hypothesis generation process. The visual representations of the data allow the user to gain newer insights into the data and come up with new hypotheses. The verification of the hypotheses can also be achieved through data visualisation. In addition to the direct involvement of the user, the main advantages of visual data exploration include:

a) It is intuitive and requires much less understanding of complex mathematical or statistical algorithms or parameters than other methods, and

b) It can provide a qualitative overview of the data, allowing data phenomena to be isolated for further quantitative analysis.

Geovisualisation provides a means to organise large amounts of multi-dimensional, information about a place in such a fashion to facilitate human exploration and understanding. In the process of geovisualisation numerical or symbolic data (Fig. 12.2) and information are converted into geometric computer generated images. It is a methodology for interpreting image data entered into a computer as well as data generated from computational models. Generally, geovisualisation is based on the application of techniques from the convergent fields of:

- computer graphics;
- image processing;
- computer vision;

- computer-aided design,
- signal processing,
- user interface design.

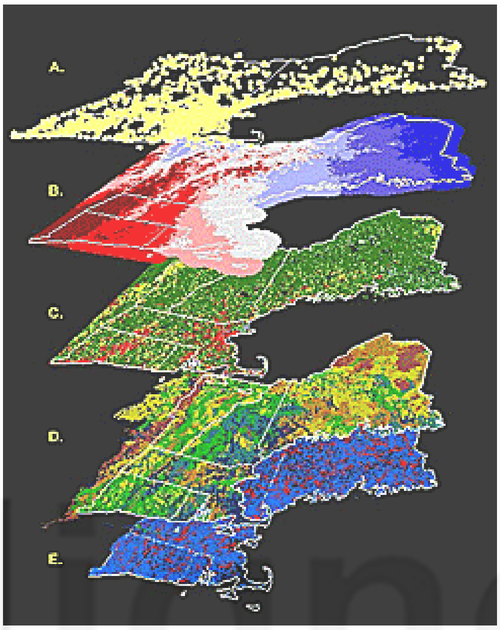


**Fig. 12.2: Multi-Layered display**
**(source: http://advanced.jhu.edu/academic/environmental)**

This convergence enhances visualizing large amounts of information interactively. Geovisualisation, not only changes the look of the graphic image but also its interpretation (Dykes et.al. 2007). This creates the possibility of multiple perspectives, which enhances a viewer's perceptive abilities to understand the phenomenon under study. Visualising data using current computing technology and interactive GIS has many advantages over traditional paper maps.

You will read about the advantages of geovisualisation, in the following section:

1. **Interactive GIS:** It involves the adding of new fields of data, switch them on/ off, changing the colour scheme. Adding text, moving symbols, and a host of other capabilities give the user a tremendous flexibility and power to comprehension and interpretation.

2. **Multi-Scale possibilities:** Most of the maps are scale dependent. The paper maps gives a viewer only one scale for reference but GIS displays have multi-scaling possibilities enabled by zoom tools.

3. **Multi-dimensional perspective :** The viewers can take advantage of computationally intensive functions such as "draping" a perspective view over a surface (like a digital elevation model) or creating the impression of three dimensions on a 2D display (the computer screen) using complex rendering and shading algorithms. Multi-dimensional viewing is created when changing time is included along with 3D perspectives of the terrain (Fig. 12.3).

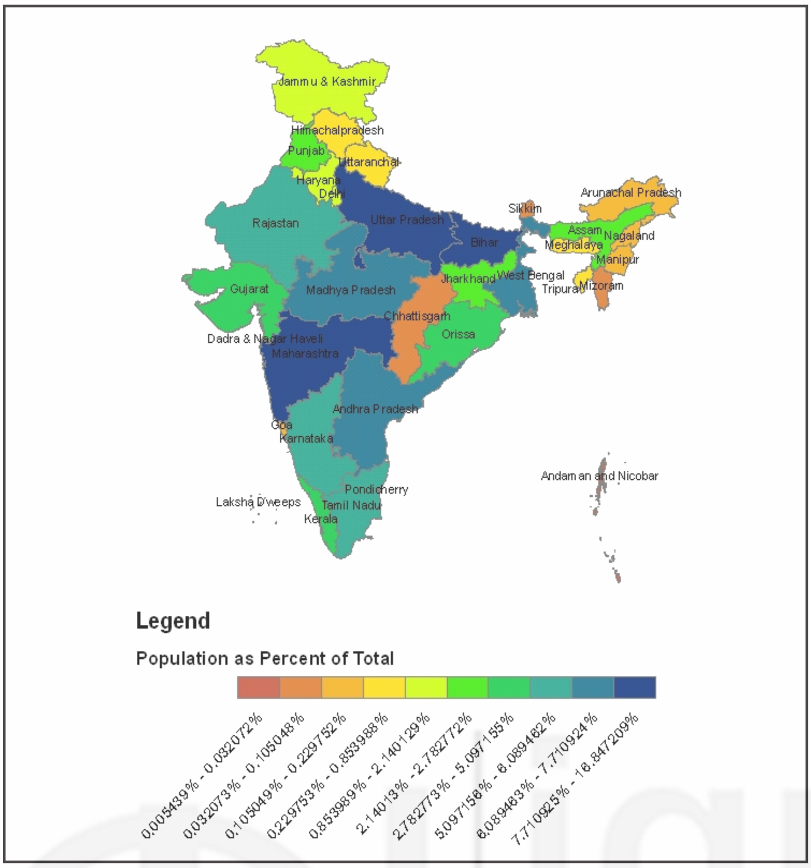


**Fig. 12.3: Display of symbols with data (www.gislabsindia.blogspot.com)**

## 12.4 DISPLAY OF ANALYSIS

There are two broad categories of GIS outputs, viz., cartographic and non-cartographic outputs.

- Cartographic outputs
- Non-Cartographic outputs

### 12.4.1 Cartographic Outputs

*Cartographic outputs* comprise maps prepared adhering to the cartographic conventions and modules for taking the printouts of the maps generated in GIS. In most of the GIS software, there are two views viz., *layout view and map view*. In layout view, we can keep the map to be printed, inside the map grid graded with latitude and longitude. There will be specific tools to insert scale bar and map legends inside the map grid. Once the map is designed as per the cartographic conventions one can take the printout of the same. There are many constraints a cartographer used to face while design a map layout, which include map generalisation and symbolisation. Let us briefly discuss here about them.

You have read about elements of map and cartographic outputs in Block 3, *Basics of Mapping* of MGY-001.

a) **Map Generalisation**

You have read in Block 1 Course 1 that while compiling maps from other maps, cartographers are often required to generalise the outlines and other details. Generalisation is one of the basic features of cartographic representation. It is carried out so that the scope and the presentation of the content can be more easily perceived by those using the map. At the same time, appropriate generalisation should guarantee that the map is a reflection of the spatial variability of the Earth's surface and the characteristics of the represented objects most important to the map user.

Cartographic generalisation is a composite process encompassing the wide range of relations between geographic area (with all its aspects being the subject of investigation in various disciplines) and the great diversity of maps that constitute its reflection. The following are the major geographic features requiring generalisation:

1. Generalisation of the coastlines: - different maps of the same area give different shapes of coastlines yet all of them may be correct according to their scale. In some cases the changing shorelines also pose a problem.

2. Generalisation of boundaries:- on a small scale map a little movement of the hand may give large chunks of land to the neighbouring countries or state. In some cases if the two neighbouring countries do not agree on their common boundaries, this may result in international dispute.

3. Generalisation of rivers;- When a map is reduced some rivers should be shown as a thin line or should be left out, this sometimes may create problems as the existing river is eliminated due to cartographic constraints.

b) **Map Symbolisation**

When several words are put together in definite order, we get a sentence. Similarly when several symbols are put together in a definite order, we get a map. Symbolisation and the arrangement of the symbols in a map are, therefore, crucial processes in map design. No map can be popular if the choice of symbols is bad. For most purposes we can classify symbols into three types, such as; point symbols, line symbols and polygon symbols.

***Point symbols:*** Point symbols are those which give the location of an object or the quantitative value represented by it exactly at the point of its location. Point symbols are of two types:

- Qualitative
- Quantitative.

Qualitative symbols are used to suggest the existence of an object for example; a dot is put for a town and a cross for a hospital. Such symbols do not represent any quantitative data. But, the quantitative point symbols can be used to indicate:

- presence
- length
- size
- volume

*Isarithms* is a line drawn on a map connecting points having same numerical value of same variable.

