Tribhuwan University

Department of Computer science and Information Technology

B.Sc.CSIT Programme

Geographical Information System

Lecture Notes

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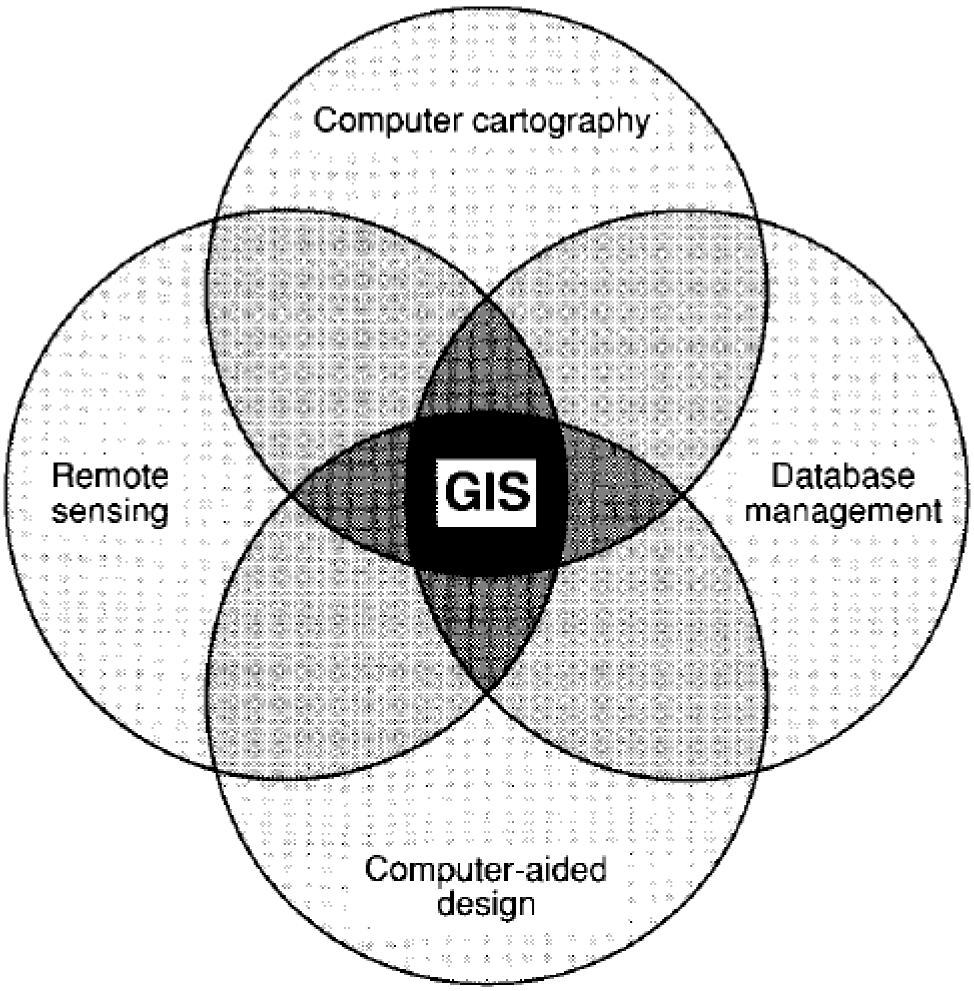
Contents

Unit 1: Introduction

"Almost everything that happens happens somewhere. Knowing where something happens is critically important." -- Longley, *et al.*, 2001, pp. 2



GIS: A particular form of *information system* applied to *geographical data*
A **system**: A group of connected entities and activities which interact for a *common purpose*
An **information system**: A set of processes, executed on raw data, to produce information which will be useful for *decision making*
Geographical data: *Spatially* referenced data sets

1.1 Overview, History and concepts of GIS

Some Definitions

1. GISs are simultaneously the telescope, the microscope, the computer, and the Xerox machine of regional analysis and synthesis of spatial data. (Ron Abler, 1988)

2. A Geographic Information System (GIS) is a computer based system that facilitates the phases of data entry, data analysis and data presentation especially in cases when we are dealing with georeferenced data.
3. A Geographic Information System (GIS) is a computer-based mapping tool that enables geographic or spatial data capture, storage, retrieval, manipulation, analysis, modeling and presentation of the real world scenario. Basically, GIS is working on the principle of geography. Geography or GIS is now proving its potential and widely accepted by interdisciplinary experts at various levels to better manage the earth's resources.

GIS is a tool box

1. "a powerful set of tools for storing and retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes" (Burrough, 1986, p. 6).

2. "automated systems for the capture, storage, retrieval, analysis, and display of spatial data." (Clarke, 1995, p. 13).

GIS is an information system

3. "An information system that is designed to work with data referenced by spatial or geographic coordinates. In other words, a GIS is both a database system with specific capabilities for spatially-referenced data, as well as a set of operations for working with the data" (Star and Estes, 1990, p. 2).

4. "A geographic information system is a special case of information systems where the database consists of observations on spatially distributed features, activities or events, which are definable in space as points, lines, or areas. A geographic information system manipulates data about these points, lines, and areas to retrieve data for ad hoc queries and analyses" (Dueker, 1979, p 106).

GIS is a science

5. "the generic issues that surround the use of GIS technology, impede its successful implementation, or emerge from an understanding of its potential capabilities." (Goodchild, 1992)

GIS is a multi billion Dollar Business

6. "The growth of GIS has been a marketing phenomenon of amazing breadth and depth and will remain so for many years to come. Clearly, GIS will integrate its way into our everyday life to such an extent that it will soon be impossible to imagine how we functioned before"

GIS is a *System* of computer software, hardware and data, and personnel to help manipulate, analyzes and presents information that is tied to a spatial location:

- ***spatial location* –** usually a geographic location
- ***information* –** visualization of analysis of data
- ***system* -** linking software, hardware, data
- ***personnel* –** a thinking explorer who is key to the power of GIS

History

- GIS's origins lie in thematic cartography
- Many planners used the method of map overlay using manual techniques
- Manual map overlay as a method was first described comprehensively by Jacqueline Tyrwhitt in a 1950 planning textbook
- HcHarg used blacked out transparent overlays for site selection in *Design with Nature*
- The 1960s saw many new forms of geographic data and mapping software
- Computer cartography developed the first basic GIS concepts during the late 1950s and 1960s
- Linked software modules, rather than stand-alone programs, preceded GISs
- Early influential data sets were the World Data Bank and the GBF/DIME files
- Early systems were CGIS, MLMIS, GRID and LUNR
- The Harvard University ODYSSEY system was influential due to its topological arc-node (vector) data structure
- GIS was significantly altered by (1) the PC and (2) the workstation
- During the 1980s, new GIS software could better exploit more advanced hardware
- User Interface developments led to GIS's vastly improved ease of use during the 1990s

- During the 1980s, new GIS software could better exploit more advanced hardware

Summary:

1960's Canada Geographic Information System (CGIS) developed: national land inventory pioneered many aspects of GIS

Harvard Lab for Computer Graphics and Spatial Analysis: pioneered software for spatial data handling

US Bureau of Census developed DIME data format

ESRI founded

1970's CGIS fully operational (and still operational today)

- First Landsat satellite launched (USA)

- CARIS founded

- USGS begins Geographical Information Retrieval and Analysis System (GIRAS) to manage and analyze large land resources databases and Digital Line Graph (DLG) data format

- ERDAS founded

- ODYSSEY GIS launched (first vector GIS)

1990's MapInfo for Windows, Intergraph, Autodesk, others

ESRI produces ArcView and ARCGIS

$7+ billion industry

1.2 Scope and application areas of GIS

Some Application Areas:

- Emergency Services (Flood Forecasting and Control)
- Environmental
- Natural Disasters (Tsunami, Flood , Plane Crash)
- Education
- Government (Socio Economic Statistics, Police,)
- Medical (Public Health Alert)
- Industry, Businesses (Tourist Information)
- Defense
- Urban management (Water Supply, Power Supply, Drainage Mgmt)
- Land Information System
- Transportation Management
- River Management
- Shipping Route Management
- Railway GIS

The following are some of those areas where GIS can be fruitfully applied:
One of the first major areas of application was in **natural resources management**, including management of

- Wildlife habitat,
- Wild and scenic rivers,
- Recreation resources,
- Floodplains,
- Wetlands,
- Agricultural lands,
- Forests.

One of the largest areas of application has been in **facilities management**. Uses for GIS in this area have included

- Locating underground pipes and cables,
- Balancing loads in electrical networks,
- Planning facility maintenance

Local, state, and federal governments have found GIS particularly useful in **land management**.
GIS has been commonly applied in areas like:

- Zoning and subdivision planning,

- Land acquisition,
- Environmental impact policy,
- Water quality management,
- Maintenance of ownership.

More recent and innovative uses of GIS have used information based **on street-networks**. GIS has been found to be particularly useful in

- Address matching,
- Location analysis or site selection,
- Development of evacuation plans.

The range of applications for GIS is growing as systems become more efficient, more common, and less expensive. An important distinction between GIS applications is whether the geographic phenomena studied are man-made or natural. Clearly, setting up a cadastral information system, or using GIS for urban planning purposes involves a study of man-made things mostly: the parcels, roads, sidewalks, and at larger scale, suburbs and transportation routes are all man made. These entities often have – or are assumed to have – clear cut boundaries: we know, for instance, where one parcel ends another begins.

On the other hand, geomorphologists, ecologists and soil scientists often have natural phenomena as their study objects. This may be looking at rock formations, plate tectonics, distribution of natural vegetation or soil units. Often these entities do not have clear-cut boundaries and there exists transition zones where one vegetation type, for instance, is gradually replaced by another. It is not uncommon, of course, to find GIS applications that do a bit of both natural and manmade entities. Examples are common in areas where we study the effect of human activity on the environment. Rail road construction is such an area: it may involve parcels to be reclaimed by government, it deals with environmental impact assessment and will usually be influenced by many restrictions, such as not crossing seasonally flooded lands, and staying within inclination extremes in hilly terrain.

A second distinction in application of GIS stems from the overall purposes of use of the system. A prototypical use of GIS is that of a research project with an explicitly defined project objective. Such projects usually have a priori defined duration. Feasibility studies like site suitability, but also simulation studies, for instance in erosion modeling, are examples. We call all of these project based GIS applications.

In contrast to these is what we call institutional GIS applications. They can be categorized in various ways. The duration of these applications is either indefinite or at least not a priori defined. Their goal is to provide base data to other, not to address a single research issue. The example is in governmental agencies like national topographic surveys, cadastral organizations and national census bureaus. They see it as their task to administer (geographic) changes, and their main business is to stay up-to-date, and provide data to others either in the form of printed materials such as maps or in the form of digital data.

The input for GIS can be obtained from remote sensing (RS) satellite Image, aerial photos, Survey of topographical maps, Census data, scanned paper maps and GPS (Global Positioning System)-derived data. Depending on the kind of study and output required, the type of input and analysis will vary. The power of GIS lies in its integration capability between spatial (geographical) and non-spatial or tabular data. Once this relationship is established, any analysis can be performed which will directly answer a set of questions regarding real world problems. Listed here are some examples which tell how GIS assumes greater significance in understanding our basic equirements:

- Which is the best route between Kalanki and Ratnapark having minimal road intersection with good road and lesser traffic jam during peak hours?

- Identify the roads served by Metro water tank in Kalanki with a population between 1,000 and 1,500?
- Which part of Gandaki zone has less literacy rate with unemployed youth between 20 and 30 years of age?
- Where are the potential aquifers located away from agricultural land with good road connectivity within 50 km of Kathmandu for groundwater extraction?
- Identify the apartment houses in new road not following building codes to withstand earthquake.

From the above examples, it can be understood that important decisions in our daily life need understanding of various geographical parameters. Here, GIS plays a crucial role to answer complex queries when real world parameters increase in number.
The importance of GIS has been felt strongly in many fields other than natural resource inventory, disaster management and water resources for which it has been in use.

1.3 Purpose and benefits of GIS

Benefits of GIS:

GIS benefits organizations of all sizes and in almost every industry. There is a growing interest in and awareness of the economic and strategic value of GIS, in part because of more standards-based technology and greater awareness of the benefits demonstrated by GIS users. The number of GIS enterprise solutions and IT strategies that include GIS are growing rapidly. The benefits of GIS generally fall into five basic categories:

1. **Cost savings resulting from greater efficiency.** These are associated either with carrying out the mission (i.e., labor savings from automating or improving a workflow) or improvements in the mission itself. A good case for both of these is Sears, which implemented GIS in its logistics operations and has seen dramatic improvements. Sears considerably reduced the time it takes for dispatchers to create routes for their home delivery trucks (by about 75%). It also benefited enormously in reducing the costs of carrying out the mission (i.e., 12%-15% less drive time by optimizing routes). Sears also improved customer service, reduced the number of return visits to the same site, and scheduled appointments more efficiently.

2. **Better decision making.** This typically has to do with making better decisions about location. Common examples include real estate site selection, route/corridor selection, zoning, planning, conservation, natural resource extraction, etc. People are beginning to realize that making the correct decision about a location is strategic to the success of an organization.

3. **Improved communication.** GIS-based maps and visualizations greatly assist in understanding situations and storytelling. They are a new language that improves communication between different teams, departments, disciplines, professional fields, organizations, and the public.

4. **Better geographic information recordkeeping.** Many organizations have a primary responsibility of maintaining authoritative records about the status and change of geography (geographic accounting). Cultural geography examples are zoning, population census, land ownership, and administrative boundaries. Physical geography examples include forest inventories, biological inventories, environmental measurements, water flows, and a whole host of geographic accountings. GIS provides a strong framework for managing these types of systems with full transaction support and reporting tools. These systems are conceptually similar to other information systems in that they deal with data management and transactions, as well as standardized reporting (e.g., maps) of changing information. However, they are fundamentally different because of the unique data models and hundreds of specialized tools used in supporting GIS applications and workflows.

5. **Managing geographically.** In government and many large corporations, GIS is becoming essential to understand what is going on. Senior administrators and executives at the highest levels of government use GIS information products to communicate. These products provide a visual framework for conceptualizing, understanding, and prescribing action. Examples include briefings about various geographic patterns and relationships including land use, crime, the environment, and defense/security situations. GIS is increasingly being implemented as enterprise information systems. This goes far beyond simply spatially enabling business tables in a DBMS. Geography is emerging as a new way to organize and manage organizations. Just like enterprise-wide financial systems transformed the way organizations were managed in the '60s, '70s, and '80s, GIS is transforming the way that organizations manage their assets, serve their customers/citizens, make decisions, and communicate. Examples in the private sector include most utilities, forestry and oil companies, and most commercial/retail businesses. Their assets and resources are now being maintained as an enterprise information system to support day-to-day work management tasks and provide a broader context for assets and resource management.

- Advantages of GIS
    - Exploring both geographical and thematic components of data in a holistic way
    - Stresses geographical aspects of a research question
    - Allows handling and exploration of large volumes of data
    - Allows integration of data from widely disparate sources
    - Allows analysis of data to explicitly incorporate location
    - Allows a wide variety of forms of visualisation
- Limitations of GIS
    - Data are expensive
    - Learning curve on GIS software can be long
    - Shows spatial relationships but does not provide absolute solutions
    - Origins in the Earth sciences and computer science. Solutions may not be appropriate for humanities research

Unit2: Digital mapping concept

2.1 Map concept: map elements, map layers, map scales and representation

Map Concept:

• Marks on a paper that stands for definable things on the earth's surface.
• A representation usually on a flat surface, of the whole or a part of an area
• Any concrete or abstract image of the distributions and features that occur on or near the surface of the earth or other celestial bodies.
The term "map", however, in non-geography uses does not necessarily refer to a representation but to how things are arranged or how they relate to one another. For whatever reason, at geographic scales, "map" means a representation of the earth and not earth's patterns themselves. And it usually refers to a graphic representation, although the term "map" can be used more broadly to refer to any representation of geographic space. To reach a graphic representation, there must be a mental conception (or representation) of the world. It determines how we map, and maps in turn influence the mental representation.

Map Resolution:

Refers to how accurately the location and shape of the map features can be depicted for a given map scale. In large-scale maps the resolution is greater because the reduction factors used to put the real-world features on a map is less. As a map scale decreases, features are simplified, smoothed or not represented at all. Features such as roads and streams must be represented as lines not areas. Millions of maps are produced and used annually throughout the world by scientists, scholars, governments, and business to meet environmental, economic, political, and social needs.

Maps gain value in three ways:
• **As a way of recording and storing information:** Governments, business, and society as large must store large quantities of information about the environment and the location of natural resources, capital assess, and people.
• **As a mean of analyzing distributions and spatial patterns:** Maps let us recognize spatial distribution and relationships and make it possible for us to visualize and hence conceptualize patterns and processes that operate Through space.
• **As a method of presenting information and communication findings:** Maps allow us to convey information and findings that are difficult to express verbally.

Virtual Maps vs. Real Maps
Real map: A hard copy or conventional map.
Virtual map: Information that can be converted into a real map, i.e. information on a computer screen, mental images, field information, notes, and remote sensing information.

Map Features

Maps convey information by representing features with graphic map components.

Points:
Points are usually represented by a special symbol or label. A point defines a map object whose boundary or shape is too small to be depicted as lines or areas. Points also represent locations that have no area, such as elevation of mountain peaks.
Lines:
Represent linear features such as roads, streams, pipelines, cable lines, etc. A line feature represents the shapes of geographic objects too narrow to be displayed as areas or linear features that have length but no area, i.e. a contour line.
Area:
Represent features such as lakes, parks and reserves, forestry, county boundaries, etc. An area feature is a closed figure whose boundary encloses a homogeneous area such as a state, county, or water body.

Elements of a Map

Almost all maps must include certain basic elements that provide the reader with critical information necessary to effectively use the map. Among these are title, scale, legend, body of the map, north arrow, cartographer, neat line, date of production, projection used, and information about sources.

The placement of this information and the style of its depiction will vary greatly from map to map depending on the purpose of the map and the audience. Some elements are found on almost all maps no matter what the theme, others depend on the context in which the map will be read.

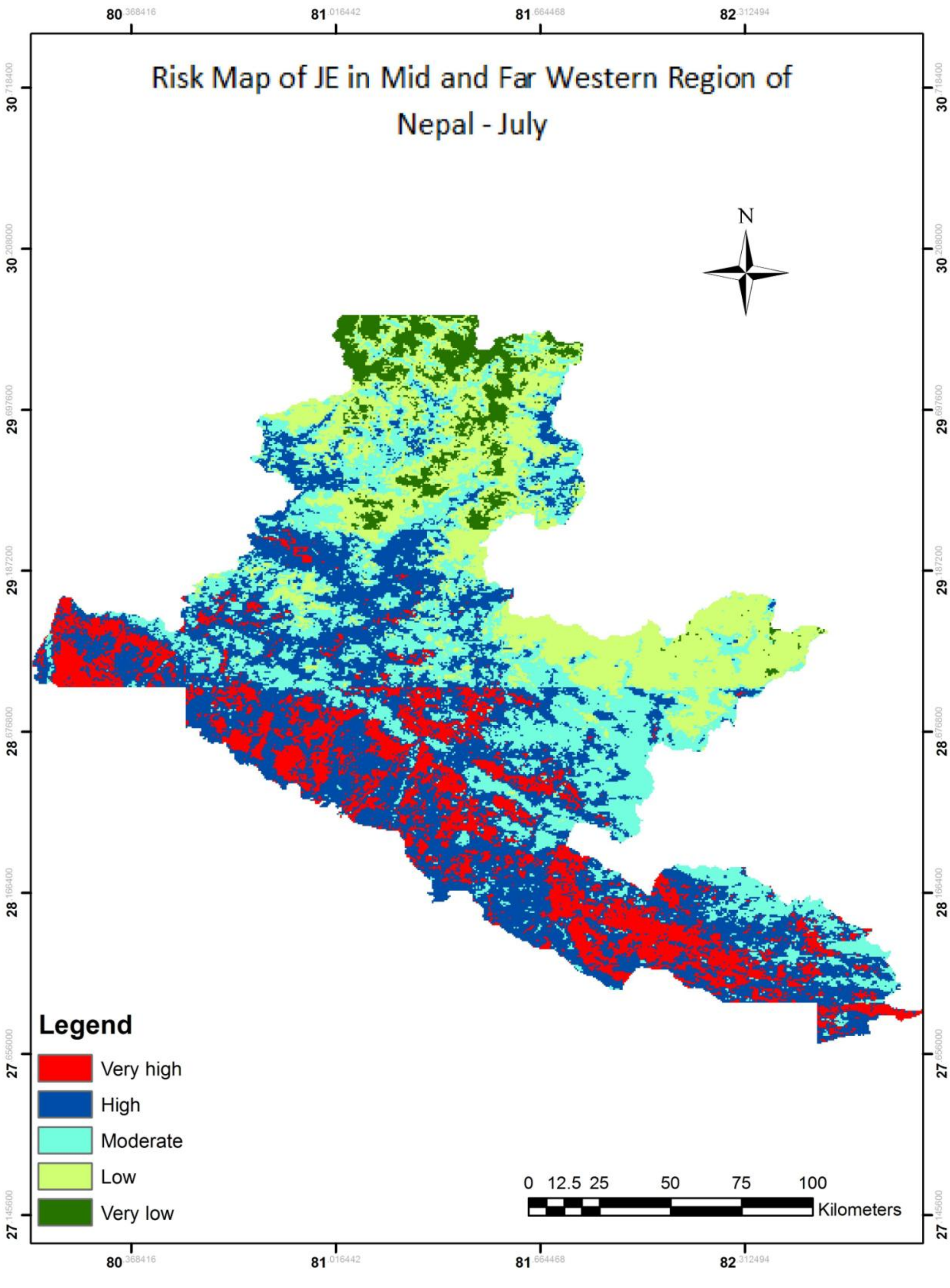
Scale: The extent of the reduction necessary to put a proportion of the earth's surface on a sheet of paper. Distance or scale must be indicated or implied. Distance and scale can be indicated in a variety of ways on a map. Scale can be represented in three different ways: ratio, statement or equation, bar or graph.