***Line symbols:*** Line symbols are used to indicate both qualitative and quantitative nature of the data. The latitudes, longitudes, boundaries, lines of transport and communication, streams, coastlines, etc, fall in the first category. Line symbols do represent quantitative values, for example, the iso-lines of various types used to represent the physical or social data, such as contours and *isarithms*.

Qualitative symbols indicate the real distribution of a given phenomenon without showing its density. The swamps, forests, deserts, political units or soil types given on a map are mostly qualitative in nature.

Area symbols are used to indicate the relative density of a phenomenon or occurrence of a phenomenon they acquire quantitative values. For example, isolines of rainfall or contour lines of height are the indicators of measurable phenomenon, while administrative boundaries include a measurable area.

### 12.4.2 Non-Cartographic Outputs

As you have understood it is obvious from *non cartographic outputs* that it includes map models and information system and primarily used for visualisation purpose0s. Let us discuss about them briefly.

a) **Map Models**

In recent years, contour values have been digitised allowing them to be manipulated into versatile displays of topographic data as digital elevation models or DEMs and Digital terrain models (DTMs). They are variants that show additional landscape attributes (Fig. 12.4). We can use existing maps as inputs by tracing contour lines on a digitising tablet or table. The data are organised into cell arrays whose X-Y positions in the rectangular grid are related to map coordinates.

There are a lot of applications for relief models, such as for teaching and education, to facilitate urban and regional planning, or to study geological and geomorphologic phenomenon. Virtual relief models help to establish realism. But real-world geographic data is very much necessary to achieve a fully immersive and realistic simulation. The geographic data represents a true-to-life landscape in the simulated environment. The data can be visualised via computer graphics and virtual reality techniques.

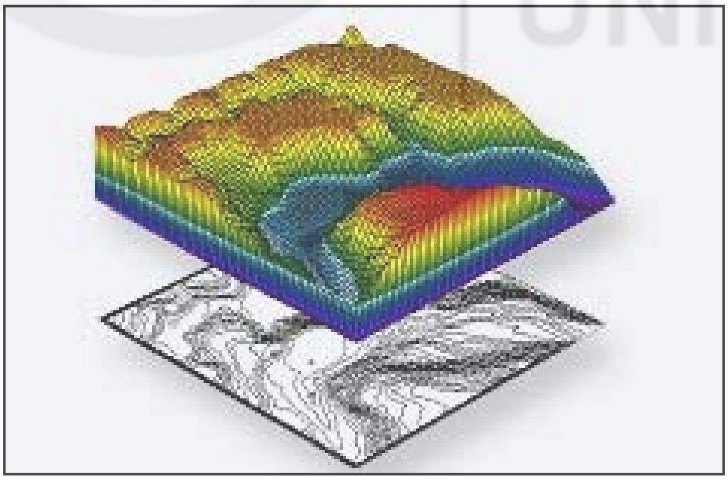

**Fig. 12.4: Digital Elevation Model (source: www.lasermapusa.com/en/projectexperience.html)**

DEM data sets have important applications. They allow for rapid reconstruction of contour maps and for plotting elevation profiles. Also, we can easily do various kinds of photogrammetric calculations with the numbers. Image processing systems can edit and filter these data to enhance the display products and merge data sets into larger maps. Cartographers can present surfaces as X-

Y-Z plots, where the Z dimension appears as regularly spaced vertical lines whose lengths are proportional to elevation. These plots are available in several formats:

- **Shaded relief maps:** They assign different shades of gray to slopes, depending on elevation or a variant, which draws in shadowing to selected slopes depending on their orientation (aspect) and on sun direction and azimuth. By shifting these parameters, we create different conditions that bring to light different surface features and trends (Fig. 12.5).

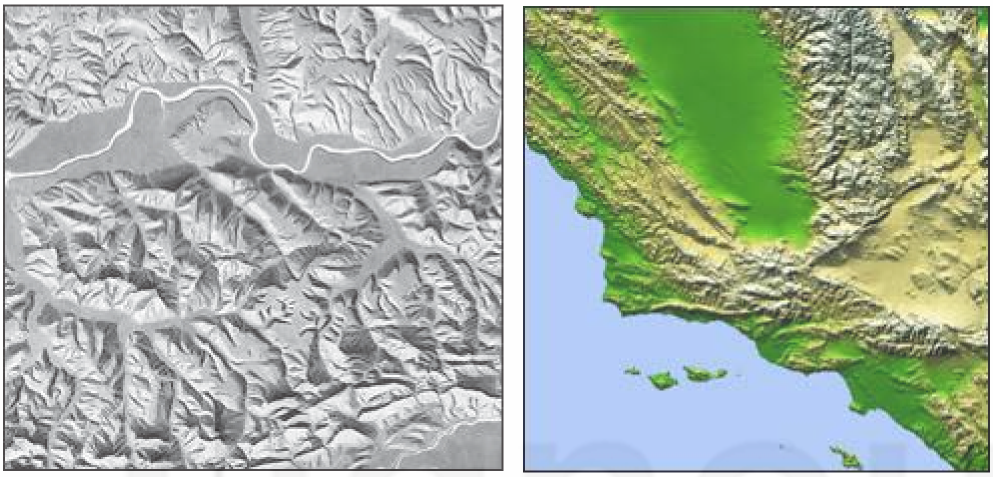

**Fig. 12.5: Shaded relief map and colour density slices of shaded relief maps (source: www.reliefshading.com/cartographers/imhof.html)**

- **Draped Views**: The ultimate display is usually one which registers or "drapes" a surface image, such as a Landsat scene, onto the DEM array (data cells match with pixels), causing that surface and the features on it to appear in some form of 3-D display (e.g., in a perspective view or by creating pseudo-stereo pairs as a stereo model). Likewise, various thematic maps, as for example, land use, urban structure, or geology, can be put into 3-D mode (Fig. 12.6).

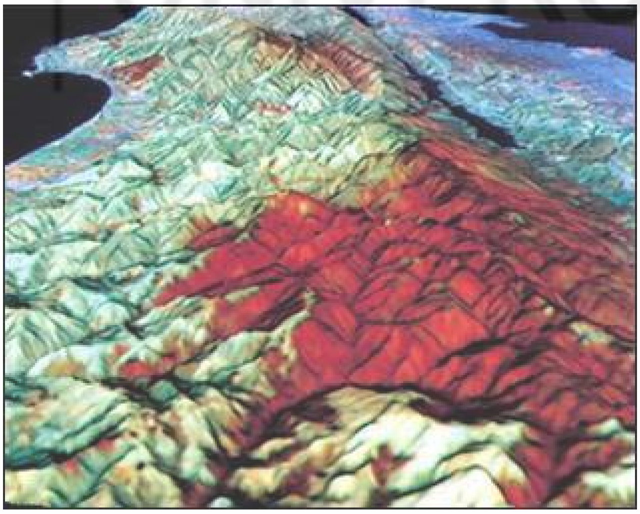

**Fig. 12.6: Image draped over a DEM (www.seamless.usgs.gov/)**

- **Perspective Views:** Since one can readily calculate geometric variables, such as orientation and height from the digitised data, the surfaces can be recreated to look like oblique photos. It is easy to examine such surfaces from different perspectives by rotating the view horizontally (along a vertical axis) or changing the look angle.

b) **Information System**

You know that information system is a set of written, electronic (computers and telecommunication technologies), or graphical method of communicating information. The basis of an information system is the sharing and processing of information and ideas (Fig. 12.7).

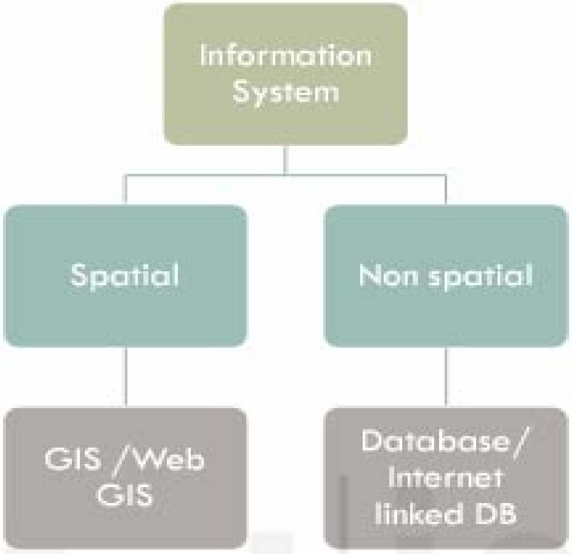


**Fig. 12.7: Components of an information system**

Any information could be spatial or non-spatial. The non-spatial information system is managed through a database and internet linked database systems. Any website is an example to the non-spatial information system. On the contrary, spatial information system requires special tools such as geospatial libraries for managing the database as well as managing the web components. For instance the webpage: http://www.seesouthernforests.org/explore-maps, is spatial information system, where maps are displayed for conveying the message rather than texts and graphics (Fig. 12.8).

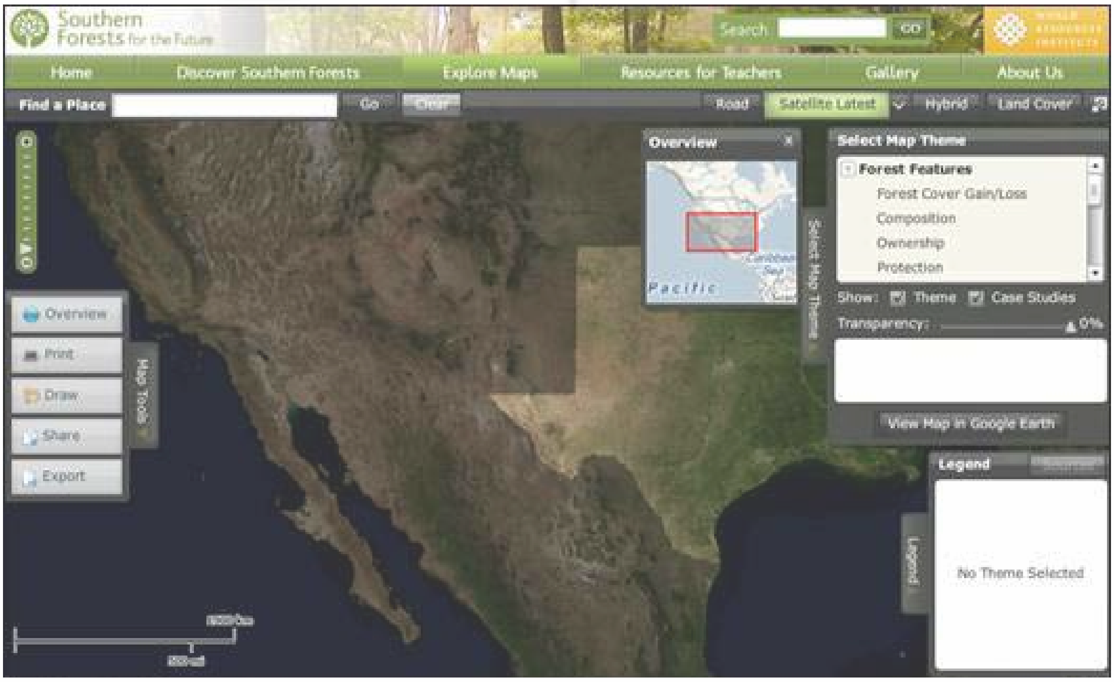


**Fig. 12.8: An internet usage of Geographic information system (www.seesouthernforests.org/explore-maps)**

## 12.5 GIS : A DECISION SUPPORT SYSTEM

*Decision Support Systems (DSS)* is a well-established area of information systems (IS) application. These systems focus on specific decisions and on supporting rather than replacing the user's decision making processes. Definitions of DSS emphasise the need to support semi-structured and unstructured decisions. Also, there is a general consensus in the definitions of DSS that interface, database and model components are usually required to fully support decisions. DSSs serve the management, operations, and planning levels of an organisation and help to make decisions, which may be rapidly changing and not easily specified in advance. DSSs include knowledge-based systems. A properly designed DSS is an interactive software-based system intended to help decision makers compile useful information from a combination of raw data, documents, personal knowledge, or business models to identify and solve problems and make decisions. In the period since DSS came to prominence there has been considerable growth in the importance of geographic information systems (GIS). This growth in GIS reflects the decreased cost of the required technology and the increasing availability of appropriate spatial data.

Within the GIS field there is increasing interest in the use of GIS software to provide decision support. When combined with GIS the Decision support system becomes *Spatial Decision Support Systems* or SDSS. It can therefore be seen as an important subset of DSS, whose potential for rapid growth has been facilitated by technical developments.

The availability of appropriate inexpensive technology for manipulating spatial data enables SDSS applications to be created (Fig. 12.9). The benefits of using GIS based systems for decision making are increasingly recognised. However, the value of SDSS is not determined by its innovative use of technology.

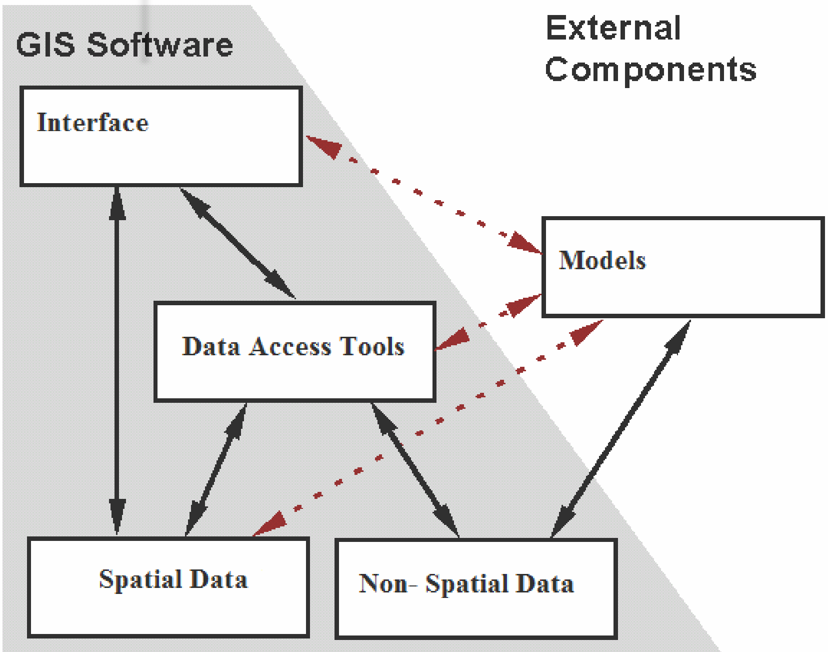


**Fig. 12.9: Components of spatial decision support systems SDSS**

Instead the contribution of these applications will be determined by how well they support the need for a spatial component in decision making. SDSS will be useful for three core groups of applications:

- *First group of decision makers* consist of decision makers in the traditional areas of application of GIS in disciplines such as geology, forestry and land planning etc.
- *The second group of decision makers*, for whom SDSS can make an important contribution, is in fields such as routing or location analysis.
- *The third group of decision makers* include those disciplines such as marketing, Additional possibilities for analysis are provided by the availability of increasing amounts of spatially correlated information, for example demographic data, where the importance of both spatial data and modelling is somewhat neglected at present.

The advances in computer technology and GIS techniques suggest that SDSS will be an important component of DSS applications in future. This trend will be driven by the relevance of spatial information as a component of the information needed for a wide range of decisions. This class of DSS will make an important contribution, not because of its use of the latest technology, but because it will allow decision makers to incorporate a spatial dimension in their decision making. This spatial dimension, which is not fully accounted for in the traditional DSS designs, is an important feature of many areas of DSS applications. These potential areas of application include fields, such as routing or marketing, which have been important fields of DSS applications in the past. Comprehensive decision support will require the effective integration of GIS and non GIS techniques. This can be achieved by building systems using a GIS as a DSS generator. The challenge for SDSS builders is to achieve an appropriate synthesis of modelling techniques and interface with database approaches, drawn from the GIS and specialised domains, to provide effective decision support for these areas.

**Check Your Progress II**

***Spend 5 mins***

1. Expand ViSc, SDSS DTM and UTM.

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2. Differentiate cartographic output from non-cartographic output.

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3. What are the components of SDSS?

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## 12.6 ACTIVITY

a) Prepare a list of websites enabled with web GIS.

b) Prepare a list of towns in GIS and export it as .kmz and open the file in Google Earth.