- Numeric or ratio scales: 1:24,000 1/24,000 both are the same, this means that one inch on a map = 24,000 inches on the ground.
- Verbal: 1 inch = 100 feet.
- Graphic or Bar: Rake scale or some other graphical representation.

In using computer systems, the graphic form of representation scale is often preferred. With computers, maps are often drafted at different scales than they are printed. In using verbal or numeric scales, the cartographer must be certain that the map is printed at precisely his scale indicated. If a graphic scale is inserted in a digital map, it will always maintain its relative size with respect to the digital map no matter how it is printed.

Direction: The question of what is north can be an issue on some maps. On the earth, true north (the direction of the North Pole) differs from magnetic north, and the magnetic north pole moves due to changing geophysical conditions of the earth's crust and core. Many reference maps indicate both. Most maps we compose are oriented to true north, even though compass readings in the field are angled to the magnetic pole.

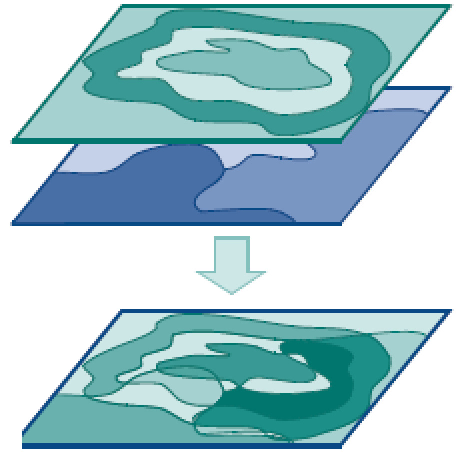
Explanation: Also known as a legend. The explanation lists symbols used on a map and what they depict. These symbols should appear in the explanation exactly as they are found in the body of the map and be described clearly and fully. Do not treat the legend as an after thought, it should receive careful attention.


Risk Map of JE in Mid and Far Western Region of Nepal - July
N
Legend
Very high
High
Moderate
Low
Very low
0 12.5 25 50 75 100
Kilometers
80
81
81
82
30
30
29
29
28
28
27
27

Map Layers

A data layer set is a collection of individual spatial data layers.
An individual file; a single layer can be added to a GIS project.
Potentially many data layers make up a single data set
Usually, spatial data is acquired in large sets. There may be as many as 150 individual data layers that make up a data set.

- Data on different themes are stored in separate "layers"
- As each layer is geo-referenced, layers from different sources can easily be integrated using location
- This can be used to build up complex models of the real world from widely disparate sources



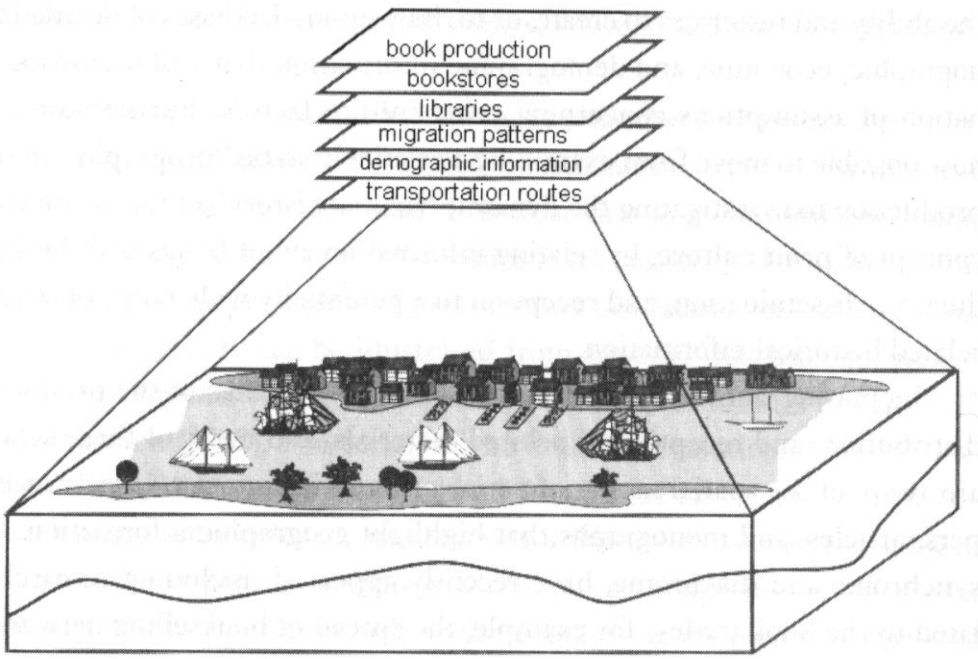
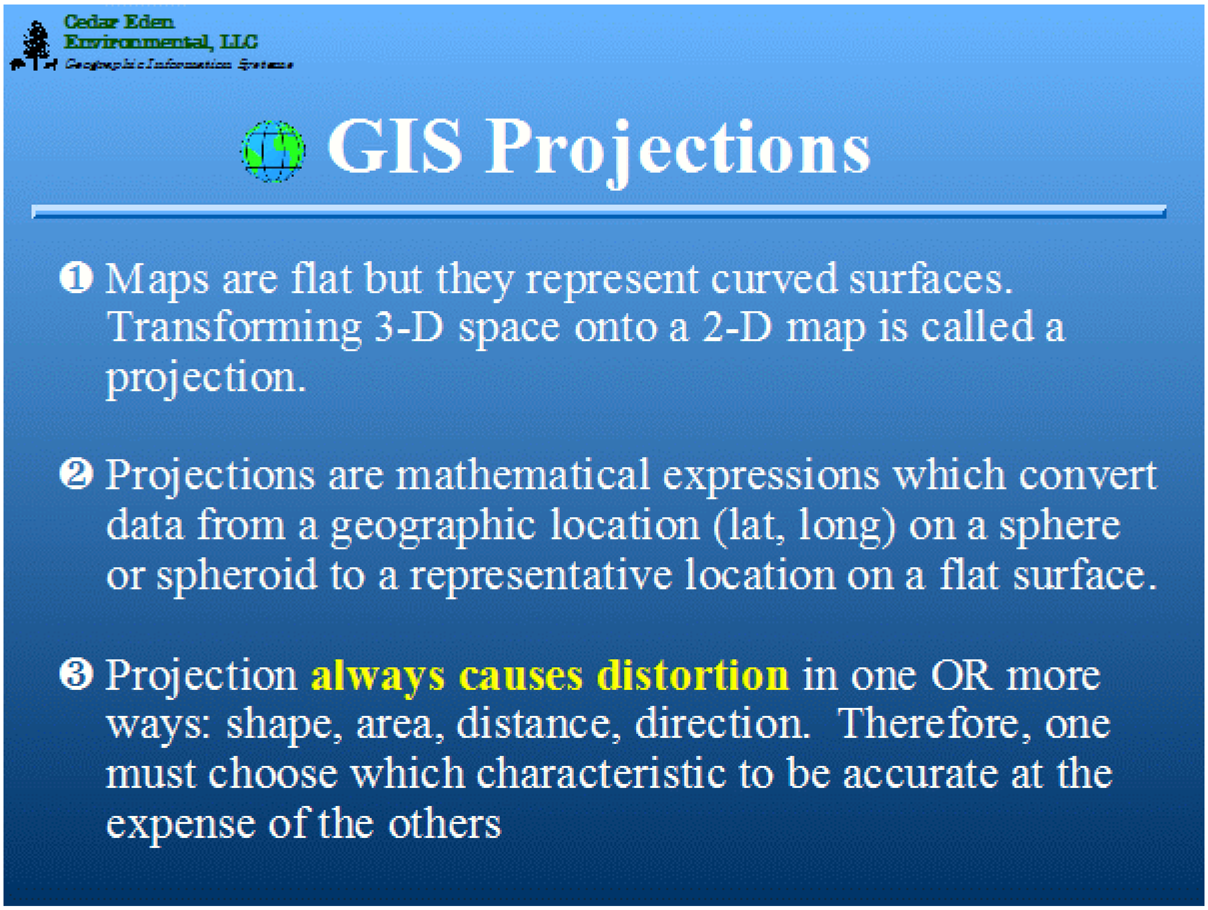


Figure : Two different object layers can be overlaid to look for spatial correlations, and the result can be used as a separate (object) layer.

2.2 Map projection: Classification, coordinate system and projection system

Map Projections

Map projections are attempts to portray the surface of the earth or a portion of the earth on a flat surface. Some distortions of conformality, distance, direction, scale, and area always result from this process. Some projections minimize distortions in some of these properties at the expense of maximizing errors in others. Some projection are attempts to only moderately distort all of these properties. We need to choose a projection that will MINIMIZE distortion in our area and be best suited for our application



Conformality: When the scale of a map at any point on the map is the same in any direction, the projection is conformal. Meridians (lines of longitude) and parallels (lines of latitude) intersect at right angles. Shape is preserved locally on conformal maps.
Distance: A map is equidistant when it portrays distances from the center of the projection to any other place on the map.
Direction: A map preserves direction when azimuths (angles from a point on a line to another point) are ortrayed correctly in all directions.
Scale: Scale is the relationship between a distance portrayed on a map and the same distance on the Earth.
Area: When a map portrays areas over the entire map so that all mapped areas have the same proportional relationship to the areas on the Earth that they represent, the map is an equal-area map.

Classification of map projections

The map projection can be onto a flat surface or a surface that can be made flat by cutting, such as a cylinder or a cone. If the globe, after scaling, cuts the surface, the projection is called secant. Lines where the cuts take place or where the surface touches the globe have no projection distortion.

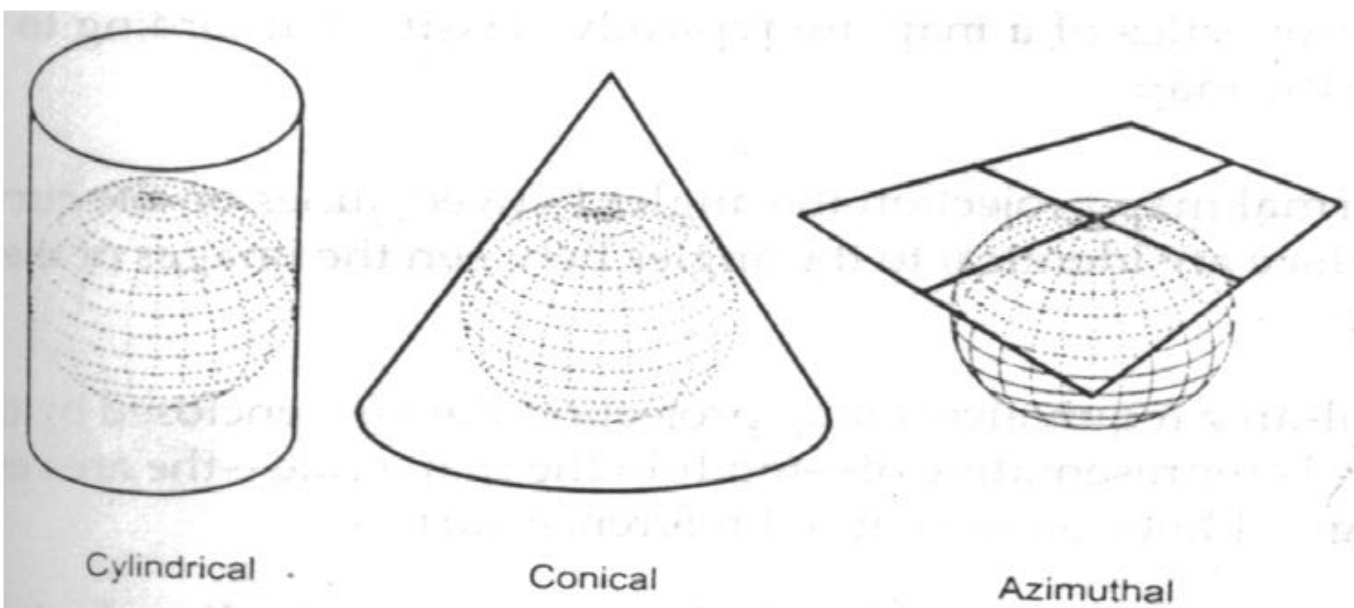
Map projections fall into three general classes:

(1) Cylindrical (2) Conical (3) Planar or Azimuthal

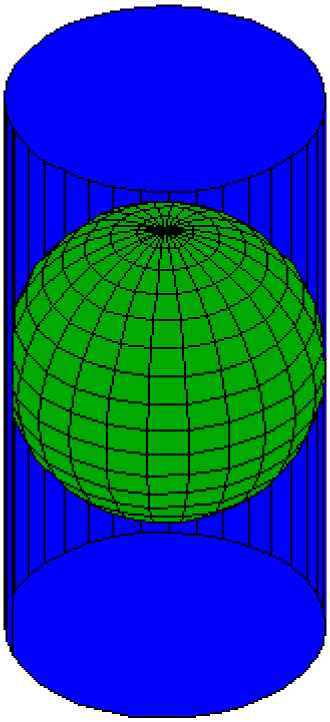
Cylindrical Projection: is assumed to circumscribe a transparent globe (marked with meridians and parallels) so that the cylinder touches the equator throughout its circumference. Assuming that a light bulb is placed at the center of the globe, the graticule of the globe is projected on to the cylinder. By cutting open the cylinder along a meridian and unfolding it, a rectangle-shaped cylindrical projection is obtained. Cylindrical are true at the equator and distortion increases toward the poles

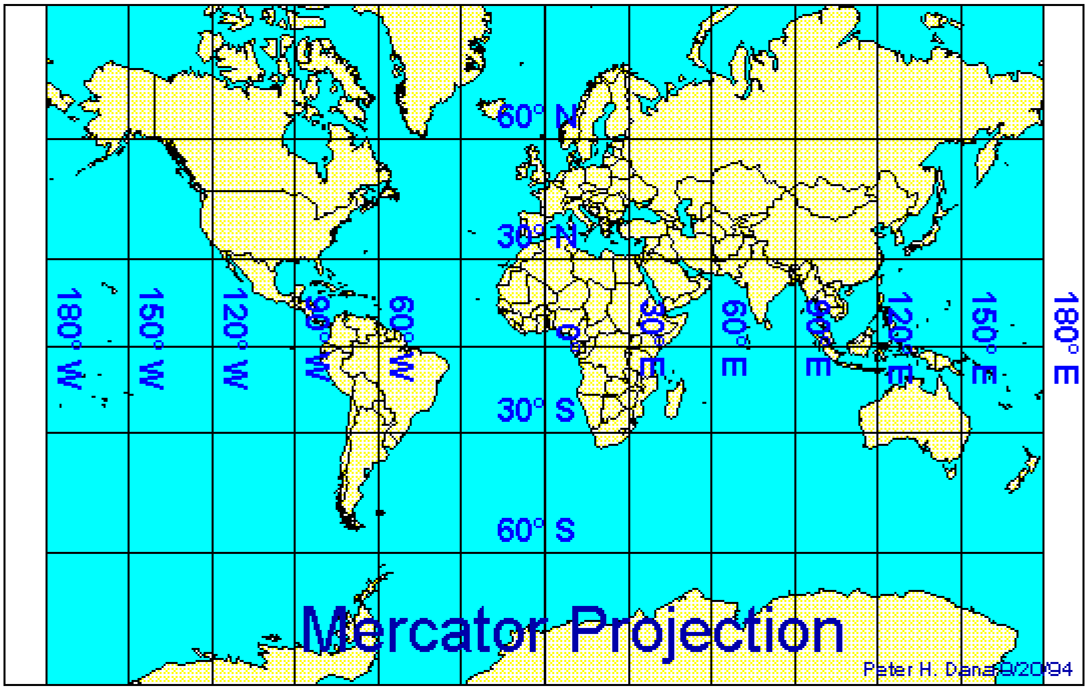
Conical Projection: a cone is placed over the globe in such a way that the apex of the cone is exactly over the polar axis. A cone must touch the globe along a parallel of latitude, known as the standard parallel, which can be selected by the cartographer. Along this standard parallel, scale is correct and distortion is the least. When the cone is cut open along a meridian and laid flat, a fan shaped map is produced, with meridians as straight lines radiating from the vertex at equals angles, while parallels are arcs of circles, all drawn using the vertex as the center.

Planar or Azimuthal Projection(planar): A plane is placed so that it touches the globe at the north or South Pole. This can be conceived as the cone becoming increasingly flattened until its vertex reaches the limit of 180o. The projection resulting is better known as the polar Azimuthal projection. It is circular in shape with meridians projected as straight lines radiating from the center of the circle, which is the pole.



Projections change a round world into a flat one.





Cylindrical Projection Surface

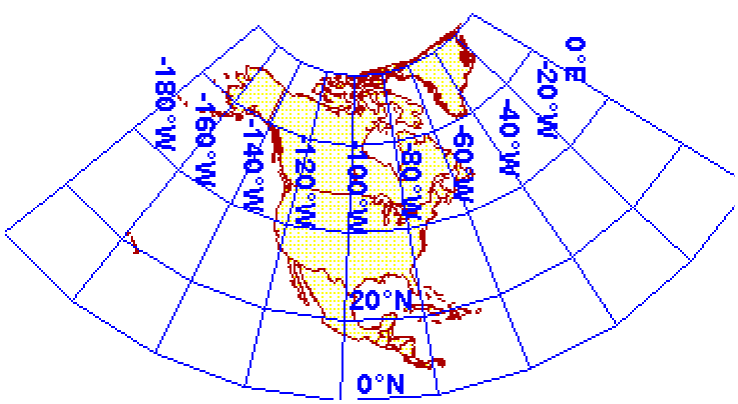


Fig: Conical Projection

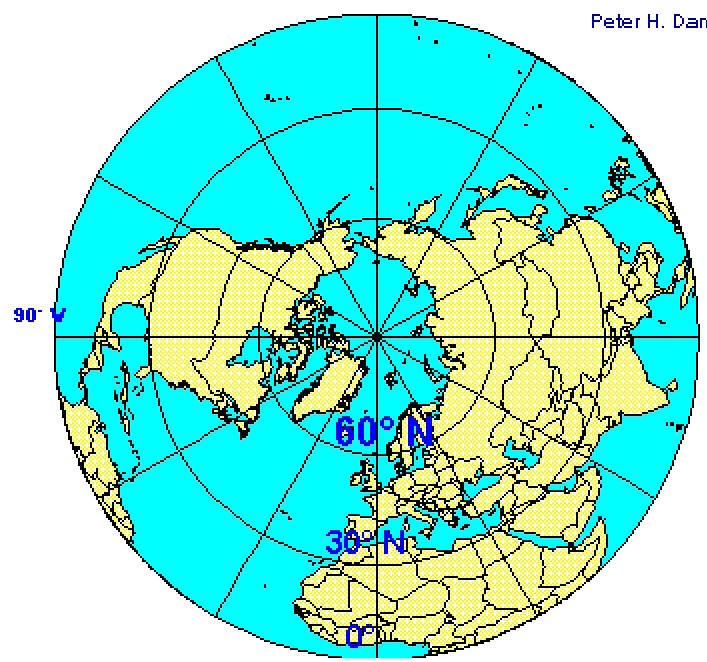


Fig: Planar (Azimuthal) Projection

Coordinate System

‣ A coordinate system is a standardized method for assigning codes to locations so that locations can be found using the codes alone. Standardized coordinate systems use absolute locations. A map captured in the units of the paper sheet on which it is printed is based on relative locations or map millimeters.

Some standard coordinate systems used are:

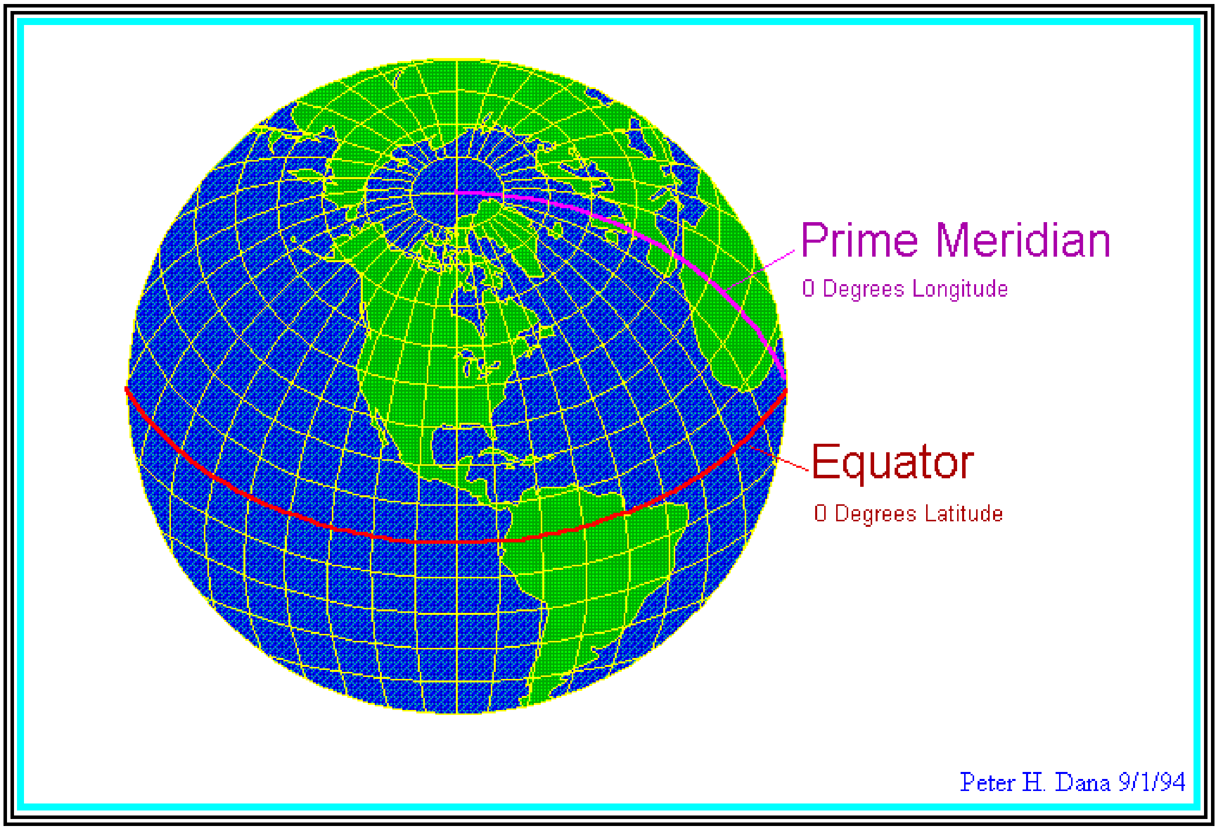
- Geographic coordinates
    - Lat-long, geodetic lat long, Earth Centered Earth Fixed XYZ
- Universal Transverse Mercator (UTM) system
- Military grid
- State plane coordinate system

Note: To compare or edge-match maps in a GIS, both maps MUST be in the same coordinate system. Else, the edges do not match and it gives us false information.