## 12.7 SUMMARY

Let us sum up about what we have learnt in this unit:

- GIS allows user to display spatial and tabular data as maps, tables and charts, visualise information in ways that reveal new relationships, patterns, trends not visible with text files, spreadsheets and databases and perform spatial analyses.
- A strong GIS platform must contain powerful tools for different types of outputs. There are four major types of outputs one can expect from a GIS, such as texts, graphic outputs, digital data and hardcopy outputs.
- There are two broad categories of GIS outputs, viz., cartographic and non-cartographic outputs. Cartographic outputs are maps prepared adhering to the cartographic conventions, while non-cartographic outputs are map models and information system and primarily used for visualisation purposes.
- Digital Elevation Models, Shaded relief maps, Perspective Views, Draped Views and information system constitute non-cartographic outputs while hard copy map represents cartographic output.
- Recently, within the GIS field there is increasing interest in the use of GIS software to provide decision support. When combined with GIS the Decision support system becomes spatial decision support systems or SDSS.

*Spend 30 mins*

## 12.8 UNIT END QUESTIONS

1. What are different types of GIS outputs?
2. What is map generalisation and how it helps in mapping rivers and boundaries?
3. What are the common types of map symbolisation ?
4. Who are the beneficiaries of SDSS?

## 12.9 REFERENCES


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- http://advanced.jhu.edu/academic/environmental
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- www.lasermapusa.com/en/projectexperience.html
- www.reliefshading.com/cartographers/imhof.html
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Data from the above mentioned websites was retrieved between 1st December 2011 to 30th January 2012.

## 12.10 FURTHER/SUGGESTED FURTHER READING


- Turban, E. (1995) *Decision Support and Expert Systems 4th ed.*, Prentice-Hall International, 241-242.
- Densham, P. J. (1991) Spatial Decision Support Systems. *Geographical Information Systems, Volume 1 : Principles*, edited by Maguire, D.J., Goodchild, M.F. and Rhind, D.W., Longman.


## 12.11 ANSWERS

**Check Your Progress I**

1. Text and tables; Graphics; Hardcopy outputs; Digital Data
2. Line printers, scanners – Raster devices; Plotters, CRT – Vector devices.
3. Digital Line Graph
   .shp (ESRI Shape), .dwg,dxf (Autodesk drawing and exchange format), .dgn (Micro station design files), .kml/kmz (Key hole markup language – Google Earth).

**Check Your Progress II**

1. Visualisation in Scientific Computing, Spatial Decision Support System, Digital Terrain Model, Universal Traverse Mercator
2. Cartographic outputs are generally maps enclosed in a grid, while non-cartographic outputs are graphic displays of spatial models.
3. Spatial Data, Non-spatial data, data access tools, interface and models.

**Unit End Questions**

1. Refer to section 12.2 for types of GIS outputs.
2. Refer to section 12.4.1 for map generalisation and its usefulness.
3. Refer to section 12.4.1 for map symbolisation and its examples.
4. Refer to section 12.5.1 for spatial decision support system and its. beneficiaries.

# UNIT 13 GIS PROJECT DESIGN AND IMPLEMENTATION

## Structure



## 13.1 INTRODUCTION

You have read and learnt about the basic concepts of spatial analysis and GIS outputs in the previous units of this block. Now, in this unit you shall learn about the design of a GIS Project and its successful implementation using the knowledge you have gained from the previous units. You shall also read about the various aspects of GIS design that will help you in preparing a successful GIS. In this regard, you should always remember that *"Careful Design"* at the beginning of a project is the only keyword to achieve a successful GIS. In this unit you will read and know about the science of GIS Design. So come and let's explore the world of GIS Design.

### Objectives

After reading this unit you should be able to:

- define and discuss the importance of GIS design;
- identify the various components, approaches and models of GIS design;

- assimilate the concepts and objectives of the system (project) life cycle;
- discuss the limitations of GIS design;
- describe the advantage of the marble model (spiral model) for GIS design as opposed to the waterfall model;
- recognise the influence of GIS information products; and
- familiarise with the idea of verification and validation.

## 13.2 HISTORY OF GIS DESIGN

*GIS design* can be defined as a plan or series of processes for developing a successful GIS application. GIS design makes use of state-of-the-art techniques and modelling tools suitable for database development with mainstream software packages.

Let us now briefly look at the history of GIS Design. It was during 1960s, when the GIS was quite a new tool, there was a rapid growth in the production of both raster and vector GIS software. Some of them were created as operational systems almost like today's GIS software; many of them were developed for academic and experimental use in colleges and universities. Unluckily, almost all of these systems failed. Some of them even didn't qualify as an analytical tool while others produced erroneous results.

Do you know why these systems failed? They failed only because of their poor design as software systems.

However, during the last few decades, we have seen more and more successful implementations of the spatial analytical software that is generally referred to as GIS. They are no doubt mostly capable of performing the tasks for which they were designed quite efficiently at a very reasonable price. So, we should remember that GIS design is not only about the software design alone but it also includes efficiency and the price too.

You might be thinking at this point that the major problem in implementing a GIS is always technical whereas this is not the case. Rather the main problem is often the mismatch between the capabilities of the software and the needs of the users, data and analytical needs, as well as personnel needs, including training and user acceptance. Actually, the availability of software capabilities in most of the GIS platforms exceeds the requirements of the user, especially in commercial sectors. Fortunately, these problems can be avoided by adopting a proper GIS design at the beginning. So, let us read in the following section the need to examine the design of GIS implementation. We shall also discuss about how structured design processes, primarily modified from the field of software engineering, can be useful for ensuring GIS success.

## 13.3 NEED FOR GIS DESIGN

Have you ever thought that why do we need design in GIS? This is a very important question that you should answer before we adopt a GIS. We all know nowadays, that the GIS professionals are working with geographic information to manage various aspects of our world. And as mentioned earlier, careful and good design is what it takes to make their work flow smoothly and successfully. Also you must keep in mind that since developing an operational GIS requires lot of money and time you should avoid the consequences of failure as far as possible. Though design doesn't guarantee the success, for example, the Edsel automobile, one of the most designed automobile in the history of United States was an absolute failure in terms of sales; still careful design will always increase the chances of success. You know that well designed shoes from companies are liked by many but we should also remember that there are still some designs from these companies which are still not liked by people. So the point is clear that proper design is an important part of success. Design in GIS is also an inseparable part of successful implementation of a GIS application.

We know that GIS uses software available in the commercial marketplace that is sometimes very complex. It often requires huge computations in a single session. And because of these computations even minor errors due to the software or poor design at the initial stage of software development eventually leads into unmanageable errors. To understand this better, let us read about the two types of errors:

- **Obscure Computational Errors:** In this case the users cannot detect the error. The error may be found only after thousands of operations have been performed on erroneous results for obtaining the intermediate output/ coverage.

- **Input or Formatting Errors:** This kind of error may cause the software to malfunction and hang up the computing session, resulting in data lost.

From the above scenario it is quite clear that poorly designed software used in the GIS can cause the failure of GIS application. The better care can be taken to minimise or remove as much error as possible in the input phase of an operation. We must always concern ourselves with the basic and more important functions of GIS Design as given below.

i) **Serving the Proper Users**: In GIS design it is important to know the users before we develop the GIS application. But most of the time especially in a multiuser institutional setting, the possibility of excluding potential users during the implementation phase is very high. However, surprisingly, you will find that many district and state organisations, perhaps having offices within easy walking distance begin developing large databases without much consultation or interaction with other interested parties. Such a narrow minded vision of GIS implementation results in duplication of effort, wasting time and money (DeMers and Fisher, 1991).

ii) **Serving the Users Properly:** After the potential users have been identified the second step is to address the needs of the users properly i.e., what are the requirements of the users in terms of software capabilities, data needs and institutional fit? The first two concerns are strong indications of why knowledge of both system functional capabilities and proper database construction are so important to the long-term functioning of a GIS. Before a GIS system is purchased, with its own data model and analytical capabilities, the spatial data handling needs of the user must be determined.

**Check Your Progress I**

*Spend 5 mins*

1. Why GIS design is important in successful implementation of GIS?

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## 13.4 COMPONENTS OF GIS DESIGN

Let us know about the basic structure of a GIS design process. GIS design consists of two major components *viz. GIS system design* and *GIS software design* (Fig.13.1).