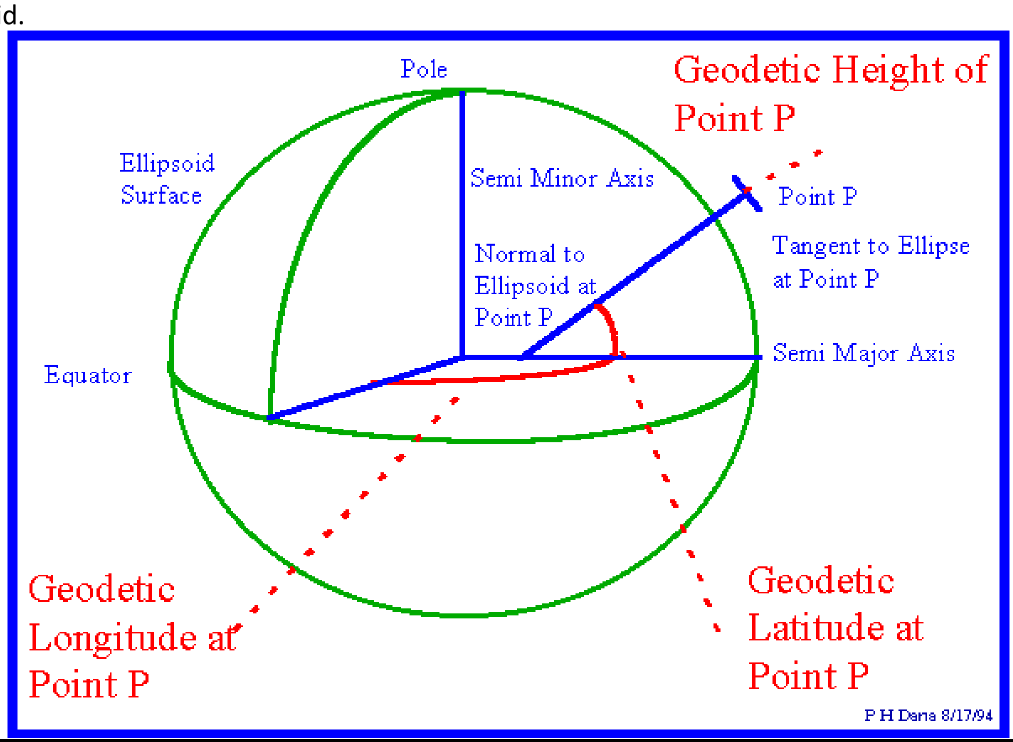
Latitude, Longitude, Height

The most commonly used coordinate system today is the latitude, longitude, and height system . The Prime Meridian and the Equator are the reference planes used to define latitude and longitude. Geographic coordinates are the earth's latitude and longitude system, ranging from 90 degrees south to 90 degrees north in latitude and 80 degrees west to 180 degrees east in longitude

- A line with a constant latitude running east to west is called a parallel
- A line with constant longitude running from the north pole to the south pole is called a meridian
- The zero-longitude meridian is called the prime meridian and passes through Greenwich, England
- A grid of parallels and meridians shown as lines on a map is called a graticule



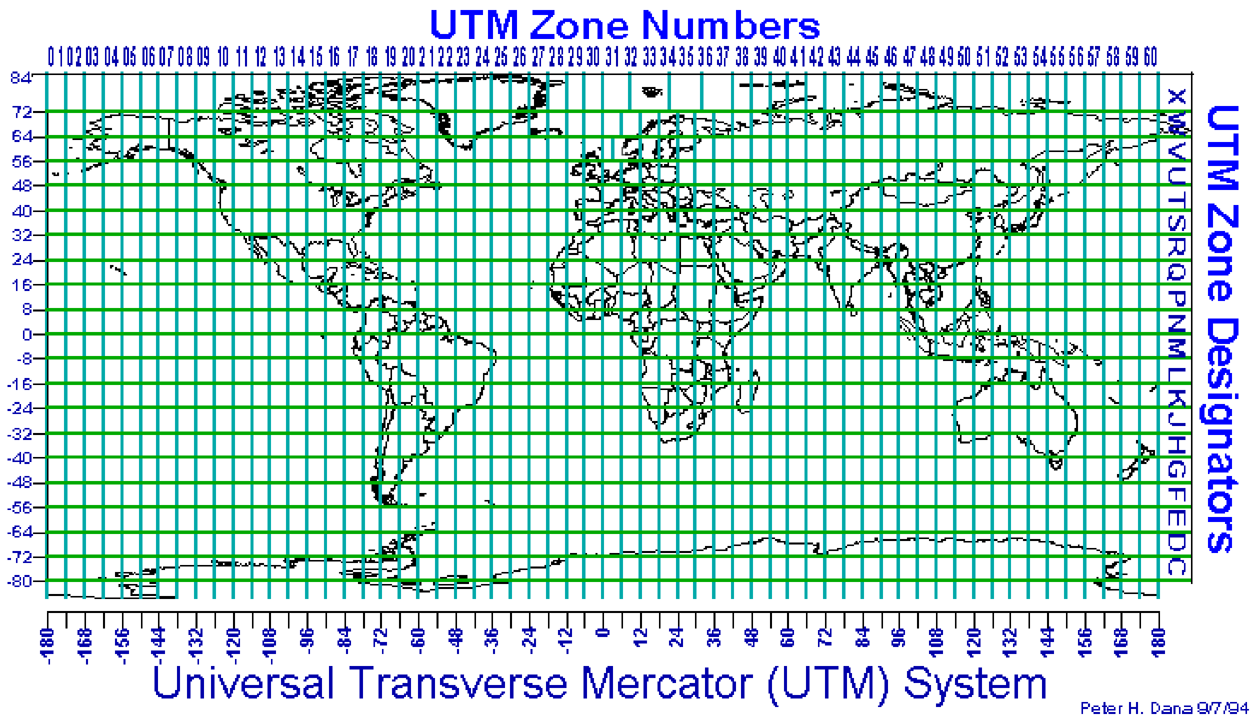
- The geodetic latitude of a point is the angle from the equatorial plane to the vertical direction of a line normal to the reference ellipsoid.
- The geodetic longitude of a point is the angle between a reference plane and a plane passing through the point, both planes being perpendicular to the equatorial plane.
- The geodetic height at a point is the distance from the reference ellipsoid to the point in a direction normal to the ellipsoid.



Universal Transverse Mercator (UTM)

‣ Universal Transverse Mercator (UTM) is the most prevalent system used for mapping and other work

‣ UTM zone numbers designate 6 degree longitudinal strips (60 vertical zones) extending from 80 degrees South latitude to 84 degrees North latitude. Zone numbers start from the 180th meridian in an eastward direction



Military Grid Reference System (MGRS)

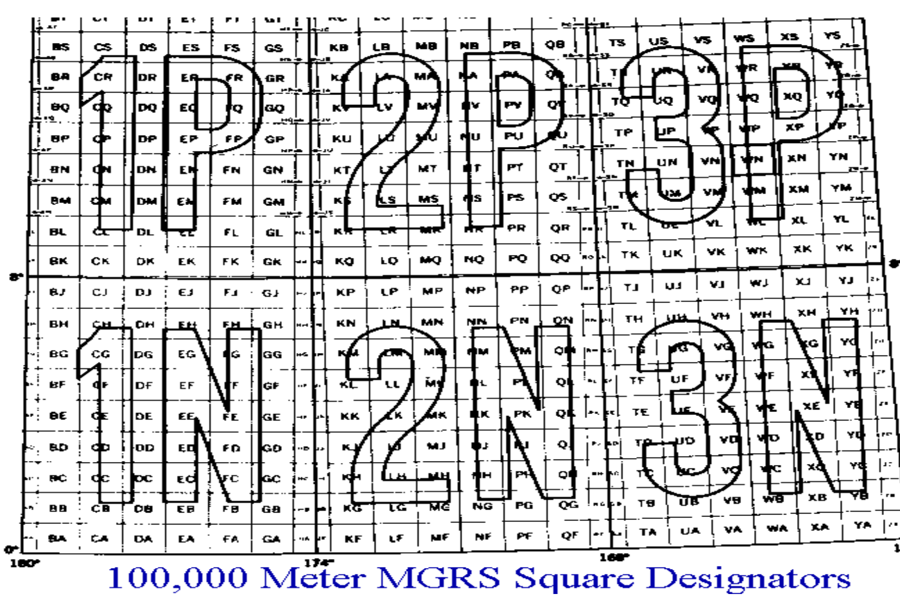
‣ MGRS is an extension of the UTM system. UTM zone number and zone character are used to identify an area 6 degrees in east-west extent and 8 degrees in north-south extent.

‣ UTM zone number and designator are followed by 100 km square easting and northing identifiers.

‣ The system uses a set of alphabetic characters for the 100 km grid squares.

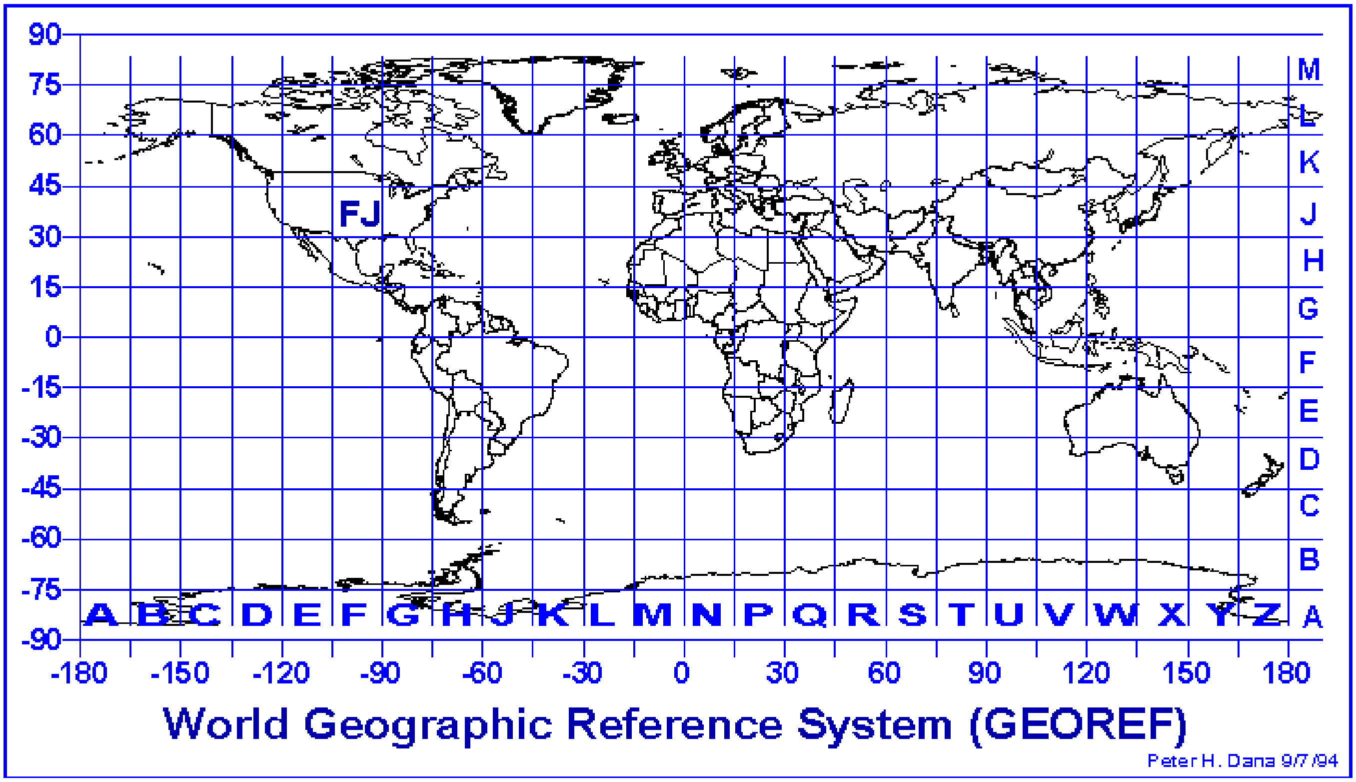
‣ Starting at the 180 degree meridian the characters A to Z (omitting I and O) are used for 18 degrees before starting over.

‣ From the equator north the characters A to V (omitting I and O) are used for 100 km squares, repeating every 2,000 km. The reverse sequence (from V to A) is used for southern hemisphere

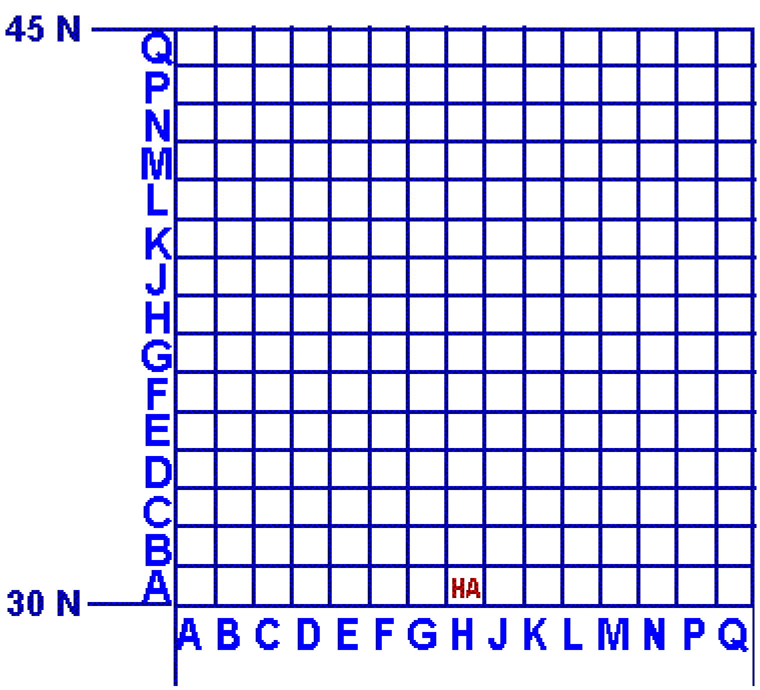


World Geographic Reference System (GEOREF)

- The World Geographic Reference System is used for aircraft navigation.
- GEOREF is based on latitude and longitude.
- The globe is divided into twelve bands of latitude and twenty-four zones of longitude, each 15 degrees in extent.



These 15 degree areas are further divided into one degree units identified by 15 characters.

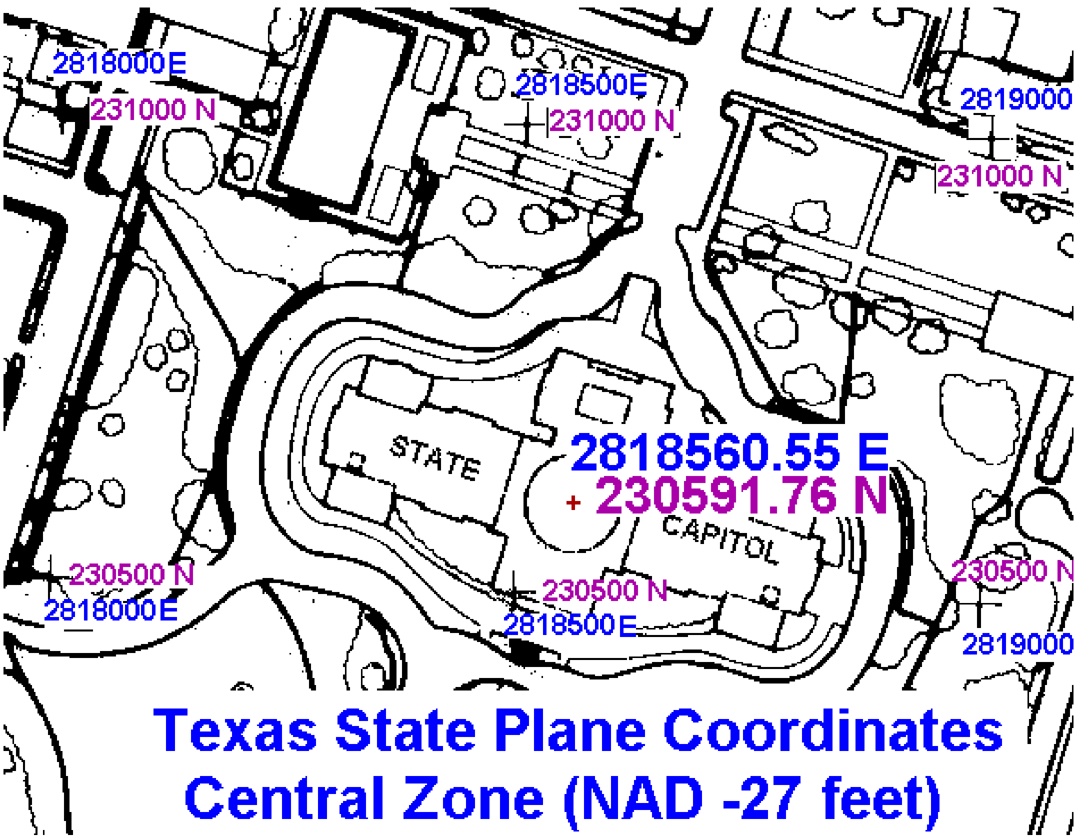


State Plane Coordinate System (SPCS)

- In the United States, the State Plane System was developed in the 1930s and was based on the North American Datum 1927 (NAD27).
- State plane systems were developed in order to provide local reference systems that were tied to a national datum

Some smaller states use a single state plane zone.

- Larger states are divided into several zones.
- State plane zone boundaries often follow county boundaries.
- Lambert Conformal Conic projections are used for rectangular zones with a larger east-west than north- south extent.
- Transverse Mercator projections are used to define zones with a larger north-south extent.



Unit 3: spatial data modeling and database design

3.1 Introduction to geographic phenomena and data modeling

Geographic Phenomenon

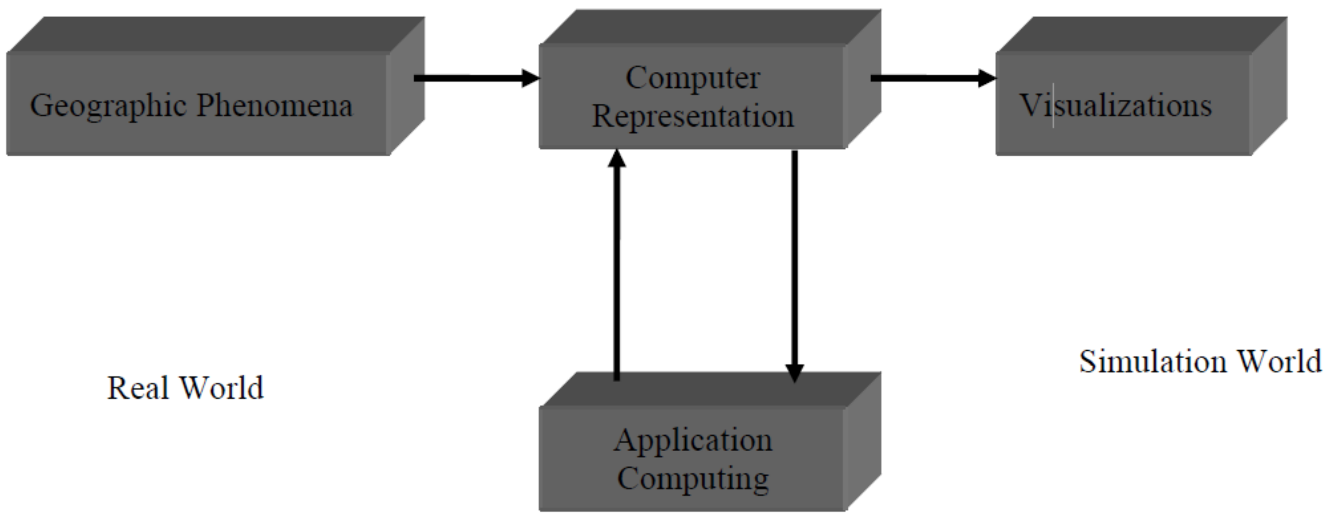


Fig. Objects of study in GIS Application

Geographic phenomena exist in the real world. In using GIS software, we first obtain some computer representation of these phenomena-stored in memory, in bits and bytes-as faithfully as possible. This is where we speak of spatial data.

Geographic phenomenon is as something of interest that

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

What are relevant phenomena are for one's current use of GIS depends entirely on the objectives that one has. For instance, in water management, the objects of study can be river basins, agro-ecologic units, measurements of actual evapotranspiration, ground water levels, irrigation levels etc…observe that all of these can be named/described, georeferenced and provided with a time interval at which each exists. In multipurpose cadastral administration, the objects of study are different houses, barns, parcels, streets of various types, land use, sewage canals and other form of urban infrastructure may all play a role. Again these can be named/described, georeferenced and assigned a time interval of existence. We do not claim that all relevant phenomena come as triplets (description, georeferenced, time interval), though many do. If the georeference is missing, we seem to have something of interest that is not position in space.