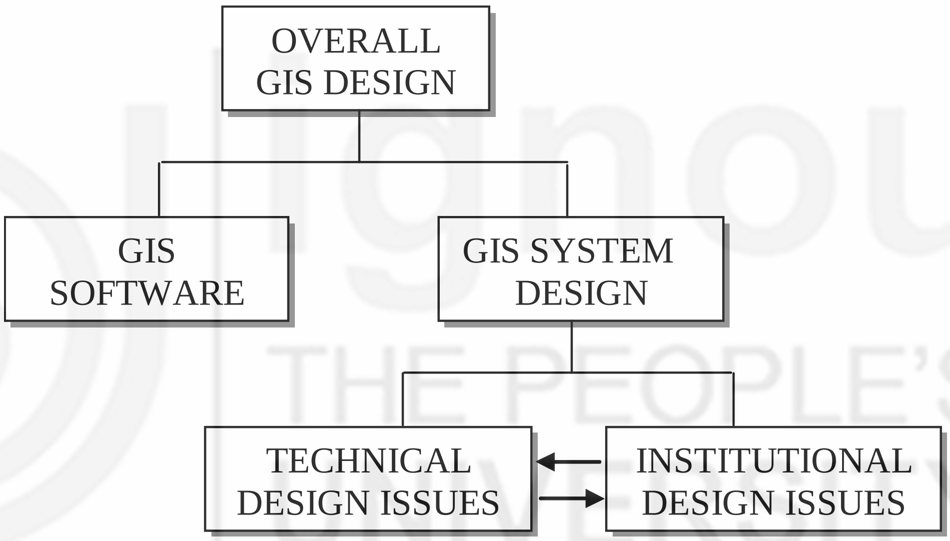


**Fig. 13.1: GIS design process (source: Marble, 1994)**

i) **GIS Software Design** deals with the software development and related issues. It requires a very good technical knowledge of data structures, data models and computer programming. Though persons in this field get comparatively higher salaries but one has to have an equivalent of a computer science or computer engineering degree in addition to knowledge of GIS basics.

ii) **GIS System Design** deals with the interactions of individual people, groups of people and computers as they function within organisations. GIS is not just about computing. It is also about how people are affected when GIS design is incorporated into an organisation. It also deals with the changes brought in the working of the people and overall functioning of the organisation.

The computerisation of many banks in different part of the world has changed the way we do transactions. Similarly, the GIS changed the functioning of many organisations. When a new technology is introduced in an organisation the structure of that organisation is generally modified due to (i) requirement of different or additional training of people doing the work, (ii) along with the funds for software and hardware and (iii) changes in the flow of information within the organisation. Since, nowadays huge databases are available that can be accessed by individuals, the integrity and quality of the data need to be maintained with proper security by developing security and quality control measures within the organisation.

As seen in Fig.13.1 GIS system design can further be divided into two highly interactive subdivisions viz.,

i) Technical or internal design issues deals mostly with the system functionality and the database

ii) Institutional or external design issues deals with the relationship between the GIS operation and the organisational setting.

Let us try to answer some of the questions that go with the technical issues are:

Will the system work the way we need it to?

Can we answer the questions needed to be answered?

Have we got the correct data in the right format?

Do we have people with the right training to run the system?

Can our system adapt to changing demands?

Likewise, some of the major questions that accompany the institutional issues are:

Do we have the funding necessary to permit continued operations?

Can we obtain data at reasonable cost?

Do we need to employ applications programmers to customise the software? Will we have adequate software support from our GIS vendor?

Will we be legally responsible for errors made through our analyses?

And are we meeting the larger goals of the organisation beyond the immediate end of performing GIS analyses?

Now it is clear to you after reading the above paragraphs that the technical design issues and the institutional issues are highly interactive and inseparable. That is even if a GIS operation is successful in every way from the technical design standpoint it will fail if there is no support from the organisation or external sponsor.

## 13.5 APPROACHES AND MODELS OF GIS DESIGN

Planning before we begin the GIS design and good management is necessary to make our GIS successful. And we also know that most of the GIS failed due to lack of a good plan at the initial stage. Let us discuss some of the approaches and models of GIS design:

### 13.5.1 The Software Engineering Approach

Software Engineering is a subfield of computer science that is dedicated to designing, implementing and modifying software so that it is of high quality, affordable, maintainable and fast to build. It is a "systematic approach to the analysis, design, assessment, implementation, test, maintenance and reengineering of software, that is the application of engineering to software" (Phillip, 2007). It has been developed mainly to address the problems of software that failed to achieve its intended goals. Since GIS is mostly driven by software, most of its problems during the initial implementation phase are very much similar to those encountered in the development of software. For example, you are developing a word processing system that allows you to write, edit, save, check spelling and grammar, use a thesaurus, import graphics, format page layouts, typeset, and print documents easily and efficiently.

Similar to the above example in case of GIS implementation, it is very important to understand the user's needs before we begin the process. In GIS systems design, the relevant user needs involve the kinds of spatial analytical technique to be applied, training and the capacity of the analytical techniques to meet the overall organisational goals.

### 13.5.2 Systems Life Cycle Approach

The systems life cycle (also known as project life cycle) is one of the first concepts developed in the field of system design. Like in any other system, GIS also has a life cycle starting all the way from project initiation going through project planning, project execution and finally the project closure (Fig.13.2). In short every GIS project has a beginning, middle and an end.

The project life cycle dictates the operations and organisational structure that will bring the project to a successful completion. If you are working on a single project, the project life cycle will focus on that one under-taking with the same principles though the operational details will differ. Whether your project is to be performed by yourself, within a small group or within a larger organisational structure, there must be methodology to give a framework for finishing the job. Let us read about the three main objectives of the project life cycle to be considered before starting the project:

- define the activities of the project and their order of performance
- assure consistency among many projects in the same organisation
- provide points for management decision making regarding starting and stopping of individual phases of the larger project

Here you must remember that the project life cycle provides only the guidelines for successful management of a project, i.e. a framework for the project. The fundamental decisions and other important aspects of the organisation like support of the workers, political issues, assurance of good moral, etc. are done by the Project Manager. The life cycle provides guidelines to facilitate the making of right decisions at the correct time (Yourdon, 1989).

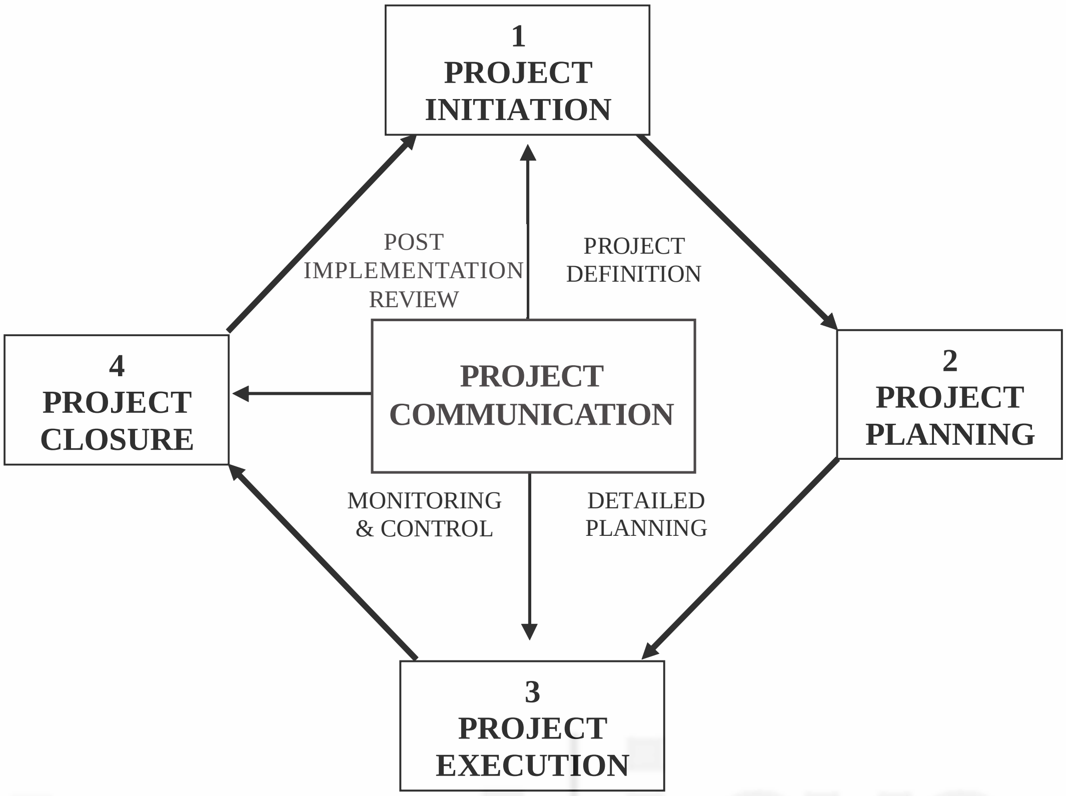


**Fig. 13.2: Typical project life cycle (source: http://cnx.org/content/m31913/latest/Fig1new.jpg)**

The main advantage of the systems life cycle approach is that it provides a very structured framework for the management of a GIS project. Let us read about the number of problems with the systems life cycle approach:

- Designers using the systems life cycle approach often fail to address the context of the business for which the system is being developed.
- The timescale and linear nature of the systems life cycle process do not allow for change in the scope and character of the problem.
- The systems life cycle approach does not put the user at the centre of the system design.
- The systems life cycle approach is often considered to favour hierarchical and centralised systems of information provision. It offers a very techno-centric view of system development.

### 13.5.3 Waterfall Model of System Life Cycle

This method although flexible in terms of the number of steps is highly structured and progresses in linear fashion. The steps cover the definition of user requirements, the specification of functional needs, systems analysis, detailed design, the testing of individual modules, the testing of subsystems, and finally system testing. In the computer industry this approach is often called the Waterfall Model (Fig.13.3) of system design (Boehm, 1981).

The waterfall model is a sequential development approach, in which development is seen as flowing steadily downwards (like a waterfall) through the phases of requirements analysis, design, implementation, testing (validation), integration, and maintenance. The basic principles of waterfall model are:

- Project is divided into sequential phases, with some overlap and splash-back acceptable between phases.
- Emphasis is on planning, time schedules, target dates, budgets and implementation of an entire system at one time.
- Tight control is maintained over the life of the project via extensive written documentation, formal reviews, and approval/signoff by the user and information technology management occurring at the end of most phases before beginning the next phase.

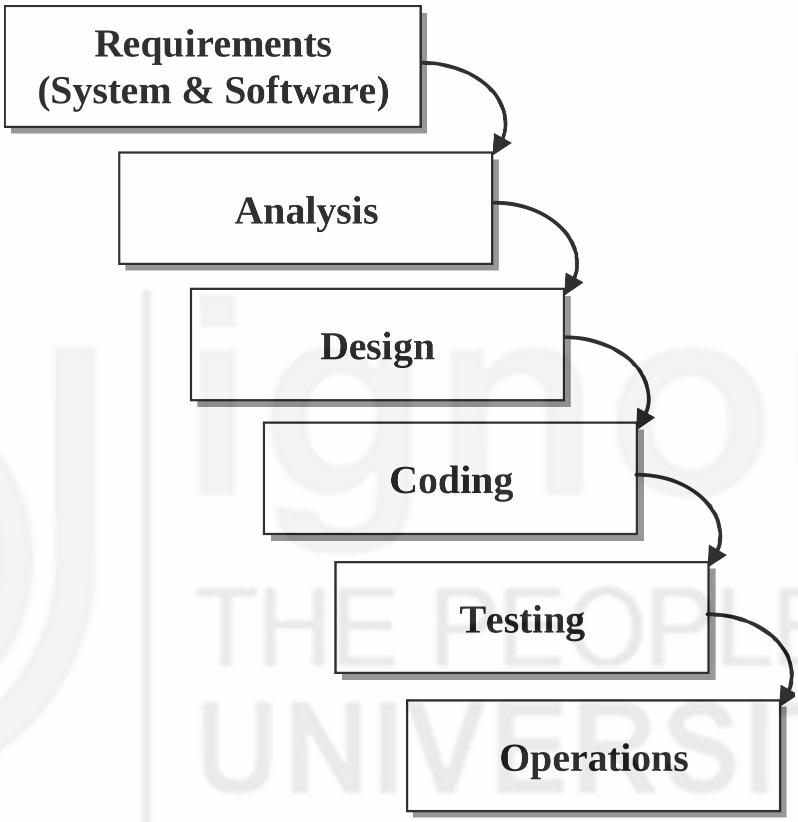


**Fig. 13.3: Waterfall model of system life cycle (source: DeMers, 1997)**

The waterfall model was developed to provide a structure for the systematic movement from requirements analysis through testing and final operation of an information system. The waterfall model generally cascades from conceptual design through program detail design, code creation and code testing to program implementation.

Despite its popularity, there are a number of problems with the waterfall model as a tool for developing a GIS. First, since the model requires each step to be completed properly before the next proceeds, any delay in a single step will slow the entire system (Yourdon, 1989). Within a GIS context, even if we know most but not all of the user requirements, we may not proceed to the input phase until the rest of the requirements have been received. In this approach most of the time new requirements are often discovered late in the requirements phase. This implies that by the time when all requirements are known input data could be out of date. Yet another problem with the waterfall model is its linear structure. Because of this linear progression almost every implementation is going to encounter problems at various steps.

### 13.5.4 The Prototyping Approach

The prototyping approach was developed as a response to the criticisms of the systems life cycle approach (waterfall model), particularly in response to the lack of consideration of users. The user first defines the basic requirements of the system by using the rich picture and root definition techniques. The system designer takes these basic ideas to construct a prototype system to meet the needs identified by the user. These prototype systems are often described as demonstrators in GIS projects. The users who identified the original requirements for the system then experiment with the demonstration system to see if it is what they expected. Other potential users of the final system may be brought in at this stage to see if the system is of wider value. The system designer uses their recommendations to improve the system.

The basic principles involved in the approach of system designer are:

- It provides a complete development methodology and approach to handling selected parts of a larger, more traditional development methodology (i.e. incremental, spiral or Rapid Application Development (RAD)).
- It attempts to reduce inherent project risk by breaking a project into smaller segments and providing more ease-of-change during the development process.
- The user is involved throughout the development process, which increases the likelihood of user acceptance of the final implementation.
- Small-scale mock-ups of the system are developed following an iterative modification process until the prototype evolves to meet the users' requirements.
- While most prototypes are developed with the expectation that they will be discarded, it is possible in some cases to evolve from prototype to working system.
- A basic understanding of the fundamental business problem is necessary to avoid solving the wrong problem.

The prototyping approach has the following advantages over the systems life cycle (waterfall model) method:

- Users have a more direct and regular involvement in the design of the system.
- It is easier to adapt the system in the face of changing circumstances which were not identified at the outset of the project.
- The system can be abandoned altogether after the first prototype if it fails to meet the needs of users. This reduces the cost of developing full systems.
- If money and time are available a number of prototypes can be built until the user is satisfied.

Though the prototyping approach has a lot of advantages over system life cycle approach yet, it is not completely fault proof. It has the following drawbacks.

- Prototyping can be difficult to manage. There may be large numbers of users with large numbers of ideas and opinions.

- The resource implications may change following the development of the first prototype.
- Knowing when to stop development can also be a problem. However, some GIS designers argue that this is a positive aspect of the approach since few, if any, GIS systems are ever finished.

### 13.5.5 The Spiral Model: Rapid Prototyping

Several attempts have been made by various workers in the field to develop and refine GIS design models. Among these varied models, Duane Marble (1994) after certain modification of software engineering approach, pioneered by earlier workers, conceptualised and developed a more flexible, multilevel design process called the *Spiral Model.*

Let us discuss the Spiral Model. In this model of GIS design the three tasks of acquiring, organising and analysing information are treated separately and impose three levels of detail. The spiral model and its component parts are shown below (Fig.13.4).

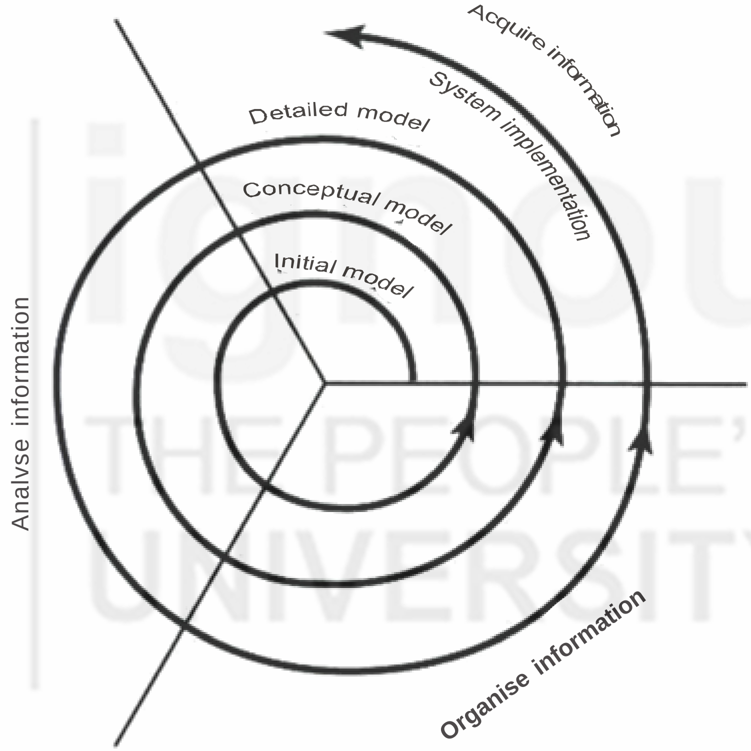


**Fig.13.4: Spiral GIS design model. The labels indicate the levels of design (source: Marble, 1994)**

The basic general principles involves with the rapid prototyping of spiral model are:

- Focus is on risk assessment and on minimising project risk by breaking a project into smaller segments and providing more ease-of-change during the development process.
- Each cycle involves a progression through the same sequence of steps, for each part of the product and for each of its levels of elaboration, from an overall concept-of-operation document down to the coding of each individual program.
- Each trip around the spiral traverses three basic quadrants: (1) acquire information (2) organise information and (3) analyse information.
- Begin each cycle with an identification of stakeholders and their win conditions and end each cycle with review and commitment.