Types of geographic phenomena

Geographic phenomena come in different flavors. To this end, first make the observation of a phenomenon in a GIS requires us to state what it is, and where it is. We must provide a description-or at least a name-on the one hand and a georeference on the other hand. There is another issue to time dependent data which is not provide much automatic support by the current GIS and it must be considered as issue of advanced GIS use. A second fundamental observation is that some phenomenon **manifests** themselves essentially everywhere in the study area, while others only occur in certain localities. If we define our study area as the equatorial ocean, for instance we can say that **sea surface temperature** can be measured anywhere in the study area. Therefore, it is the example of a geographic field.

> A (Geographic) field is a geographic phenomenon for which, for every point in the study area, a value can be determined.

The usual examples of **geographic fields** are temperature, barometric pressure and elevation. These fields are actually continuous in nature. Examples of discrete fields are land use and soil classification.

Many other phenomena do not manifest themselves everywhere in the study area, but only in certain localities which are called **geographic objects**.

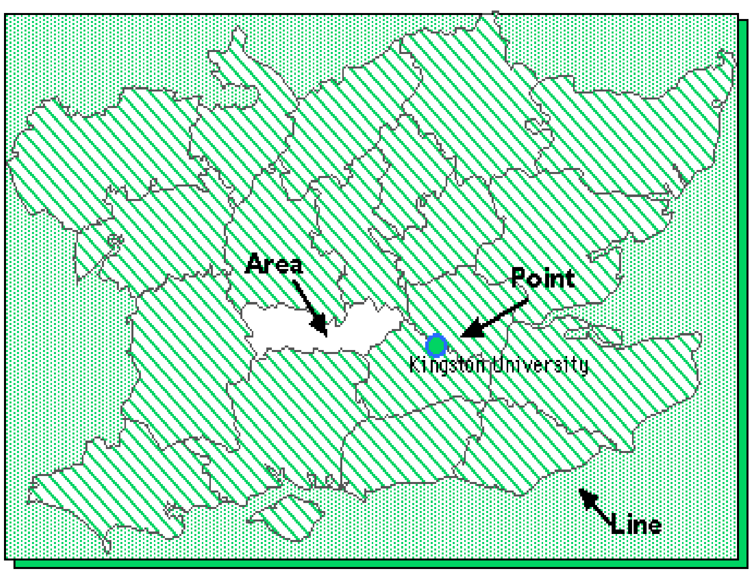
> (Geographic) Objects populate the study area, and are usually well distinguishable, discrete, bounded entities. The space between them is potentially empty.

A general rule-of-thumb is that **natural geographic phenomena are more often fields**, and **man-made phenomena are more often objects.**

Modeling

Reality is too complex for even the most sophisticated GIS software, so in order to represent reality in a spatial database, a simplification of reality is created. This simplification is known as a **data model**. Modeling is the process of producing an abstraction of the 'real world' so that some part of this can be more easily handled. In a data model, reality is simplified into just three spatial entities, or elements, which can be used to represent the real world. These three spatial entities are:

- The Point
- The Line
- The Area/surfaces



3.2 Spatial relationships and topology

General spatial topology

Topological deals with spatial properties that do not change under certain transformation. A simple example will illustrate what we mean. Assume you have some features that are drawn on the sheet of rubber (as in figure). Now take the sheet and pull on its edges, but do not tear or break it. The features will change in shape and size. But some properties, however, do not change

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

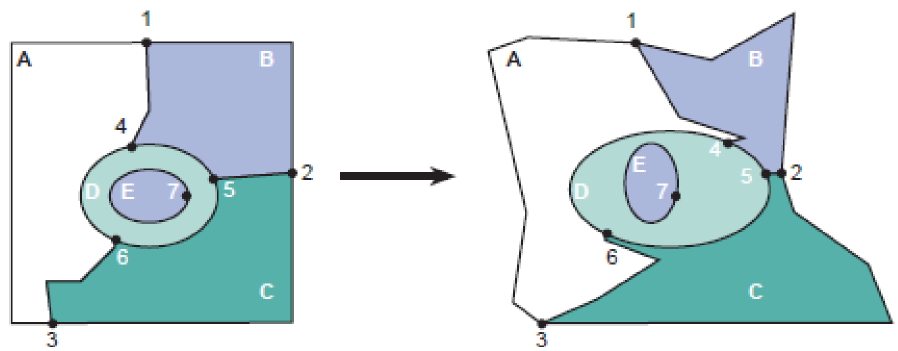


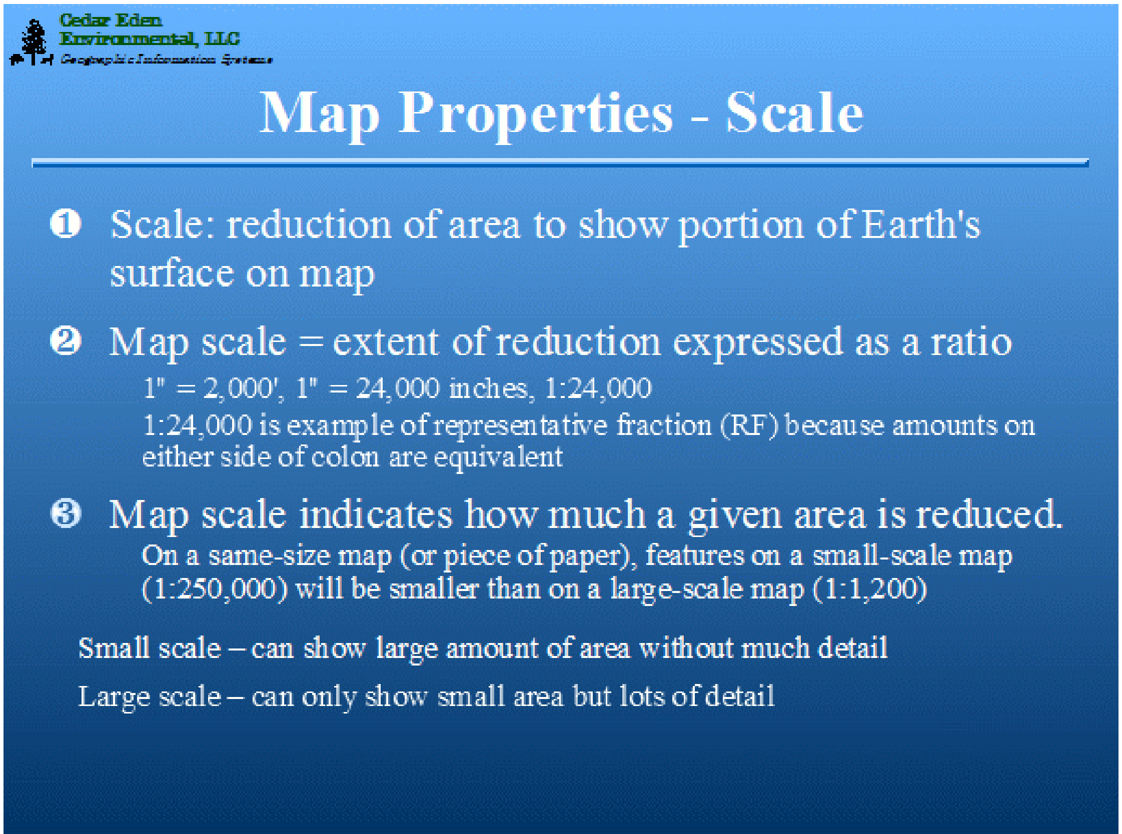
Figure : Rubber sheet transformation: The space is transformed, yet many relationships between the constituents remain unchanged.

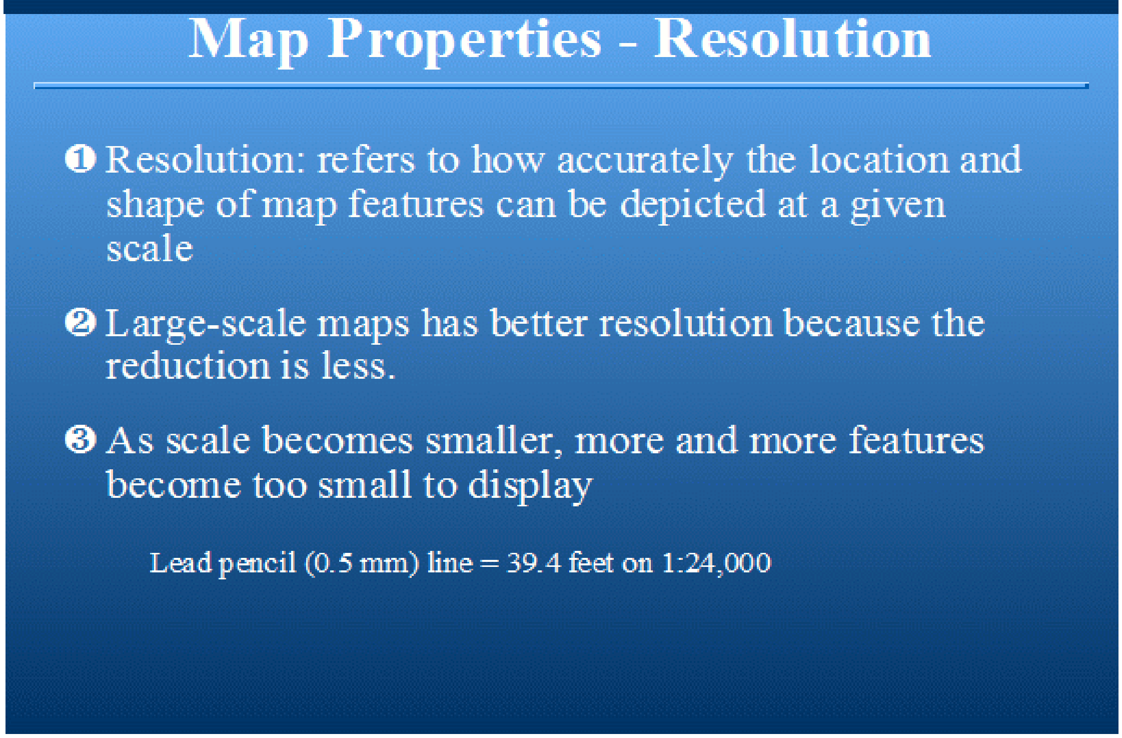
> Topology refers to the spatial relationships between geographical elements in a data set that do not change under a continuous transformation.

These relationships are invariant under continuous transformations. Such properties are called topological properties, and the transformation is called a topological mapping. The mathematical properties of the geometric space used for spatial data can be described as follows.

- The space as a three dimensional Euclidean space where for every point we can determine its three dimensional coordinates as a triple (X , Y, Z) of real numbers. In this space we can define features like points , lines , polygons and volume as geometric primitives of the respective dimension. A point is zero dimensional a line one dimensional, a polygon two dimensional, and a volume is a three dimensional primitive.
- The space is a metric space, which means that we can always compute the distance between two points according to a given distance functions. Such a function is also known as a metric.
- Interior and boundary are properties of spatial features that remain invariant under topological mapping. This means that under any topological mapping the interior and the boundary of a feature remain unbroken and intact.

3.3 Scale and resolution





In the practice of spatial data handling, one often comes across questions like "what is the resolution of the data?" or "at what scale is your data set?" Now that we have moved firmly into the digital age, these questions sometimes defy an easy answer.

Map scale can be defined as the ratio between the distance on a paper map and the distance of the same stretch in the terrain. A 1:50,000 scale map means that 1 cm on the map represents 50,000 cm, i.e. 500 m, in the terrain. 'Large-scale' means that the ratio is large, so typically it means there is much detail, as in a 1:1,000 paper map. 'Small-scale' in contrast means a small ratio, hence less detail, as in a 1:2,500,000 paper map. When applied to spatial data, the term *resolution* is commonly associated with the cell width of the tessellation applied.

Digital spatial data, as stored in a GIS, is essentially without scale: scale is a ratio notion associated with visual output, like a map or on-screen display, not with the data that was used to produce the map. We will later see that digital spatial data can be obtained by digitizing a paper map, and in this context we might informally say that the data is at this-or-that scale, indicating the scale of the map from which the data was derived.

When digital spatial data sets have been collected with a specific map-making purpose in mind, and these maps were designed to be of a single map scale, like 1:25,000, we might suppose that the data carries the characteristics of "a 1:25,000 digital data set."

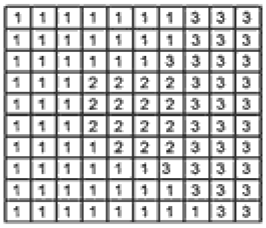
3.4 vector, raster and digital terrain model

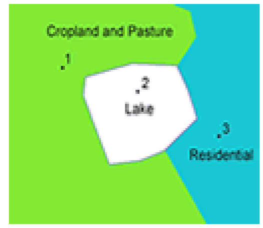
Vector and Raster Data

The graphical representation of spatial and attribute data in GIS software takes the form of either **raster** or **vector** graphics. The differences between raster and vector graphics, as detailed below, effect the level of detail, visual appeal, speed of manipulating graphics and data storage space required.

Aerial photographs and satellite images are generally in a **raster** format and are used in GIS to view a detailed map at a given extent or for the purpose of digitizing. Raster graphics are predominantly used to display spatial data and use a grid-type architecture in terms of storing spatial and graphic value data. **Vector graphics** are commonly used to represent features like roads, rivers, housing, and the like using points, lines and polygons. Based on scalable vector graphics, vector graphics provide a linear and detailed approach to manipulating attribute data. Raster and Vector graphics are frequently used together.

The key difference between Raster and Vector graphics is how they are structured. Raster graphics use pixels ("dots") whereby a graphic is made up of a large number of pixels, each pixel having a location & colour value in a grid-like format. A vector graphic is rendered by a mathematical manipulation referenced by co-ordinates. Given the different structure of these graphic types, the following differences arise as a result:





Raster Structure

Vector Structure

1. **Storage Space**: Raster graphics require more storage space than vector graphics, as they store a location & colour value per pixel.

2. **Detail**: Raster images are more detailed within a given extent ("zoom"), however raster images become pixelated if too tight a zoom is applied. Vector images are less detailed, but maintain their original aesthetics regardless of extent or zoom.

3. **Responsiveness**: performance & responsiveness when manipulating vector image is faster than raster images, as the data structured used to render vectors is mathematically based whereas rasters requires the retrieval of individual pixel values and a manipulation of each pixel.

Advantages and Disadvantages of Raster and Vector

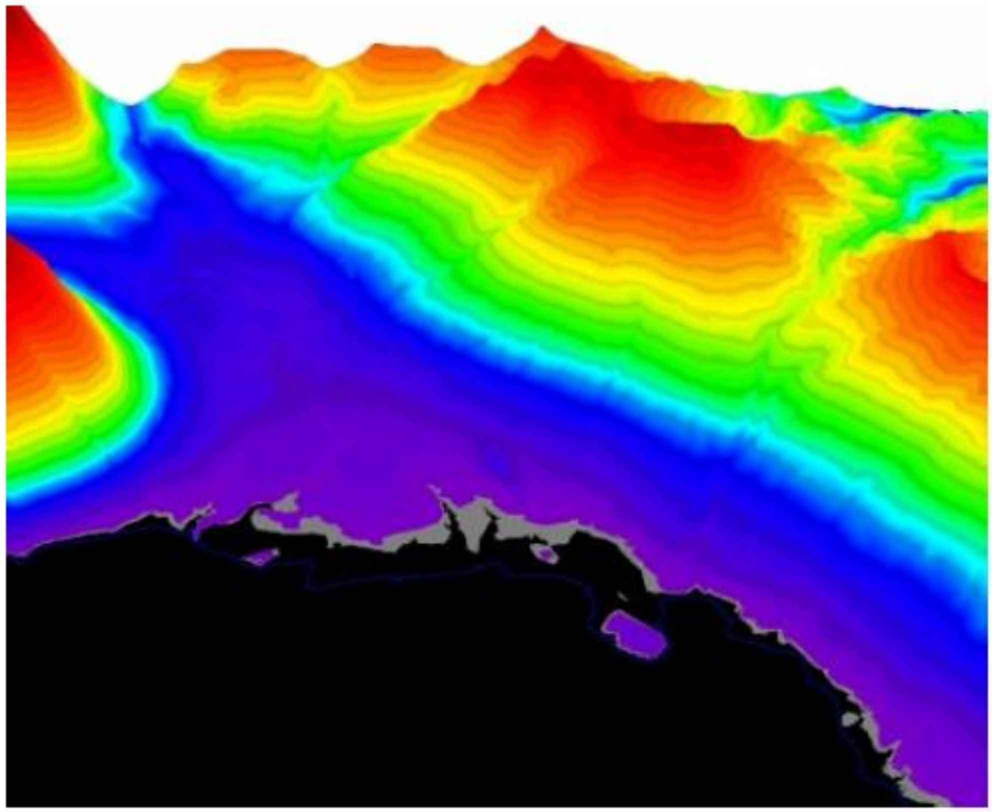
There are several advantages and disadvantages for using either the vector or raster data model to store spatial data. These are summarized below.

Vector Data		**Advantages :**
	➡	Data can be represented at its original resolution and form without generalization.
	➡	Graphic output is usually more aesthetically pleasing (traditional cartographic representation);
	➡	Since most data, e.g. hard copy maps, is in vector form no data conversion is required.
	➡	Accurate geographic location of data is maintained.
	➡	Allows for efficient encoding of topology, and as a result more efficient operations that require topological information, e.g. proximity, network analysis.
		Disadvantages:
	➡	The location of each vertex needs to be stored explicitly.
	➡	For effective analysis, vector data must be converted into a topological structure. This is often processing intensive and usually requires extensive data cleaning. As well, topology is static, and any updating or editing of the vector data requires re-building of the topology.
	➡	Algorithms for manipulative and analysis functions are complex and may be processing intensive. Often, this inherently limits the functionality for large data sets, e.g. a large number of features.
	➡	Continuous data, such as elevation data, is not effectively represented in vector form. Usually substantial data generalization or interpolation is required for these data layers.
	➡	Spatial analysis and filtering within polygons is impossible
Raster Data		**Advantages :**
	➡	The geographic location of each cell is implied by its position in the cell matrix. Accordingly, other than an origin point, e.g. bottom left corner, no geographic

		coordinates are stored.
	➨	Due to the nature of the data storage technique data analysis is usually easy to program and quick to perform.
	➨	The inherent nature of raster maps, e.g. one attribute maps, is ideally suited for mathematical modeling and quantitative analysis.
	➨	Discrete data, e.g. forestry stands, is accommodated equally well as continuous data, e.g. elevation data, and facilitates the integrating of the two data types.
	➨	Grid-cell systems are very compatible with raster-based output devices, e.g. electrostatic plotters, graphic terminals.
		Disadvantages:
	➨	The cell size determines the resolution at which the data is represented.;
	➨	It is especially difficult to adequately represent linear features depending on the cell resolution. Accordingly, network linkages are difficult to establish.
	➨	Processing of associated attribute data may be cumbersome if large amounts of data exists. Raster maps inherently reflect only one attribute or characteristic for an area.
	➨	Since most input data is in vector form, data must undergo vector-to-raster conversion. Besides increased processing requirements this may introduce data integrity concerns due to generalization and choice of inappropriate cell size. Most output maps from grid-cell systems do not conform to high-quality cartographic needs.

Digital terrain model

A digital terrain model is a topographic model of the bare earth – terrain relief - that can be manipulated by computer programs. The data files contain the spatial elevation data of the terrain in a digital format which usually presented as a rectangular grid. Vegetation, buildings and other man-made (artificial) features are removed digitally - leaving just the underlying terrain (on the other hand, Digital Surface Model (DSM) is usually the main product produced from photogrammetry, where it does contain all the features mentioned above, while a filtered DSM results in a DTM).



DTM model is mostly related as raster data type (opposed to vector data type), stored usually as a rectangular equal-spaced grid, with space (resolution) of between 50 and 500 meters mostly presented in cartesian coordinate system – i.e. x, y, z (there are DTMs presented in geographic coordinate system – i.e. angular coordinates of latitude and longitude). For several applications a higher resolution is required (as high as 1 meter spacing). A DTM can be used to guide automatic machinery in the construction of a physical model or even in computer games.

Modeling terrain relief via DTM is a powerful tool in GIS (Geographic Information System) analysis and visualization. DTM can be stored in a GIS databases in several ways:

1) a set of contour vectors (left);
2) a rectangular grid of equal-spaced corner/point heights (middle); or,
3) an irregularly spaced set of points connected as triangles (TIN - Triangular Irregular Network) (right).

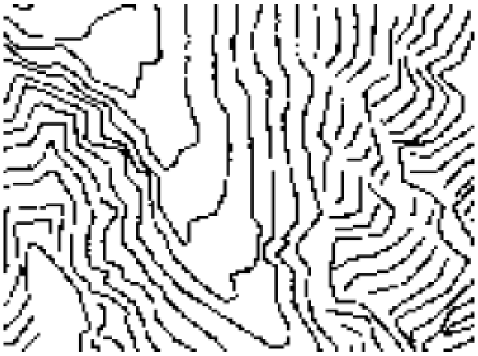


Figure 1

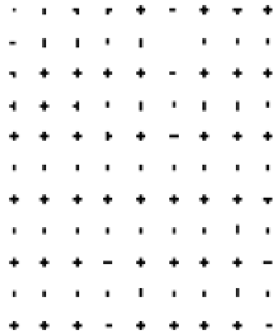


Figure 2

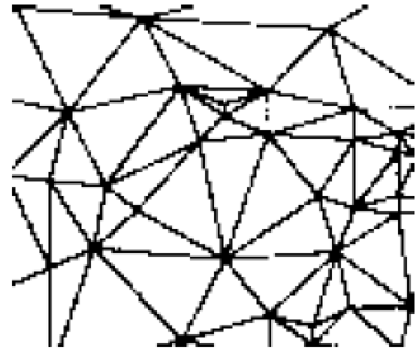


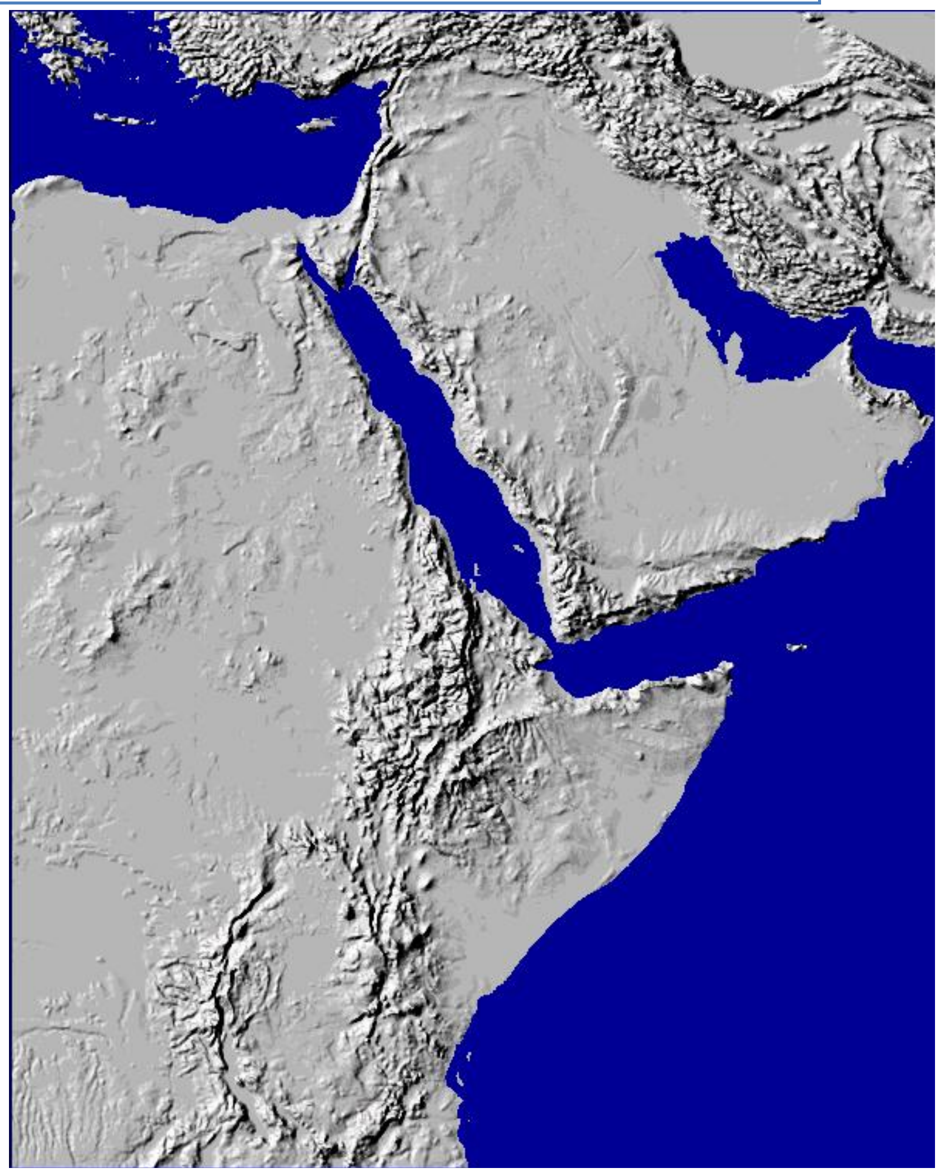
Figure 3

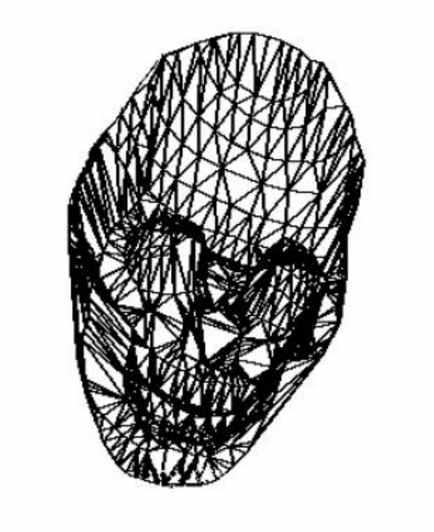
Application of DTM

The DTM data sets are extremely useful for the generation of 3D renderings of any location in the area described. 3D models rendered from DTM data can be extremely useful and versatile for a variety of applications.

DTMs are used especially in civil engineering, geodesy & surveying, geophysics, and geography. The main applications are:

1. Visualization of the terrain
2. Reduction (terrain correction) of gravity measurements (gravimetry, physical geodesy)
3. Terrain analyses in Cartography and Morphology
4. Rectification of airborne or satellite photos
5. Extraction of terrain parameters, model water flow or mass movement





TIN Representation of a human skull from a low resolution laser scan

SSX3 video game featuring complex terrain relief (represented by *DTM*)

3.5 Functional components of GIS

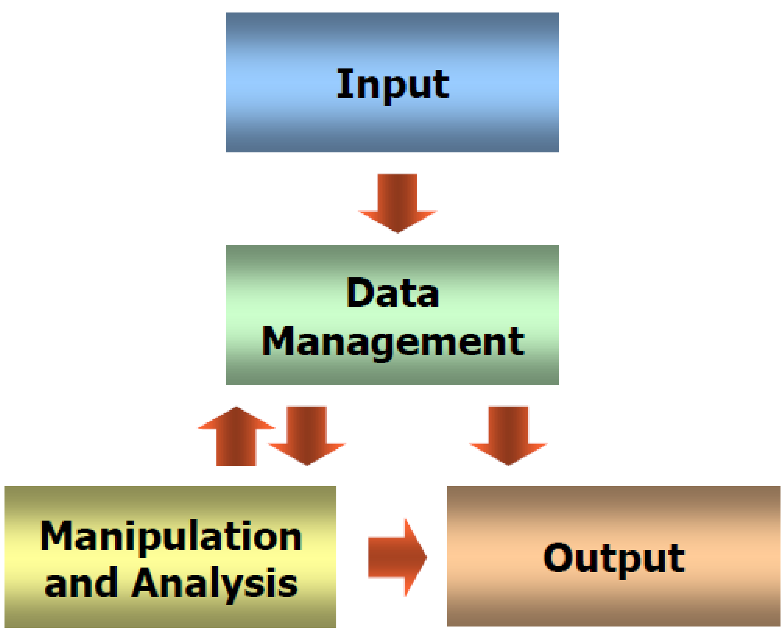


Figure : Functional modules of a GIS

According to the definition, a GIS always consists of modules for input, storage analysis, display and output of spatial data. Figure above shows a diagram of these modules. For a particular GIS, each of these modules may provide many or only few functions. However, if one of these functions would be completely missing, the system should not be called a geographic information system.
Beside data input (data capture), storage and maintenance, analysis and output, geoinformation processes involve also dissemination, transfer and exchange as well as organizational issues. The latter defines the context and rules according to which geoinformation is acquired and processed.

- Data input: bringing data in the GIS environment.
- Data manipulation: allowing alteration of primary data.
- Data output: moving data (or analysis results) out of the GIS.
- Data management: controlling access to data and ensuring data integrity and storage efficiency.
- Data retrieval: calling data from a stored format into use.
- Data display: visualizing primary or derived data.
- Data analysis and modeling: gathering insights into relationships in the data, and modelling spatial phenomena

Data input

The functions for data input are closely related to the disciplines of surveying engineering, Photogrammetry, remote sensing and the processes of digitizing i.e. the conversion of analog data into digital representations. Remote sensing in particular is the field that provides photographs and images as the raw base data from which to obtain spatial data sets. Additional techniques for obtaining spatial data are manual digitizing, scanning and sometimes semi-automatic line following. Today, digital data on various media and on computer networks are used increasingly. Table below lists the method and devices used in spatial data input.

Methods	Devices
Manual Digitizing	Coordinate entry via keyboard
	Digitizing tablet with curser
	Mouse cursor on the computer monitor
	Photogrammetry
Automatic digitizing	Scanner
Semi-Automatic digitizing	Line following devices
Input of available digital data	Magnetic tape or CD-ROM
	Via computer network

Data Output and visualization:

Data output is closely related to the disciplines of cartography, printing and publishing. Cartography and scientific visualization make use of these methods and devices to produce their products. The importance of digital products is increasing and data dissemination on digital media or on computer network become extremely important.
In both data input and data output, the internet has a major share. The World Wide Web plays the role of an easy to use interface to repositories of large data sets. Aspects of dissemination, security, copyright and pricing require special attention. The design and maintenance of a spatial information infrastructure needs to deal with those issues.

Methods	Devices
Hard copy	Printer
	Plotter
	Film writer
Soft copy	Computer screen (CRT), flat panel
Output of digital data sets	Magnetic tape
	CD-ROM
	Via computer network

Data Storage

The representation of spatial data is crucial for any further processing and understanding of their data. In most of the available processing systems, data are organized in layers according to different themes or scales. They are stored either according to thematic categories, like land use, topography and administrative subdivisions, or according to map scales representing map series of different scale. An important underlying need or principle is a representation of the real world that has to be designed to reflect phenomena and their relationships as close as possible to what exists in reality. Data are stored either in raster or in vector but each representation have their merits and demerits which are described previously.

Querying, maintenance and spatial analysis

The most distinguishing part of a GIS is its functions for spatial analysis, i.e. operators that use spatial data to derive new geoinformation. Spatial queries and process models play an important role in satisfying user needs.
The combination of a database, GIS software, rules and a reasoning mechanism leads to what is sometimes called a spatial decision support system (SDSS).
In GIS data are stored in layers (or themes). Usually, several themes are part of a project. The analysis functions of a GIS use the spatial and non-spatial attributes of the data in spatial database to answer questions about the real world. In spatial analysis, various kinds of question may arise. They are listed with their possible answers and the required GIS functions. The following three classes are the most important query and analysis functions of a GIS:

- Maintenance and analysis of spatial data (GIS Specific)
- Maintenance and analysis of attribute data, and
- Integrated analysis of spatial data and attribute data. (GIS Specific)

Maintenance and analysis of spatial data

Maintenance of spatial data can be best defined as the combined activities to keep the data set up-to-date and as supportive as possible to the user community. It deals with obtaining new data, and entering them into the system, possibly replacing outdated data. The purpose is have available an up -to- date, stored data set. After a major earthquake, for instance, we may have to update our digital elevation model to reflect the current elevations better so as to improve our hazard analysis. Operators of this kind operate on the spatial properties of GIS data, and provide a user with functions as described below.

Format transformation function convert between data formats of different systems.
Geographic transformations help to obtain data from an original hardcopy source through digitizing the correct world geometry. These operators transform device coordinates (coordinates from digitizing tablets or screen coordinates) into world coordinates (geographic coordinates, meters etc…).
Map projections provide means to map geographic coordinates onto a flat surface (for map production), and vice versa.
Edge matching is the process of joining two or more map sheets. At the map sheet edges, feature representations have to be matched so as to be combined.
Graphic element editing allows changing digitized features so as to correct errors, and to prepare a clean data set for topology building.
Coordinate thinning is a process that often is applied to remove redundant vertices from line representations.

Integrated analysis of spatial data and attribute data

Analysis of (spatial) data can be defined as computing from the existing, stored data set new information that provides insights we possibly did not have before. Road construction in mountainous area is a complex engineering task with many cost factors such as the amount of tunnels and bridges to be constructed. GIS can help to compute such costs on the basis of an up-to-date digital elevation model and soil map. Function of this kind operate on both spatial and non-spatial attributes of data, and cane be grouped into the following types.

Retrieval, classification and measurement functions

Retrieval functions allow the selective search and manipulation of data without the need to create new entities.

Classification allows assigning features to a class on the basis of attribute values or attributes ranges.

Generalization is a function that joins different classes of objects with common characteristics to a higher label class.

Management functions allow measuring distances, lengths or areas

Overlay functions belong to the most frequently used functions in a GIS application. They allow combining two spatial data layers by applying the set theory operations of intersection, union, difference and complement using set of positions as their arguments. Thus we can find

- the potato fields on clay soils (intersection),
- the fields where potato or maize is the crop (union),
- the potato fields not on clay soils (difference),
- the fields that do not have potato as crop (complement)

Neighborhood functions operate on neighboring features of a given set of features.

- Search functions allow the retrieval of features that fall within a given search window (whichmay be rectangle, circle or polygon).
- Line-in-polygon and point-in-polygon functions determine whether a given linear or point feature is located within a given polygon, or they report the polygons that a given point or line are contained in.
- Proximity function is the buffer zone generation. This function determines a fixed-width environment surrounding a given feature.
- Interpolation functions predict unknown values using the known values at nearby locations.

Connection functions accumulate values as they traverse over a feature or over a set of features.

- Network analysis is used to compute the shortest path (in terms of distance or travel time)between two points in a network.
- Visibility functions are used to compute the points that are visible from a given location.

3.6 Spatial database design with the concepts of geodatabase.

Spatial DBMS:

A spatial database system may be defined as a database system that offers spatial data types in its data model and query language, and supports spatial data types in its implementation, providing at least spatial indexing and spatial join methods.

Spatial database systems offer the underlying database technology for geographic information systems and other applications. We survey data modeling, querying, data structures and algorithms, and system architecture for such systems. The emphasis is on describing known technology in a coherent manner, rather than listing open problems.

In various fields there is a need to manage *geometric*, *geographic*, or *spatial* data, which means data related to *space*. The space of interest can be, for example, the two-dimensional abstraction of (parts of) the surface of the earth or a 3d-space representing a digital terrain model. At least since the advent of relational database systems there have been attempts to manage such data in database systems.

Characteristic for the technology emerging to address these needs is the capability to deal with *large collections of relatively simple geometric objects*, for example, a set of 100 000 polygons. Several terms have been used for database systems offering such support like *pictorial*, *image, geometric, geographic*, or spatial database *system*. The terms “pictorial” and “image” database system arise from the fact that the data to be managed are often initially captured in the form of digital raster images (e.g. remote sensing by satellites, or computer tomography in medical applications).

The term “spatial database system” has become popular during the last few years, and is associated with a view of a database as containing sets of objects in space rather than images or pictures of a space. Indeed, the requirements and techniques for dealing with objects in space that have identity and well-defined extents, locations, and relationships are rather different from those for dealing with raster images.

A spatial database therefore has the following characteristics:

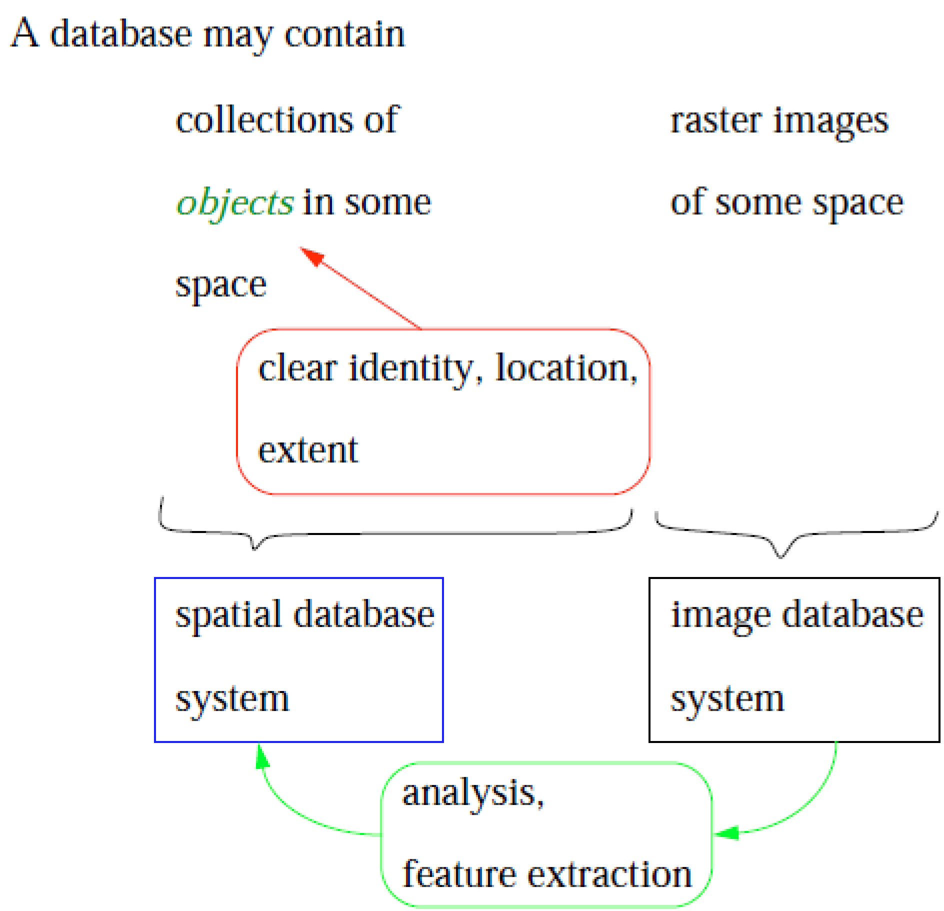
(1) A spatial database system is a database system.

(2) It offers spatial data types (SDTs) in its data model and query language.

(3) It supports spatial data types in its implementation, providing at least spatial indexing and efficient algorithms for spatial join.

Nobody cares about a special purpose system that is not able to handle all the standard data modeling and querying tasks. Hence a spatial database system is a full-fledged database system with *additional* capabilities for handling spatial data. Therefore spatial indexing is mandatory. It should also support connecting objects from different classes through some spatial relationship.

Spatial Database Design



A spatial database includes collections of information about the spatial location, relationship and shape of topological geographic features and the data in the form of attributes. The design of the spatial database is the formal process of analyzing facts about the real world into a structured model. Database design is characterized by the following phases: requirement analysis, logical design and physical design. In other words, you basically need a plan, a design layout and then the data to complete the process.

Having a solid well designed spatial database is the key to performing good Spatial Analysis. The database can be complex and designed with expensive sophisticated software or can be merely a simple well organized collection of data that can be utilized in a geographic form.

Three main categories of spatial modeling functions that can be applied to geographic features within a GIS are: (1) geometric models, such as calculating the Euclidean distance between features, generating buffers, calculating areas and perimeters, and so on;

(2) coincidence models, such as topological overlay; and

(3) adjacency models (path finding, redistricting, and allocation).

All three model categories support operations on spatial data such as points, lines, polygons, tins, and grids. Functions are organized in a sequence of steps to derive the desired information for analysis.

Almost all entities of geographic reality have at least a 3-dimensional spatial character, but not all dimensions may be needed. E.g. a highway pavement actually has a depth which might be important, but is not as important as the width, which is not as important as the length. Representation should be based on the types of manipulations that might be undertaken. Map-scale of the source document is important in constraining the level of detail represented in a database. E.g. on a 1:100,000 map individual houses or fields are not visible

Steps in database design

1. Conceptual
    a. software and hardware independent
    b. describes and defines included entities
    c. identifies how entities will be represented in the database
       i.e. selection of spatial objects - points, lines, areas, raster cells
    d. requires decisions about how real-world dimensionality and relationships will be represented
       these can be based on the processing that will be done on these objects
       e.g. should a building be represented as an area or a point?
       e.g. should highway segments be explicitly linked in the database?
2. Logical
    a. software specific but hardware independent
    b. sets out the logical structure of the database elements, determined by the data base management system used by the software
3. Physical
    a. both hardware and software specific
    b. requires consideration of how files will be structured for access from the disk

Characteristics of a Good Database Design

In order that the GIS database provides the best service it should be:

- Contemporaneous – the data should be updated regularly so as to yield information that pertains to the same time-frame for all its measured variables
- Flexible and extensible so that additional datasets may be added as necessary for the intended applications
    - the categories of information and subcategories within them should contain all of the data needed to analyze or model the behavior of the resource using conventional methods and models
- Positionally accurate – if for example the boundary between the residential and agricultural land has changed, this may be incorporated with ease.
- Exactly compatible with other information that may be overlain with it

- o Internally accurate, portraying the nature of phenomena without error - requires clear definitions of phenomena that are included
- o Readily updated on a regular schedule
- o Accessible to whoever needs it

Spatial Database Management

Many factors influence a successful Geographic Information System (GIS) implementation. None however are more fundamental than having the right management strategies and software to implement these. The spatial database is the foundation by which all data is uniformly created and converted. But maintaining the integrity and currency of the data is of fundamental importance. A classic mistake made by many organizations is thinking that a generic spatial database design will be sufficient for their needs. That is simply not the case. The spatial database is the end result of a series of processes that determine the specific functional requirements for the user and the key applications. Interoperability of data is also a critical area of concern in the development of spatial data information systems. As we move from newly created data to assimilation of all existing data, a properly designed spatial database is insurance for end user success. A good spatial database management software package should be able to:

1. Scale and rotate coordinate values for "best fit" projection overlays and changes.
2. Convert (interchange) between polygon and grid formats.
3. Permit rapid updating, allowing data changes with relative ease.
4. Allow for multiple users and multiple interactions between compatible data bases.
5. Retrieve, transform, and combine data elements efficiently.
6. Search, identify, and route a variety of different data items and score these values with assigned weighted values, to facilitate proximity and routing analysis.
7. Perform statistical analysis, such as multivariate regression, correlations, etc.
8. Overlay one file variable onto another, i.e., map superpositioning.
9. Measure area, distance, and association between points and fields.
10. Model and simulate, and formulate predictive scenarios, in a fashion that allows for direct interactions between the user group and the computer program.

Geodatabase

The physical store of geographic information, primarily using a database management system (DBMS) or file system is called a geodatabase.