## 13.6 GIS INFORMATION PRODUCTS

You have read about the potential of GIS and now let us discuss about the GIS information products. Generally, the GIS information products are the result of analysis within the software. These products are very much dependent on the nature of organisation, its goals and its experience with the system. Even in scientific organisations there are most often general ideas of what the GIS is capable of doing and what the technology might offer the individual institution.

Organisations have a particular goal in mind while considering the implementation of GIS. They most likely know roughly about the general data that might be part of the system. In fact, many organisations recognise the value of the data in an automated form even before they could see the potential utility for analysis. To extract particular spatial information products from the users, we must recognise the close linkage between what goes into the system (data input) and what comes out (output).

### 13.6.1 Managing and Organising the Local Views

It is always a good practice to keep track of the relationships between each user and each GIS product because mostly we'll be working with many potential users of differing individual needs. The use of a decision system matrix has been suggested that lists the users along the side of and the products along the top; Fig.13.5 shows a highly simplified version. Decision System Matrix is a useful tool.

This device allows us to keep track of the Spatial Information Products (outputs) for each user. Later, while integrating each of the local (individual user) views into a larger global view, data from this matrix provides much of what we need.

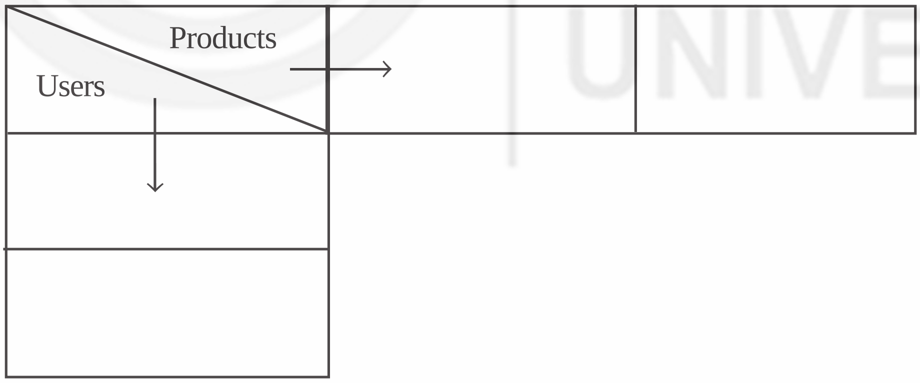


**Fig. 13.5: Decision system matrix. Simplified decision system matrix used to organise individual user views of the GIS (source: DeMers, 1997)**

An alternative to the decision matrix is an organisational diagram such as that shown in Fig. 13.6. This type of diagram, like the matrix format, is useful for integrating the local views into a more general global view. Both can also be used to decide which products are the most important, based on which are most often called for by individual users.

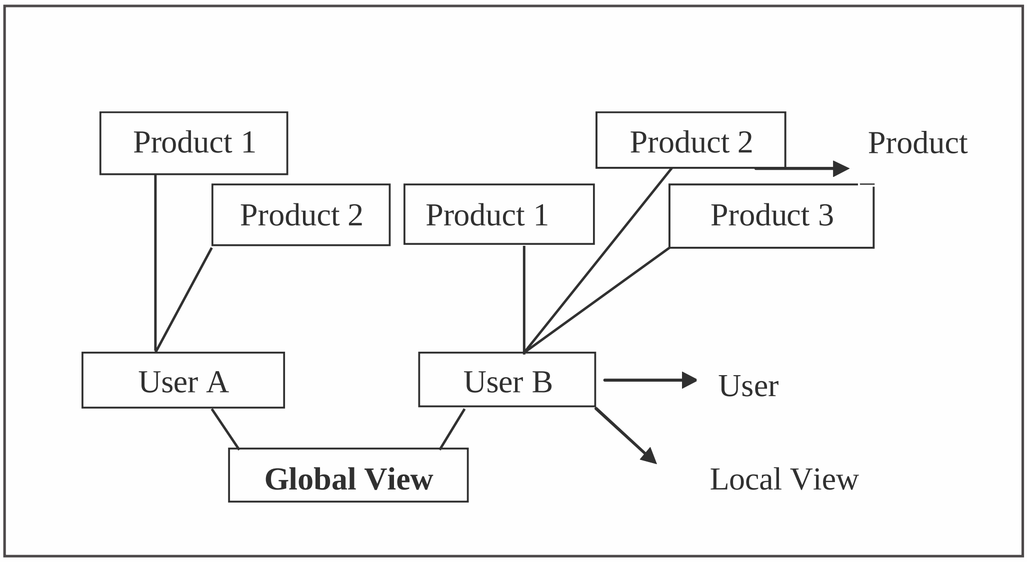


**Fig. 13.6: Organisational chart used to display individual user views of the GIS (source: Marble, 1994)**

### 13.6.2 Design Creep

Design creep, can be defined in terms of its results: at one extreme is a system with more functionality than is necessary and at the other is a system having an incorrect functionality. Fig. 13.7a shows a model for a rather structured approach to GIS design, proceeding from the feasibility study at the left through the design phase and finally into the implementation phase. The two curves indicate the relationship between the technical design process (light curve) and organisational learning. As you can see, organisational learning begins late in the process, when the system is almost completely designed and is nearly ready for implementation. Thus users are forced to learn and operate a system that may not meet their needs.

In Fig.13.7b the more flexible spiral model (Marble, 1994) is shown where the organisational learning drives system development. As users become familiar with what a GIS is capable of, they can describe their system needs at a point well in advance of implementation stage. You can also see that the more sophisticated the organisational learning, the more sophisticated the system becomes, but the learning curve is always above the design curve. In short, the users are driving the design of the GIS, rather than being driven to learn by an in-place system. The latter approach avoids design creep and allows the system to grow in complexity as the organisation's needs increase.

**Organisational learning**

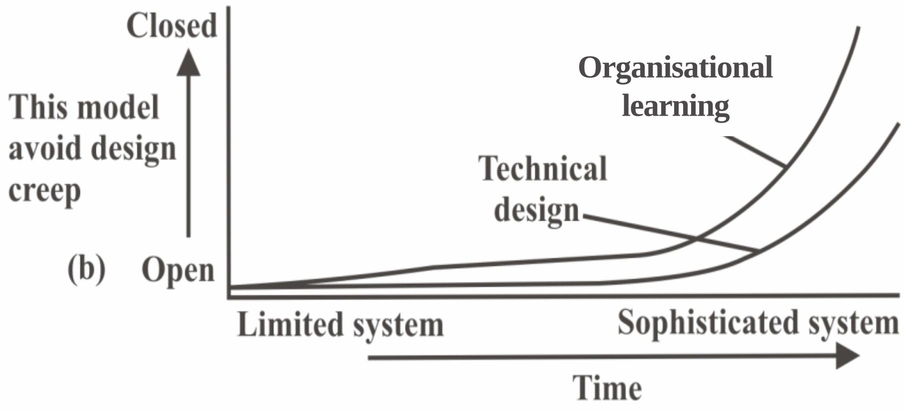


**Fig. 13.7: Avoiding Design creep. Two approaches to system design:**
**(a) a structured, linear approach that leads to design creep and**
**(b) the Marble spiral mode, which avoids design creep**
**(source:DeMers, 1997)**

## 13.7 VERIFICATION AND VALIDATION

In any software related project *Verification and Validation* is the process of checking that a software system meets specifications and that it fulfills its intended purpose. It is normally part of the software testing process of a project. This is the same in case of GIS also. In GIS, *validation* ensures that the product actually meets the user's needs and that the specifications were correct in the first place, while *verification* is ensures that the product has been built according to the requirements and design specifications.