- **A *geodatabase* is a collection of feature classes and tables. Feature classes can be organized into feature datasets.**
- **The *geodatabase data model* is an object-oriented data model that lets you make the features in your GIS datasets smarter by endowing them with natural behaviors**
- **The objects in a geodatabase can be related to each other (it stores relationships)**
- **The *geodatabase* lets you implement custom behaviors by implementing domains, validations rule or writing software code.**

Unit 4: capturing the real world

4.1 Different methods of data capture

Data: the fuel

The geographic data is information about the earth's surface and the objects found on it. Data is fuel to GIS. How can we feed data like map in a GIS? Data capture is a process of putting information into the system. A wide variety of sources can be used for creating geographic data, which is discussed below.

Types and Sources of Geographic Data

Geographic data are generally available in two forms: analogue data and digital data. Analogue data is a physical product displaying information visually on paper, e.g. maps. Digital data is information on computer readable form, e.g. satellite data (figure 4.1).

There are various sources from where we can get these different types of data. For example, as shown in the figure 4.2, the sources are – maps, aerial photo, satellite images, existing tabular data (in analogue and digital format), and field data (GPS). GIS is able to capture these different types of data from various sources. Creating a database, i.e. capturing the data, is the initial stage and time consuming task of a GIS project.

Figure 4.1 Analogue and digital data

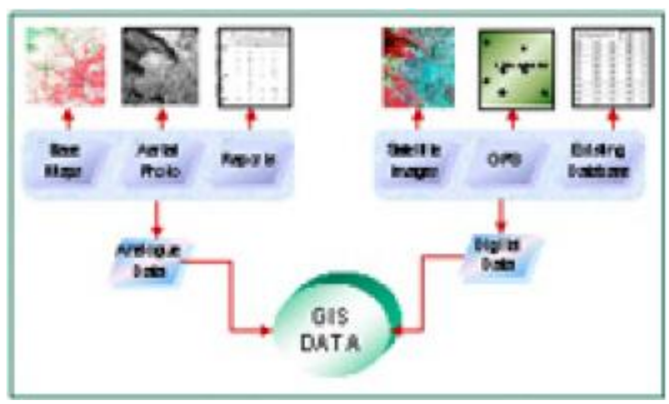


Figure 4.2 Data sources

Private Suppliers (Commercial Data)

There are many private sources of information. Commercial mapmaking firms are among the largest providers, but other firms have for years supplied detailed demographic and economic information, such as data on retail trade and marketing trends. Some of this information can be quite expensive to purchase. Also, it is important to check on restrictions that might apply to the use of commercially provided data. In some cases, copyright and licensing restrictions may apply to your intended use and publication of the information. Many software vendors earn a substantial income by repackaging and selling data in the proprietary forms used by their software products. Because the data is usually checked and corrected as it is repackaged, the use of these converted datasets can save time. The widespread expansion of this marketing and re- marketing of data has been a boon to many users who do not wish to be invest resources in building the datasets they need on a day-today basis--they simply buy what they need.

It is important for us to consider the following question about GIS data sources:

- What is the age of the data?
- Where did it come from?
- In what medium was it originally produced?
- What is the area coverage of the data?
- To what map scale was the data digitized?
- What projection, coordinate system, and datum were used in maps?
- What was the density of observations used for its compilation?
- How accurate are positional and attribute features?
- Does the data seem logical and consistent?
- Do cartographic representations look "clean?"
- Is the data relevant to the project at hand?
- In what format is the data kept?
- How was the data checked?
- Why was the data compiled?
- What is the reliability of the provider?

Data Capturing Methods

The different data capturing methods from various sources commonly used in a GIS are briefly discussed below (see figure 4.3).

Photogrammetric Compilation

The primary source used in the process of photogrammetric compilation is aerial photography. Generally, the process involves using specialized equipment (a stereoplotter) to project overlapping aerial photos so that a viewer can see a three-dimensional picture of the terrain, known as a photogrammetric model. The current technological trend in photogrammetry is toward a greater use of digital procedures for map compilation.

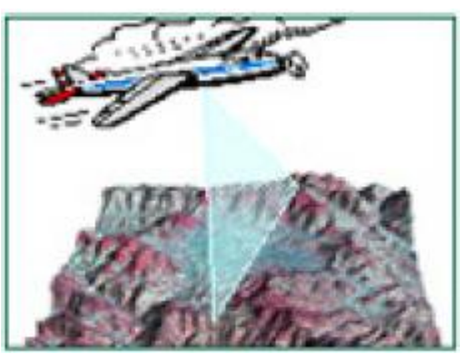


Figure 4.3a Aerial Photography

Digitizing

A digitizing workstation with a digitizing tablet and cursor is typically used to trace digitize. Both the tablet and cursor are connected to a computer that controls their functions. Most digitizing tablets come in standard sizes that relate to engineering drawing sizes ("A" through "E," and larger). Digitizing involves tracing features on a source map, taped to the digitizing tablet, with a precise cross hair in the digitizing cursor and instructing the computer to accept the location and type of feature. The person performing the digitizing may separate features into map layers, or attach an attribute to identify the feature.

Figure 4.3b Digitiiser

Map Scanning

Optical scanning systems automatically capture map features, text, and symbols as individual cells, or pixels, and produce an automated product in raster format as described earlier . Scanning outputs files in raster form, usually in one of several compressed formats saves storage space (e.g., TIFF 4, JPEG). Most scanning systems provide software to convert raster data to a vector format differentiating point, line, and area features. Scanning systems and software is becoming more sophisticated with some abilities to interpret symbols and text, and store this information in databases. Creating an intelligent GIS database from a scanned map will require vectorizing the raster data and manual time for entering attribute data from a scanned annotation.

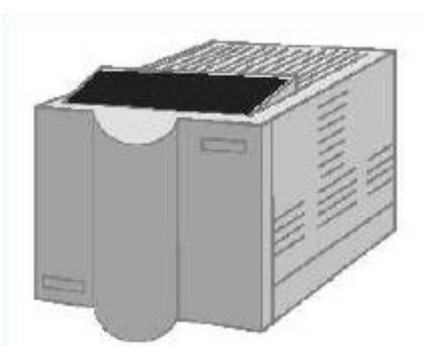


Figure 4.3c Map Scanner

Satellite Data

Earth Resources Satellites have become a source of huge amount of data for GIS applications. The data obtained from the Satellites are in digital form, which can be directly imported to GIS. There are numerous satellite data sources such as LANDSAT or SPOT. A new generation of high-resolution satellite data that will increase opportunities and options for GIS database development is becoming available from private sources and national governments. These satellite systems will provide panchromatic (black and white) or multi-spectral data in the 1- to 3-meter ranges as compared to the 10- to 30-meter range available from traditional remote sensing satellites.

Figure 4.3d Satellite data

Field Data Collection

Advances in hardware and software have greatly increased opportunities for capture of GIS data in the field (e.g., sign of utility inventory, property surveys, land use inventories). In particular, electronic survey systems and the global positional system (GPS) have revolutionized surveying and field data collection. Electronic distance measurement services allow for survey data to be gathered quickly in automated form for uploading to a GIS. Sophisticated GPS collection units have provided a quick means of capturing the coordinates and attributes of features in the field.

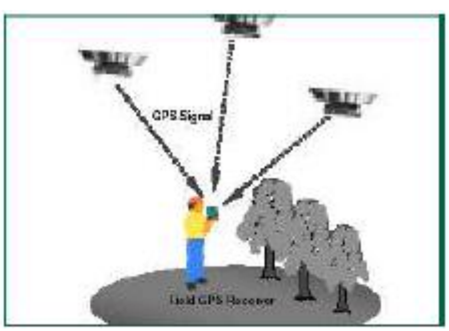


Figure 4.3e GPS

Tabular Data Entry

Some of the tabular attribute data that is normally in a GIS database exists on maps as annotation and or can be found in paper files. Information from these sources will be required for GIS applications and will have to be converted to digital form through keyboard entry. This kind of data entry is commonplace and relatively easy to accomplish.

Document Scanning

Smaller-format scanners can also be used to create raster files of documents such as permit forms, service cards, site photographs, etc. These documents can be indexed in a relational database by number, type, date, engineering drawings, etc., and queried and displayed by users. GIS applications can be built which allows users to point to and retrieve for display a scanned document (e.g., tax parcel) interactivley.

Translation of Existing Digital Data

Existing automated data may be available from existing tabular files maintained by outside sources. Many programs are available that perform this translation and, in fact, many GIS packages can be acquired with programs that translate data to and from several "standard" formats which are accepted widely by the mapping industry and have been used as intermediate "exchange" formats for moving data between platforms (e.g., Intergraph SIF, TIGER, Shapefile and AutoCAD DXF)

4.2 Spatial reference (ITRS, ITRF)

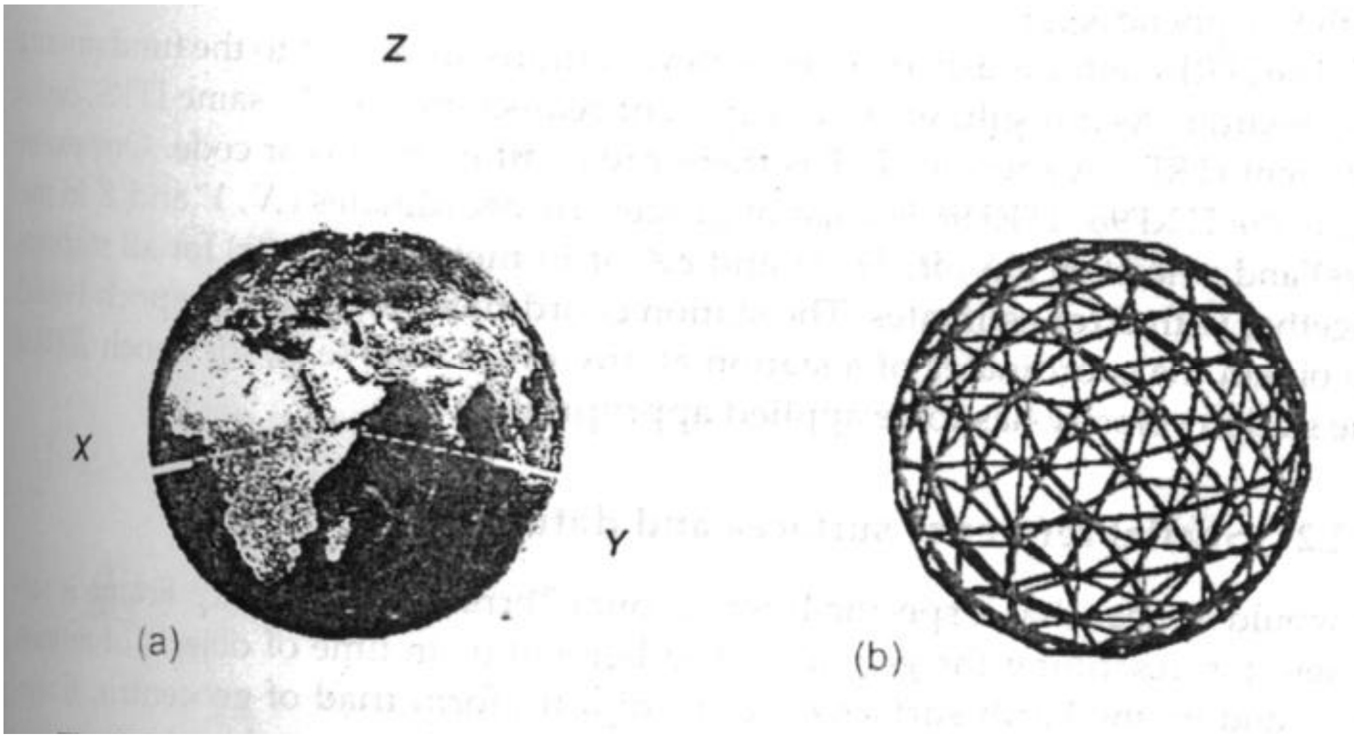
Spatial Referencing

In the early days of GIS, users were handling spatially referenced data from a single country. The data was derived from paper maps published by the countries mapping organization. Nowadays, GIS users are combining spatial data from a certain country with global spatial data sets, reconciling spatial data from a published map with coordinates established with satellite positioning techniques and integrating spatial data from neighboring countries. To perform these tasks successfully, GIS users need a certain level of appreciation for a few basic spatial referencing concepts pertinent to published maps and spatial data.
Geographic referencing, which is sometimes simply called *georeferencing*, is defined as the representation of the location of real-world features within the spatial framework of a particular coordinate system. The objective of georeferencing is to provide a rigid spatial framework by which the position of the real-world features are measured, computed, recorded, and analyzed. In practice georeferencing can be seen as series of concepts and techniques that progressively transform measurements carried out on the irregular surface of a map, and make it easily and readily measurable on this flat surface by means of a coordinate system. The concept of representing the physical shape of earth by means of a mathematical surface and the realization of this concept by the definitions of the *geoid* and *ellipsoid* are fundamental to georeferencing.

Spatial reference system and frames

The geometry and motion of objects in 3D Euclidean space are described in a reference coordinate system. A reference coordinate system is a coordinate system with well-defined origin and orientation of the three orthogonal, coordinate axes. We shall refer to such a system as a *spatial reference system* (SRS). A spatial reference system is a mathematical abstraction. It is realized by means of *spatial reference frame* (SRF). We may visualize an SRF as a catalogue of coordinates of specific, identifiable point objects, which implicitly materialize the coordinate axes of SRS.

Several spatial reference systems are used in the earth sciences. The most important one for the GIS community is the *International Terrestrial Reference System* (ITRS). The ITRS has its origin in the center of mass of the earth. The Z-axis points towards a mean earth north pole. The X-axis is oriented towards a mean Greenwich meridian and is orthogonal to the Zaxis. The Y-axis completes the right handed reference coordinate system.



(a) The ITRS and (b) The ITRF visualized as the fundamental polyhedron

Introduction

Today it is common to determine a point's position using Global Navigation Satellite Systems (GNSS). If GNSS - "GPS" is used then the point's position is determined in the reference system 'WGS 84'. Observing in a good GNSS environment, the absolute accuracy for a 'single point position fix' will be ± 5 - 10 metres in the horizontal – ie 2 dimensions at the 2 sigma (2σ) confidence level. It is however possible to increase the accuracy of point positioning but positional services such as 'Fugro Omnistar' are needed OR post-processing using precise orbits is usually necessary. If higher accuracy is required (mm to cm) then GNSS data from points of 'known position' in the region are needed. The resulting co-ordinates for the point will then be in the same reference frame as the local point. This local point could be a permanent GNSS station in continuously operating reference station (CORS) network that is linked to an International Terrestrial Reference Frame (ITRF).

In a GNSS CORS network the surveyor will normally derive a height based on the reference ellipsoid ie Geodetic Reference System 1980 (GRS80). Most users however are working with 'physical' heights based on a local height datum (ie local mean sea level) and thus need to relate the derived ellipsoid height to this local height datum. This is achieved by using a geoid model for the subject survey area.

From a spatial information perspective, it is common for spatial datasets and geographical information data to extend over national or regional boundaries. In this situation it is needed to have a common reference frame for the collection, storage, visualisation and exchanging of the information. ITRF is the most accurate reference frame that exists internationally and consequently more countries are using a national solution based on ITRF.

What is ITRS and ITRF?
Co-ordinates in an International Terrestrial Reference System (ITRS) are computed at different epochs and the solutions are called ITRF. Due to plate tectonics and tidal deformation, the co-ordinates changes for a certain point between the different ITRF. The latest version of ITRF is ITRF 2005. In simple terms the ITRF is a realisation of the ITRS

What is the difference between ITRF based datums and WGS84 coordinates?
WGS84 or the World Geodetic System 1984 is the geodetic reference system used by the GNSS - "GPS". WGS84 was developed for the United States Defence Mapping Agency (DMA), now called NGA (National Geospatial - Intelligence Agency). Although the name WGS84 has remained the same, it has been enhanced on several occasions to a point where it is now very closely aligned to ITRF and referenced as WGS 84 (G1150). The origin of the WGS84 framework is also the earth's centre of mass. For all practical purposes, an ITRF based geodetic datum or CORS network and WGS84 are the same. The difference is of the order of cms.

What are ITRF Co-ordinates?
ITRF co-ordinates or positions are articulated as three dimensional geocentric or Earth Centred Cartesian co-ordinates ie "X, Y and Z". To convert these Cartesian co-ordinates to geographic co-ordinates (latitudes and longitudes and ellipsoid height) the GRS80 ellipsoid is normally used as it is the best fitting scientific and mathematical global figure or model for the earth's surface.

Note - in some cases it is necessary to describe an ITRF position in plane (grid) co-ordinates (eg two dimensions – eastings and northings) hence a mathematical map projection is used. A popular map projection which retains the angle is the Transverse Mercator projection.

What are the benefits of a geodetic datum based on ITRF?
Adopting an ITRF based geodetic datum allows for a single standard for collecting, storing and using geographic or survey related data. This will ensure compatibility across various geographic, land and survey systems at the local, regional, national and global level. This is the main reason that the ITRF based CORS networks should form the basis for Spatial Data Infrastructure (SDI) which is the enabling infrastructure to manage a country's key spatial data sets ie it underpins or is the reference layer for the cadastre, transit / road networks, infrastructure corridors like gas, water, power, communications etc. An ITRF based geocentric datum or CORS network will also:

- provide direct compatibility with GNSS measurements and mapping or geographic information system (GIS) which are also normally based on an ITRF based geodetic datum;
- minimise the need for casual users to understand datum transformations;
- allow more efficient use of an organisations' spatial data resources by reducing need for duplication and unnecessary translations;
- help promote wider use of spatial data through one user friendly data environment;
- reduce the risk of confusion as GNSS, GIS and navigation systems become more widely used and integrated into business and recreational activities.

4.3 GPS and remote sensing

What is GPS:

Where do I stand?

Knowing where you are and where you are going was the most crucial and challenging task faced by the explorers since ancient ages. Positioning and navigation are very important in many activities and many tools and techniques have been adopted for this purpose. People have used magnetic compass, sextant, theodolite and measured the positions of sun, moon and stars to find out his own position. Today, the Global Positioning System

(GPS) has been developed by the US Department of Defence (DoD) for world wide positioning, at the cost of 12 billion Dollars.

GPS is a worldwide radio-navigation system formed from a constellation of 24 satellites and their ground stations. It uses these "man-made stars" as reference points to calculate positions accurate to a matter of meters. GPS receivers have become very economical, making the technology accessible to virtually everyone. GPS provides continuous three-dimensional positioning 24 hours a day to the military and civilian users throughout the world. These days GPS is finding its way into cars, boats, planes, construction equipment, farm machinery, even laptop computers. It has a tremendous amount of applications in GIS data collection, surveying, and mapping. GPS is increasingly used for precise positioning of geospatial data and the collection of data in the field.

Components of the GPS

The Global Positioning System is divided into three major components: the control segment, the space segment, and the user segment. All three of these segments are required to perform positional determination.

CONTROL SEGMENT

The Control Segment consists of five monitoring stations - Colorado Springs, Ascension Island, Diego Garcia, Hawaii, and Kwajalein Island (figure 6.1). Colorado Springs serves as the master control station. The Control Segment is the sole responsibility of the DoD who undertakes construction, launching, maintenance, and virtually constant performance monitoring of all GPS satellites. The monitoring stations track all GPS signals for use in controlling the satellites and predicting their orbits.

Figure 6.1 Control segment

SPACE SEGMENT

The Space Segment consists of the constellation of earth orbiting satellites. The satellites are arrayed in 6 orbital planes, inclined 55 degrees to the equator (figure 6.2). They orbit at altitudes of about 12,000 miles each. Each satellite contains four precise atomic clocks (Rubidium and Cesium standards) and has a microprocessor on board for limited self-monitoring and data processing. The satellites are equipped with thrusters, which can be used to maintain or modify their orbits.

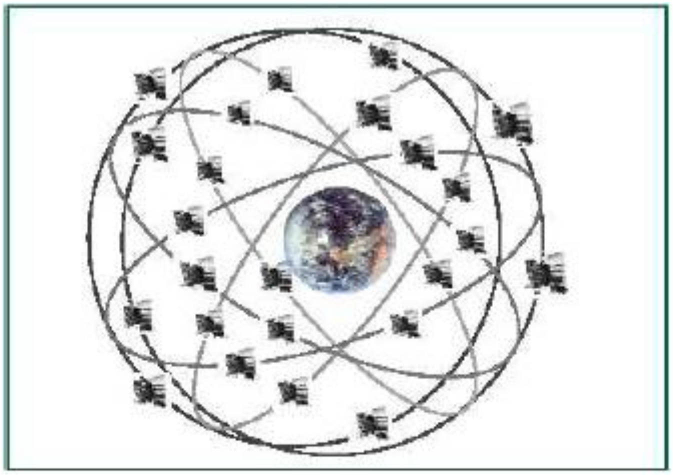


FIGURE 6.2 SPACE SEGMENT

USER SEGMENT

The User Segment consists of all earth-based GPS receivers (figure 6.3). Receivers vary greatly in size and complexity, though the basic design is rather simple. The typical receiver is composed of an antenna and preamplifier, radio signal microprocessor, control and display device, data recording unit, and power supply (figure 6.3). The GPS receiver decodes the timing signals from the 'visible' satellites (four or more) and, having calculated their distances, computes its own latitude, longitude, elevation, and time. This is a continuous process and generally the position is updated on a second-by-second basis, output to the receiver display device and, if the receiver provides data capture capabilities, stored by the receiver logging unit.

Figure 6.3 GPS receiver

HOW GPS WORKS?

The GPS uses satellites and computers to compute positions anywhere on earth. The GPS is based on satellite ranging. That means the position on the earth is determined by measuring the distance from a group of satellites in space. Triangulation from the satellite is the basis of the system. To triangulate, the GPS measures the distance using the travel time of a radio message, for which it needs a very accurate clock. Once the distance to a satellite is known, then we need to know where the satellite is in space.

To compute a position in three dimensions, we need to have four satellite measurements. The GPS uses a trigonometric approach to calculate the positions (figure 6.4). The GPS satellites are so high up that their orbits are very predictable and each of the satellites is equipped with a very accurate atomic clock.

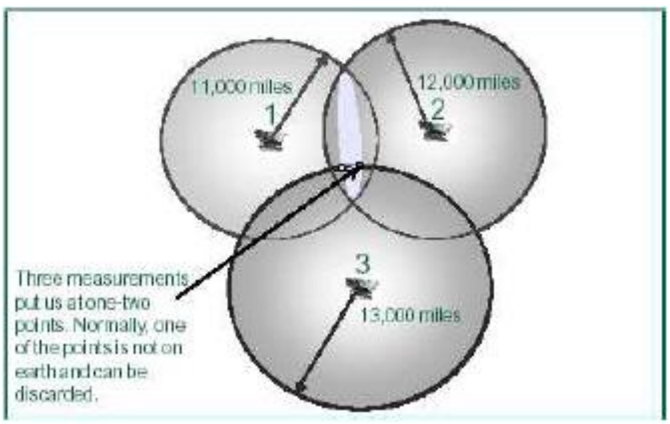


Figure 6.4 GPS triangulation

GPS errors

Although the GPS looks like a perfect system, there are a number of sources of errors which are difficult to eliminate (figure 6.5). The ultimate accuracy of GPS is determined by sum of these several sources of error.

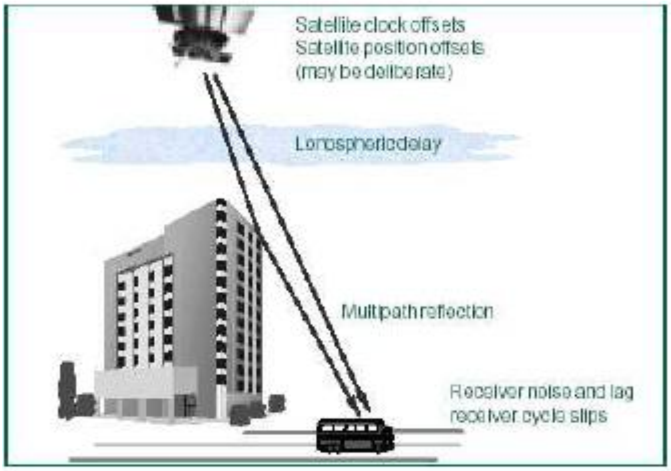


Figure 6.5 GPS Errors

SATELLITE ERRORS

Slight inaccuracies in time keeping by the satellites can cause errors in calculating our positions. Similarly, the satellite's position in space is equally important as it is the starting point of the calculations. Although the GPS satellites are at very high orbits and are relatively free from the perturbing effects of atmosphere, they still drift slightly from their predicted orbits which contributes to our errors.

THE ATMOSPHERE

The GPS signals have to travel through charged particles and water vapour in the atmosphere which delays its transmission. Since the atmosphere varies at different places and at different times, it is not possible to accurately compensate for the delays that occur.

Multipath error

As the GPS signal finally arrives at the earth's surface, it may be reflected by local obstructions before it gets to the receiver's antenna. This is called multipath error as the signal is reaching the antenna by multiple paths.

RECEIVER ERROR

Since the receivers are also not perfect, they can introduce their own errors which usually occur from their clocks or internal noise.

SELECTIVE AVAILABILITY

Selective availability (SA) was the intentional error introduced by DoD to make sure that no hostile forces used the accuracy of GPS against the US or its allies. It introduced some noise into the GPS satellite clocks which reduced their accuracy. The satellites were also given some erroneous orbital data which was transmitted as a part of each satellite's status message. These two factors significantly reduced the accuracy of GPS in civilian uses.

On May 1st, 2000, the White House announced a decision to discontinue the intentional degradation of the GPS signals to the public. Civilian users of GPS will be able to pinpoint locations up to ten times more accurately. The decision to discontinue SA is the latest measure in an on-going effort to make GPS more responsive to civil and commercial users worldwide.

Differential positioning

To eliminate most of the errors discussed above, the technique of differential positioning is applied. Differential GPS carries the triangulation principle one step further, with a second receiver at a known reference point. The reference station is placed on the control point - a triangulated position or the control point coordinate. This allows for a correction factor to be calculated and applied to other roving GPS units used in the same area and in the same time series. This error correction allows for a considerable amount of error to be negated, potentially as much as 90 per cent. The error correction can either be post processed or on real time (figure 6.6).

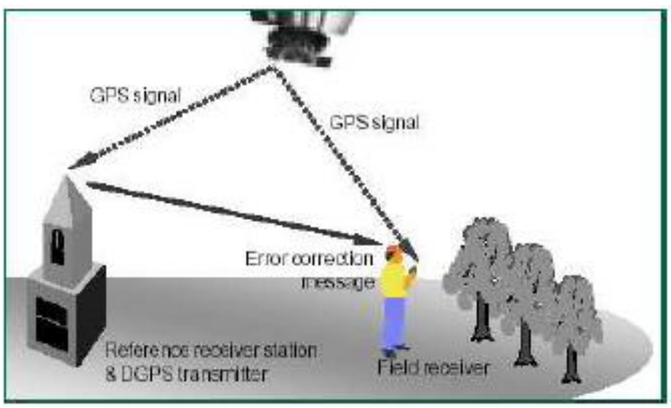


Figure 6.6 Differential positioning

Integration of GPS and GIS

It is possible to integrate GPS positioning in GIS for filed data collection. GPSs are also used in remote-sensing methods such as photogrammetry, aerial scanning, and video technology. GPS are becoming very effective tools for GIS data capture. The GIS user community benefits from the use of GPS for locational data capture in various GIS applications. The GPS can easily be linked to a laptop computer in the field, and, with appropriate software, users can also have all their data on a common base with very little distortion. Thus GPS can help in several aspects of construction of accurate and timely GIS databases

Some Applications of GPS:

- **Fishing**
- **Hiking**
- **Sailing/Boating**
- **Automobile**
- **Cell Phones**
- **Pilots**
- **Biking**
- **Education**

Remote Sensing

Remote Sensing satellite images gives a synoptic (bird's eye) view of any places of the Earth surface, which helps to study, map, and monitor the Earth's surface at local and/or regional/global scales. It is cost effective and gives better spatial coverage as compared to ground sampling. Generally, Remote Sensing refers to the activities of recording/observing/perceiving (sensing) objects or events at far away (remote) places.
Remote Sensing is defined as the science and technology by which the characteristics of objects of interest can be identified, measured or analyzed the characteristics without direct contact. Remote Sensing deals with gathering information about the Earth from a distance. This can be done from a few metres off the Earth's surface, an aircraft flying hundreds thousands of metres above the surface, or a satellite orbiting hundreds of kilometers above the Earth.

Figure 5.1 Earth from Space

Remote-sensing satellite

The remote sensing satellites are equipped with sensors looking down to the earth. They are the "eyes in the sky" constantly observing the earth as they move around the earth (figure 5.2).

Figure 5.2 Remote Sensing satellite

How does remote sensing work?

Electro-magnetic radiation which is reflected or emitted from an object is the usual source of remote sensing data. A device to detect the electro-magnetic radiation reflected or emitted from an object is called a "remote sensor" or "sensor". Cameras or scanners are examples of remote sensors. A vehicle to carry the sensor is called a "platform". Aircraft or satellites are used as platforms.
The characteristics of an object can be determined, using reflected or emitted electro-magnetic radiation, from the object. That is, "each object has a unique and different characteristics of reflection or emission if the type of object or the environmental condition is different. "Remote sensing is a technology to identify and understand the object or the environmental condition through the uniqueness of the reflection or emission. This concept is illustrated in figure 5.3.

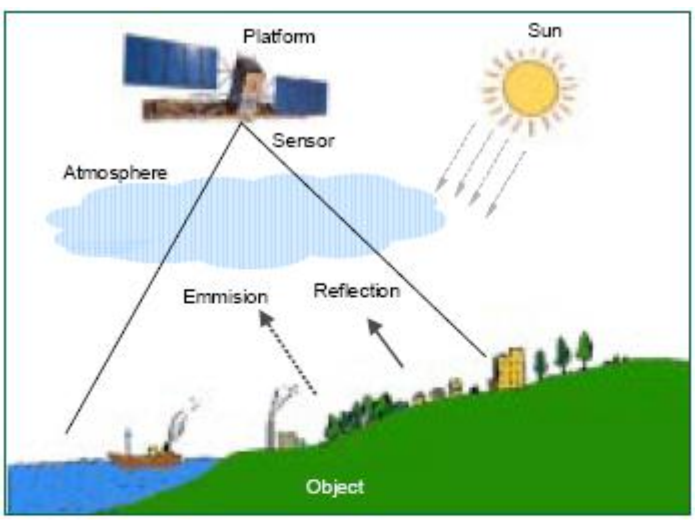


Figure 5.3 Remote Sensing

Types of remote-sensing images

Presently there are several remote sensing satellite series in operation. Different satellite systems have different characteristics, e.g. resolutions, number of bands, and have their own importance for different application. Some major satellite systems and their major characteristics are given below:

Satellite Systems	Spatial Resolution	Type	Number of Bands	Launched by
LANDSAT-TM	30m	Multi-spectral	7	USA
LANDSAT-MSS	80m	Multi-spectral	4	USA
SPOT-XS	20m	Multi-spectral	3	France
SPOT-PAN	10m	Panchromatic	1	France
IRS-1C PAN	6m	Panchromatic	1	India
LISS-III	24m	Multi-spectral	4	India
WiFS	188m	Multi-spectral	2	India
SPIN-2	2m	Panchromatic	1	USA/Russia
IKONOS	1m	Panchromatic	1	Canada
IKONOS	4m	Multi-spectral	4	Canada
ADEOS-AVNIR M	16m	Multi-spectral	4	Japan
NOAA	1.1Km	Multi-spectral	5	USA
MOS	50m	Multi-spectral	4	USA

Remote-sensing images

Remote sensing images are normally in the form of digital images (figure 5.4). In order to extract useful information from the images, image processing techniques are applied to enhance the image to help visual interpretation, and to correct or restore the image if the image has been subjected to geometric distortion, blurring or degradation by other factors. There are many image analysis techniques available and the methods used depending upon the requirements of the specific problem concerned.

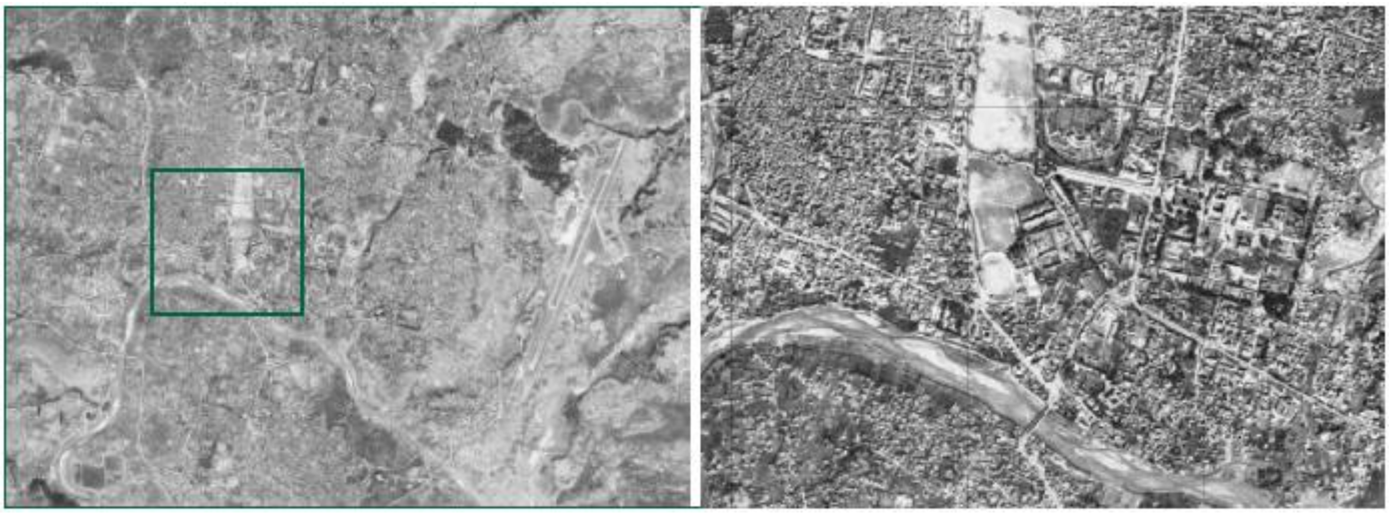


Figure 5.4 Satellite Image of Kathmandu

Use of Remote Sensing Data in GIS

Remote sensing data after can be integrated with various other geographic data. There has been an increasing trend in integration of remote sensing data into GIS for analytical purpose. There many ways we could use remote sensing data and some examples are illustrated as below:
Land cover maps or vegetation maps classified from remote sensing data can be overlaid onto other geographic data, which enables analysis for environmental monitoring and its change.
Image data are sometimes also used as image maps, with an overlay of political boundaries, roads, rivers etc. Such an image map can be successfully used for visual interpretation (figure 5.5 and 5.6).

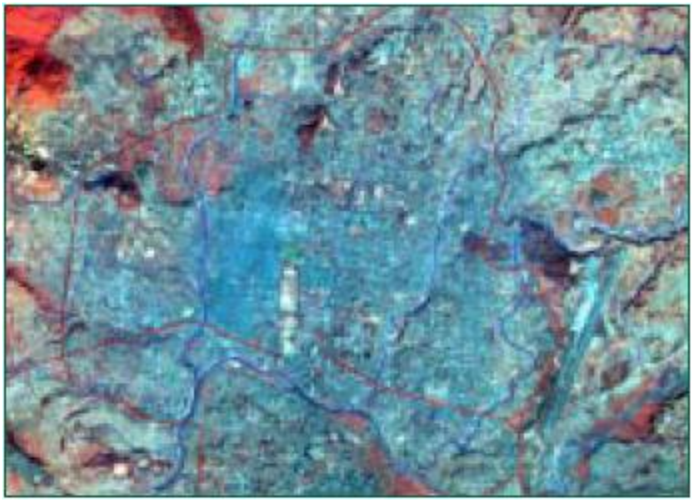


Figure 5.5 Kathmandu urban area observed from an ADEOS-AVNIR M Japanese satellite image, 1997, and overlaid with road and river features

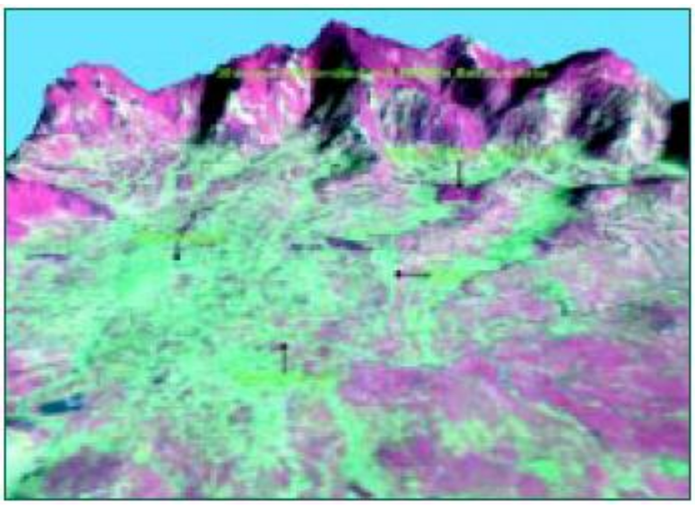


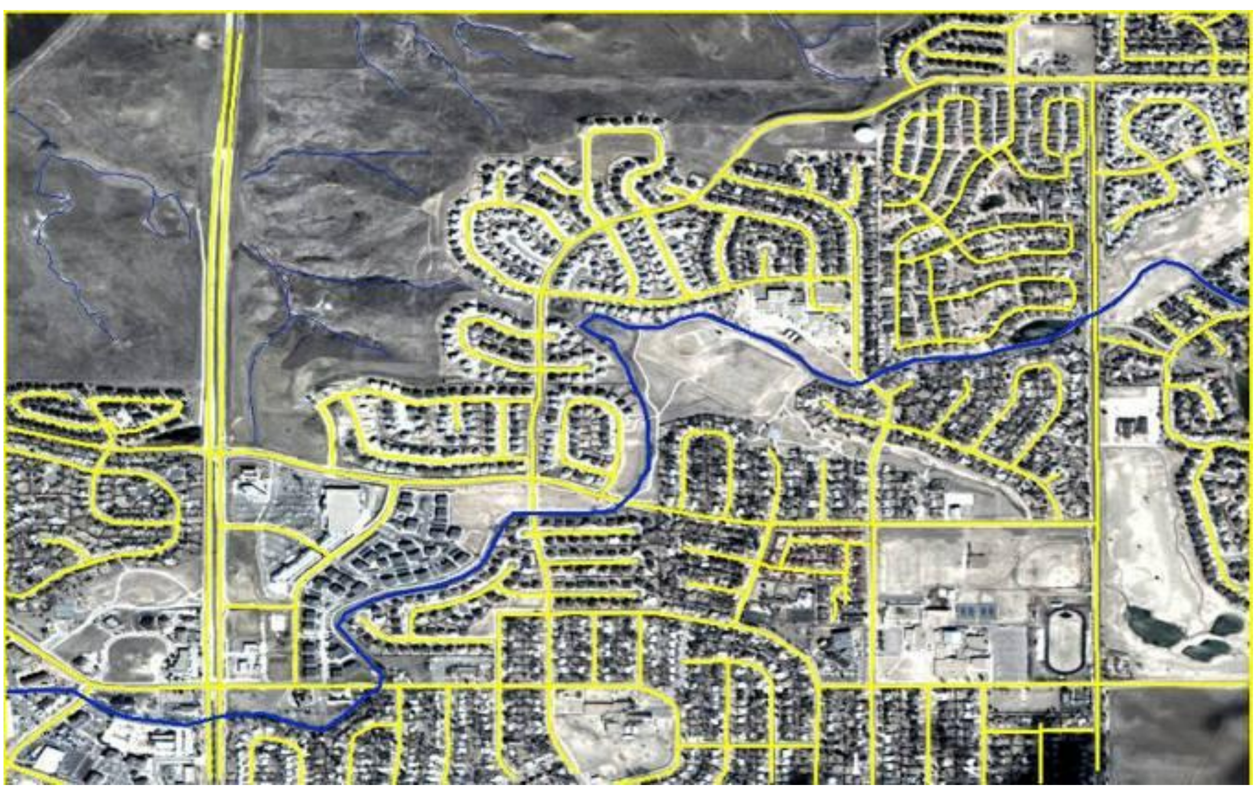
Figure 5.6 3-D perspective of the Kathmandu valley generated by draping a LANDSAT-TM, 1988, satellite image over a DEM

Importance:

- Large amounts of data needed, and Remote Sensing can provide it
- Reduces manual field work dramatically
- Allows retrieval of data for regions difficult or impossible to reach:
    - Open ocean
    - Hazardous terrain (high mountains, extreme weather areas, etc.)
    - Ocean depths
    - Atmosphere

- Allows for the collection of much more data in a shorter amount of time
  - Leads to increased land coverage AND
  - Increase ground resolution of a GIS
- Digital Imagery greatly enhances a GIS
  - DIRECTLY: Imagery can serve as a visual aid
  - INDIRECTLY: Can serves as a source to derive information such as…
    - Land use/land cover
    - Atmospheric emissions
    - Vegetation
    - Water bodies
    - Cloud cover
    - Change detection (including sea ice, coastlines, sea levels, etc.)

Extracting RS Data



- Layers such as roads (yellow) and rivers (blue) can be easily seen from air/satellite photos
- This information is digitized, separated into layers, and integrated into a GIS

Data Digitizing Process:

- **MANUAL**
  - Map is fixed to digitizer table
  - Control Points are digitized
  - Feature Boundaries are digitized in stream or point mode
  - The layer is proofed and edited
  - The layer is transformed/registered to a known system
- **AUTOMATED SCANNERS**
  - Digitizing done automatically by a scanner
  - There is a range of scanner qualities
  - Most utilize the reflection/transmission of light to record data
  - “Thresholding” allows for the determination of both line and point features from a hardcopy map
  - Editing still required
- **DIRECT DATA ENTRY**
  - Coordinate Geometry is used, with GPS playing a vital role
  - This involves directly entering in coordinates measured in the field
  - These coordinates can then be tagged with attribute data
  - This data this then downloaded to a computer and incorporated into a GIS

4.4 Data preparation, conversion and integration, Quality

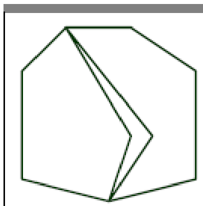
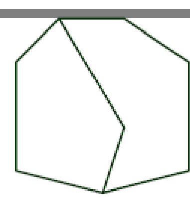
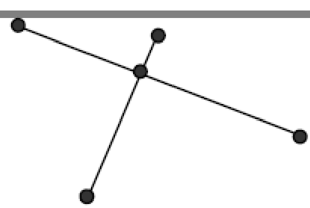
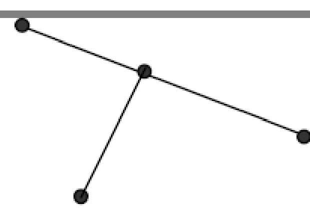
Data Preparation

Spatial data preparation aims to make the acquired spatial data fit for use. Images may require enhancements and corrections of the classification scheme of the data. Vector data also may require editing, such as the trimming of overshoots of lines at interactions, deleting duplicate lines, closing gaps in lines, and generating polygons. Data may need to be converted to either vector format or raster format to match other data sets. Additionally, the process includes associating attribute data with the spatial data through either manual input or reading digital attribute files into the GIS/DBMS.

The intended use of the acquired spatial data, furthermore, may require thinning the data set and retaining only the features needed. The reason may be that not all features are relevant for subsequent analysis or subsequent map production. In this case, data and/or cartographic generalization must be performed to restrict the original data set.