*Validation* ensures that 'you built the right thing' while *verification* ensures that 'you built it right'.

Let us look at the primary questions that are required to be asked here:

Will the GIS perform the tasks the organisation needs in a timely and correct manner? The answer should be YES if the design process has been performed properly. This is possible only when all the details and specific needs of the organisation are available to the GIS provider otherwise the system is likely to fail to meet the needs. This will in turn help the GIS vendor to determine whether the system under consideration can meet those needs because doing the right thing at the first time is better than fixing it later with huge expenditure.

**Check Your Progress II**

***Spend 5 mins***

1. Mention the two components of GIS Design.

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2. How is Waterfall model different from Spiral model?

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3. What is verification and validation?

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## 13.8 ACTIVITY

1. Write down the steps involved in developing a GIS project using the waterfall model.

## 13.9 SUMMARY

You have read in this unit about GIS project design and implementation. Let us sum up about what we have learnt in this unit:

- Careful and proper design at the beginning makes the GIS design work flow smoothly and successfully.
- The basic and more important func-tions other than the software issues of GIS Design are Serving the Proper Users and Serving the Users Properly.
- The overall GIS design has been divided into GIS software design and GIS system design. The GIS system design is again divided into the technical design and the institutional design.
- When a new technology is introduced in an organisation the structure of that organisation is generally modified due to (i) requirement of different or additional training of peo-ple doing the work, (ii) along with the funds for software and hardware and (iii) changes in the flow of information within the organisation.
- Due to increase in the volume of databases that are available for individual accessibility, the maintenance of integrity and data quality becomes eminent through security and quality control measures within the organisation.
- The technical design issues and the institutional issues are highly interactive and inseparable.
- The various approaches and models of GIS design are: The Software Engineering Approach, Systems Life Cycle Approach (Waterfall model of system life cycle), The Prototyping Approach and The Spiral Model: Rapid Prototyping. In the section advantages and disadvantages of each approach and the models were discussed.
- The Spiral model has certain advantages over waterfall model. The products of a GIS are related to the organisational needs or requirements.
- There is a close relationship between the technical design and the organisational needs. It is very important to gather all the requirements of the organisation prior to its GIS Design.
- Verification of GIS verification is ensuring that the product has been built according to the requirements and design specifications while validation ensures that the product actually meets the user’s needs, and that the specifications were correct in the first place.

## 13.10 UNIT END QUESTIONS

*Spend 30 mins*

1. What are the components of GIS? Explain in GIS System design.
2. Give a brief account of the various approaches and models of GIS Design.
3. What is GIS Information Product?

## 13.11 REFERENCES


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## 13.12 FURTHER/SUGGESTED READING


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## 13.13 ANSWERS

**Check Your Progress I**

1. Refer section 13.3.

**Check Your Progress II**

1. GIS design consists of two major components – GIS system design and GIS software design
2. Refer to section 13.5.3, 13.5.4 and 13.5.5
3. Refer to section 13.7

**Unit End Questions**

1. Refer to section 13.4
2. Refer to section 13.5
3. Refer to section 13.6

# GLOSSARY

- **Address Geocoding:** It is the process of assigning alphanumeric locational identifiers to spatially related information.
- **Alphanumeric:** It consists of both letters and numbers and including other symbols such as punctuation marks.
- **Analog/Digital Conversion:** It is the process of converting data from analog to machine usable digital format via processes such as digitising or scanning.
- **Arc:** It is a portion of the perimeter of a two-dimensional closed figure lying between two nodes at which two or more arcs intersect. An arc usually represents a continuous common boundary between two adjoining mapping units.
- **Area:** It is a level of spatial measurement referring to a two-dimensional defined space. A polygon on the earth as projected onto a horizontal plane is an example of an area.
- **Attribute:** This is a set or collection of data that describe the characteristics of real world entities or conditions. Attribute data are usually alphanumeric. Small amounts of attribute data are frequently used to describe the graphic representation of an entity on a map as a label, e.g., a polygon label. Large amounts of attribute data are usually maintained as separate attribute data sets, related to a map by names or codes.
- **Cartographic Model:** It is a flow diagram depicting a process of combining and analysing multiple layers of mapped information to create a new synthesised map.
- **Digital Data:** It is the information stored and processed with numerical digits, often in base 2.
- **Digital Elevation Model (DEM):** This is a file with terrain elevations recorded for the intersection of a fine-grained grid and organized by quadrangle as the digital equivalent of the elevation data on a topographic base map.
- **Digital Terrain Model (DTM):** This is a land surface represented in digital form by an elevation grid or lists of three-dimensional coordinates.
- **Digitisation:** It is the process of converting an analog display into a digital display.
- **Digitiser:** It is a device for scanning an image and converting it into numerical format.
- **Drawing Exchange Format (DXF):** This is used by several mapping programs that are based on AutoCad.
- **Drum Plotter:** It is a device with a rotating cylindrical drawing surface and paper reels for plotting graphic images on a long roll of
- **Drum Scanner:** It is a device for converting maps to digital form automatically.
- **ESRI:** This is a software development and services company providing Geographic Information System (GIS) software and geodatabase management applications with headquarters in Redlands, California.

- **Global Positioning System:** This is a network of radio-emitting satellites deployed by the U.S. Department of Defense.
- **IDRISI:** This is a public domain, raster-based GIS system from Clark University. It is also the name of a cartographer and geographer of major significance during the medieval period.
- **Line in Polygon:** It is the process to superimpose a set of lines on a set of polygons, and determine which polygons (if any) contain each line.
- **Line:** It is a level of spatial measurement referring to a one-dimensional defined object having a length and direction and connecting at least two points. Examples are roads, railroads, telecommunication lines, streams, etc.
- **Map Generalisation:** It is the process of reducing the detail of spatial features in a map layer. This process is relatively easy for humans and relatively difficult for computers.
- **Map Projection:** It is a device for representing all or part of a rounded surface on a flat sheet.
- **Overlay Analysis:** This is the process of combining spatial information from two or more maps to derive a map consisting of new spatial boundaries.
- **Overlay:** This is a transparent layer placed on an underlying layer or image. The overlay is where symbols, annotations, or image traces can be created or displayed without changing the underlying image.
- **Planimeter:** This is an instrument for measuring mechanically the area of plane figures.
- **Planimetric** map is a map designed to portray the horizontal positions of features; vertical information is specifically ignored.
- **Plotter:** This is a device for drawing maps and figures
- **Point in Polygon:** This is the ability to superimpose a set of points on a set of polygons and determine which polygons (if any) contain each point.
- **Polygon:** It is a two-dimensional figure with three or more sides intersecting at a like number of points.
- **Query:** This is the process to find specific information in a database.
- **Raster-to-Vector:** This is the process of converting an image made of cells into one described by lines and polygons.
- **Spatial:** This refers to phenomena distributed in two or three dimensional space and therefore having physical dimensions.
- **Text File:** It is a file containing only letters, digits, and symbols.
- **Topology:** It is a description of the relationship between node, line, and polygon elements in a vector object.

# ABBREVIATIONS

| | | |
|---|---|---|
| **.dgn** | : | Micro station design files |
| **.dwg** | : | Autodesk exchange format |
| **.dxf** | : | Autodesk drawing |
| **.kml/kmz** | : | Key hole markup language |
| **CAD** | : | Computer Aided Drafting/Design/Drawing |
| **COTS** | : | Commercially available Off-The-Shelf |
| **CRT** | : | Cathode Ray Tube |
| **DEM** | : | Digital Elevation Models |
| **DLG** | : | Digital Line Graphs |
| **DSS** | : | Decision Support Systems |
| **DTM** | : | Digital Terrain Model |
| **DXF** | : | Data Exchange Format |
| **ESRI** | : | Environmental Systems Research Institute |
| **IS** | : | Information Systems |
| **RAD** | : | Rapid Application Development |
| **SDSS** | : | Spatial Decision Support System |
| **SQL** | : | Structured Query Language |
| **USGS** | : | United States Geological Survey |
| **UTM** | : | Universal Traverse Mercator |
| **ViSC** | : | Visualisation in Scientific Computing |

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