Data precision, error and repair

Acquired data sets must be checked for consistency and completeness. This requirement applies to the geometric and topological quality as well as the semantic quality of the data. There are different approaches to clean up data. Errors can be identified automatically, after which manual editing methods can be applied to correct the errors. Alternatively, a system may identify and automatically correct many errors. Alternatively, a system may identify and automatically correct many errors. Clean-up operations are often performed in a standard sequence. For example, crossing lines are split before dangling lines are erased, and nodes are created at intersections before polygons are generated.

Before cleanup	After cleanup	Description
		Erase duplicates or silver lines
		Erase dangling objects or overshoots

Precision refers to the level of measurement and exactness of description in a GIS database. Precise location data may measure position to a fraction of a unit. Precise attribute information may specify the characteristics of features in great detail. It is important to realize, however, that precise data--no matter how carefully measured--may be inaccurate. Surveyors may make mistakes or data may be entered into the database incorrectly.

- The level of precision required for particular applications varies greatly. Engineering projects such as road and utility construction require very precise information measured to the millimeter or tenth of an inch.
- Highly precise data can be very difficult and costly to collect. Carefully surveyed locations needed by utility companies to record the locations of pumps, wires, pipes and transformers cost $5-20 per point to collect

Error encompasses both the imprecision of data and its inaccuracies

Multiple data sources

A GIS project usually involves multiple data sets, so a next step addresses the issue of how these multiple sets relate to each other. There are three fundamental cases to be considered if we compare data sets pair wise:

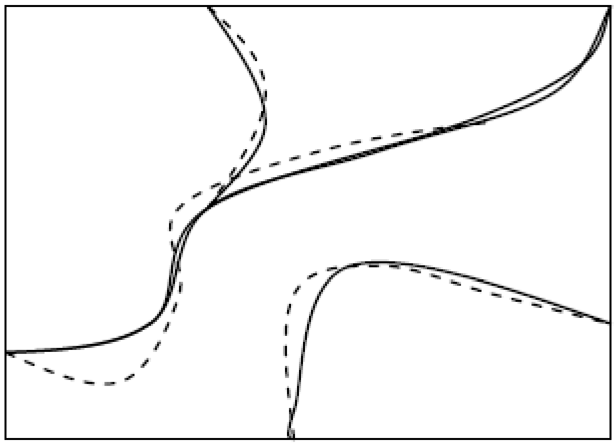
They may be about the same area, but differ in accuracy,

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

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

Differences in accuracy

Images come at a certain resolution, and paper maps at certain scale. This typically results in differences of resolution of acquired data sets, all the more since map features are sometimes intentionally displaced to improve the map. For instance, the course of a river will only be approximated roughly on a small scale map, and a village on its northern bank should be depicted north of the river, even if this means it has to be displaced on the map a little bit. The small scale causes an accuracy error. If we want to combine a digitized version of that map, with a digitized version of a large-scale map, we must be aware that features may not be where they seem to be. Analogous examples can be given for images at different resolutions.

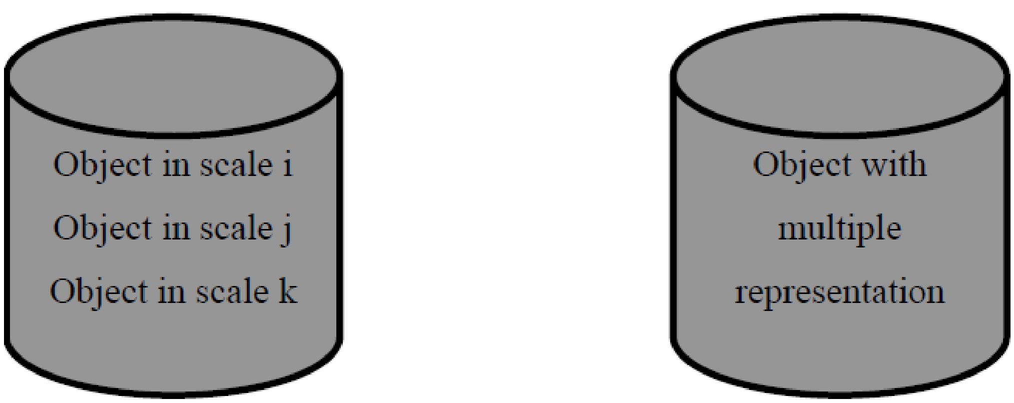


The integration of two vector data sets may lead to silver

In the figure above, the polygons of two digitized maps at different scales are overlaid. Due to scale differences in the sources, the resulting polygons do not perfectly coincide, and polygon boundaries cross each other. This causes small, artifact polygons in the overlay known as silver polygon.

Differences in representation

There exist more advanced GIS applications that require the possibility of representing the same geographic phenomenon in different ways. Map production at various map scale is again an example but there are numerous others. The commonality is that phenomena must sometimes be viewed as points, and at other times as polygons, for instance. The complexity that this requirement entails is that the GIS or the DBMS must keep track of links between different representations for the same phenomenon and must also provide support for decisions as to which representations to use in which situation.



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

For example, a small-scale national road network analysis may represent villages as point objects, but a nation wide urban population density study should regard all municipalities as represented by polygons. The links between various representations for the same things maintained by the system allows interactive traversal, and many fancy applications of their use seem possible. The systems that support this type of data traversal are called multi representation systems.

Data Transformation

In virtually all mapping applications it becomes necessary to convert from one cartographic data structure to another. The ability to perform these object-to-object transformations often is the single most critical determinant of a mapping system's flexibility.

Format Change: Raster to vector and vector to raster conversion within the same GIS system. May also include raster to vector and vector to raster data.

Issues to consider:

Loss of detail: especially at features edges, generally vector data more accurately represents a feature

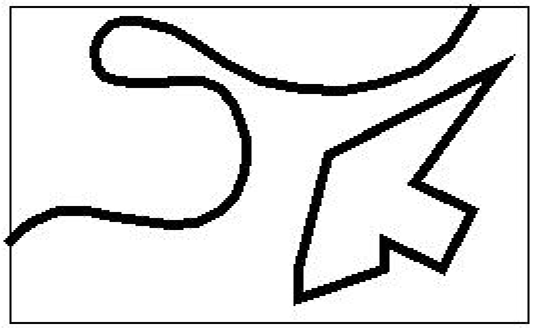
Loss of attribute data: some raster formats do not allow for multiple attributes per cell

Vector and raster formats store similar GIS data in very different ways.

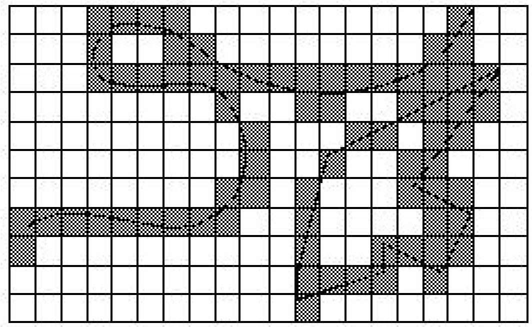
A particular GIS will adopt one of two strategies for dealing with two types of data. Some systems use only one format exclusively and provide utilities or import options to bring in the data and convert it to the needed format.

Other GIS software supports the native format of each type of data and requires the GIS operator to change the formats explicitly when operation requires commonality of formats. The computer program in both cases performs raster-to-vector and vector-to-raster conversion. Most often when converting from vector to raster the results are visually satisfactory, but the conversion techniques can produce results that are not satisfactory to the attributes each grid cell represents. It is particularly true along the edges of areas, where the user seldom knows the decision rules concerning how the partial cells are handled.

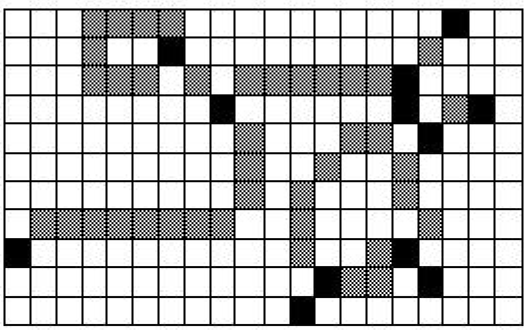
Alternatively, by converting from raster to vector, you may preserve the vast majority of the attribute data, but the visual results will often reflect the blocky, step-like form. The size of the grid cells from which conversion proceeds is an important factor controlling the "blockiness" of the resulting vector.
Different mathematical smoothing algorithms can minimize this effect.



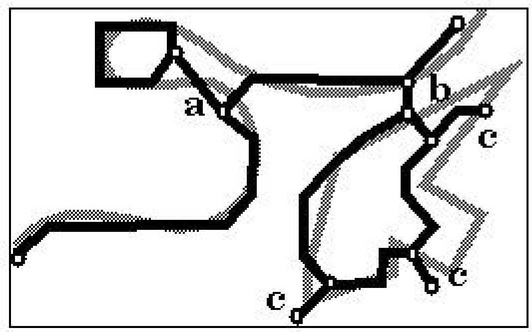
Vector lines



Raster scan of lines



Thinned Image: Endpoints located



Conversion to topological vectors

Unit 5: spatial analysis and visualization

5.1 Spatial analysis

Playing with places

When you think of a name and address database, you probably think of tabular data in rows and column. What you might miss is that each of those records represents a person or family who lives somewhere (location). GIS allows us to think spatially. Again that somewhere (location) can tell about that persons' standard of living, neighbourhood, access to school, access to hospital, crime statistics surrounding that area, distance to the main market, pollution level and so on. Through GIS analysis, it allows us to visualize the "big picture" by letting us see patterns and relationship in your geographic data. The results of analysis will give you insight into a place, helps you focus your actions, or help you choose the best option. The beauty of GIS is its ability to perform spatial analysis.

What is Spatial Analysis?

Spatial analysis is a process for looking at geographic patterns in your data and relationships between features. The actual methods you use can be very simple –sometimes, 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.

Spatial analysis allows us to study real-world processes. It gives the information about the real world including the present situation of specific areas and features, the change in situation or the trends. For instance – 'where and how much the forest areas are decreasing or increasing?', 'where the urban areas are growing up in the Kathmandu valley?' and so on.

Spatial Analysis Functions

Spatial analysis functions range from simple database query to arithmetic and logical operation to complicated model analysis. Each of these functions are described briefly below:

DATABASE QUERY

Database query is to retrieve the attribute data without altering the existing data. The function can be performed by simply clicking on the feature or by means of a conditional statement for complex queries. The conditional statement involves-

Boolean (logical) operators: AND, OR, NOT, XOR (exclusive OR)
Relational (conditional) operators: =, >, <, <> (not equal to)
Example of Boolean operators to combine more than two conditions as shown in the figure 7.1.

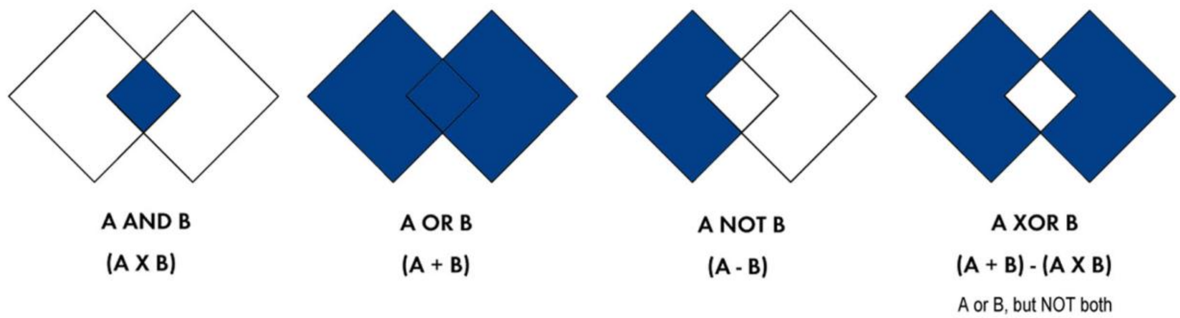


Figure 7.1 Boolean operations

For example, in figure 7.2, the Boolean operator used is ([LandUse] = 'Agriculture') OR ([LandUse] = 'Shrub'). The Boolean operators are based on 0 and 1; 0 if the attributes do not meet the condition and 1 if they do.

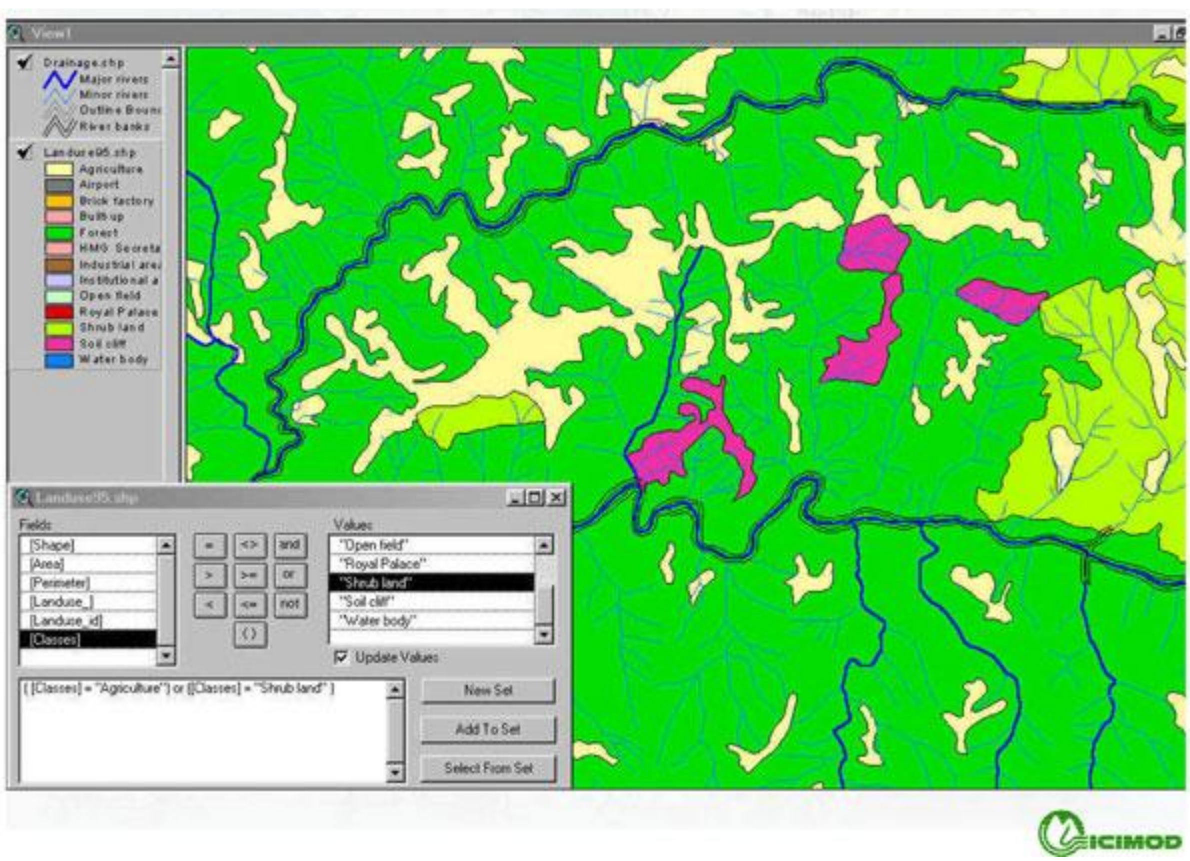


Figure 7.2 Selection using Boolean operators

RECLASSIFICATION

(Re)classification operations involve the reassignment of thematic values to the categories of an existing map.

Examples:
Reclassify a VDC (Village Development Committee) map based on population density. (Figure 7.3)
Classify an elevation map into classes with intervals of 500 m. (Figure 7.4)

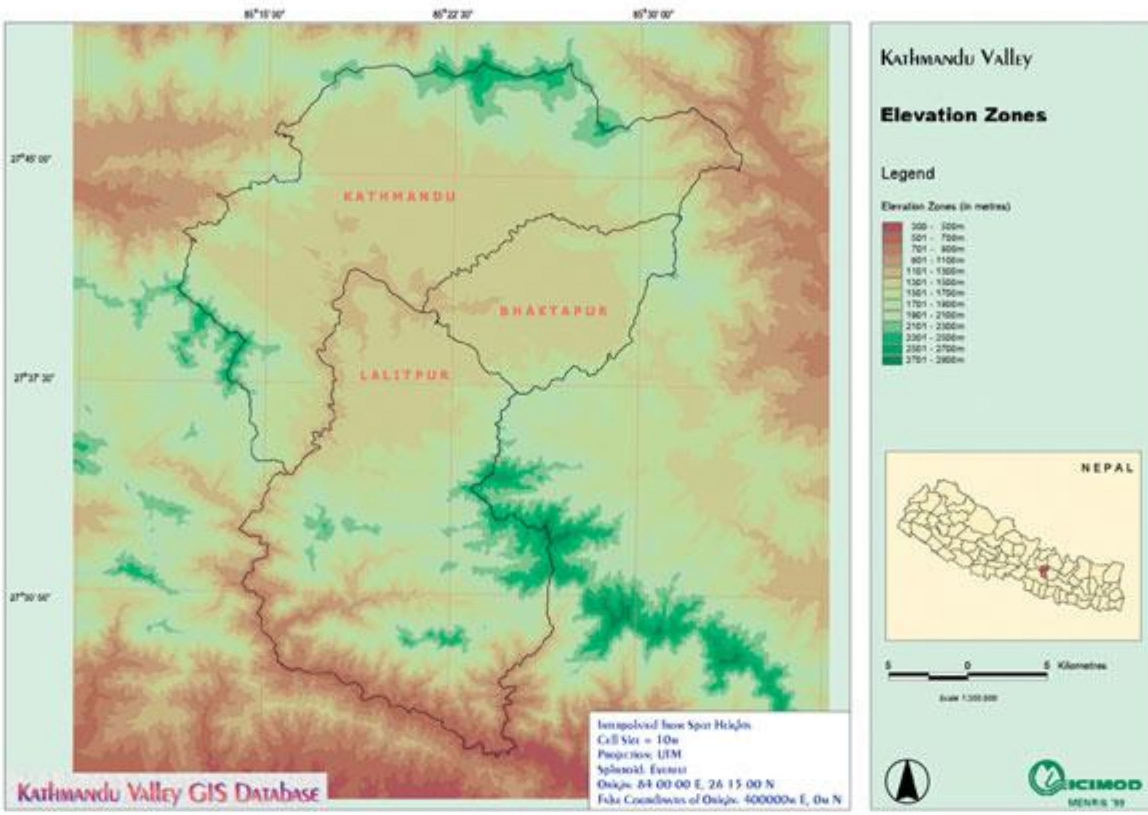


Figure 7.3 Classification of an elevation map of Kathmandu valley into different intervals

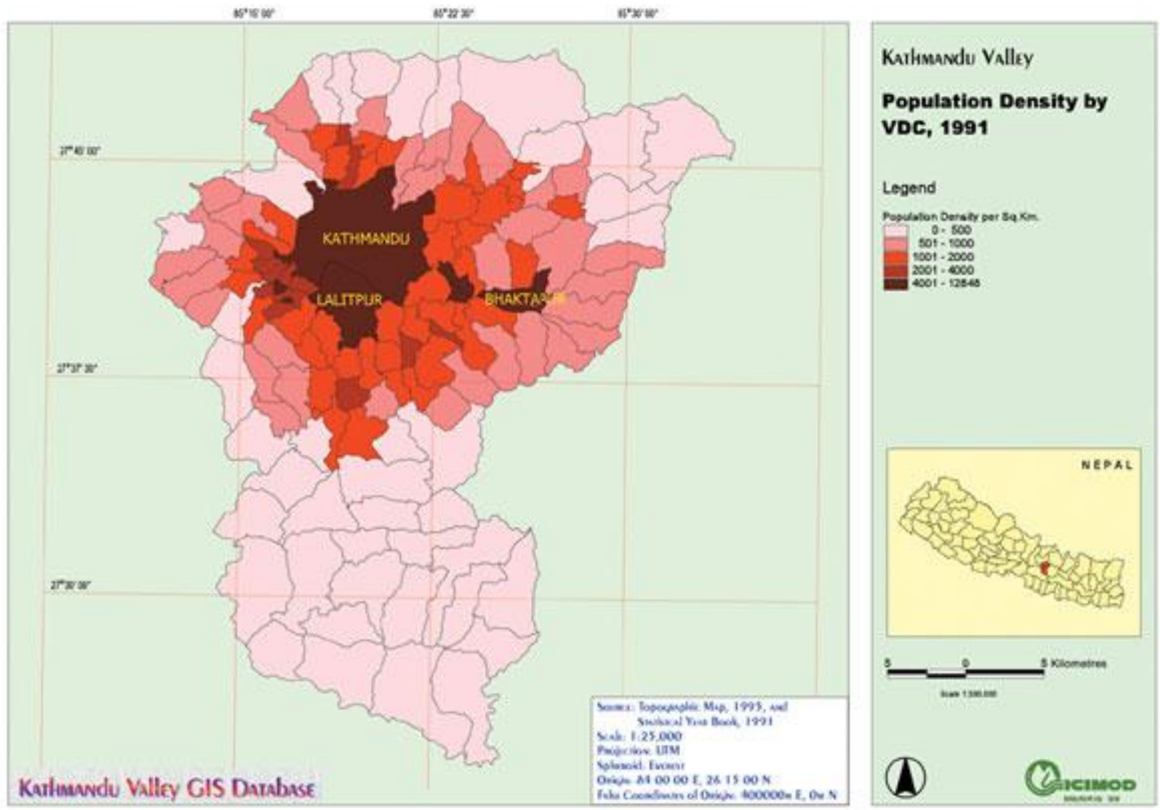


Figure 7.4 Classification of a VDC map of Kathmandu valley based on population density, 1991

i. Overlay

Overlay is the core part of GIS analysis operation. It combines several spatial features to generate new spatial elements. In other word, overlay can be defined as a spatial operation, which combines different geographic layers to generate new information. Overlay is done using Arithmetic, Boolean, and Relational operators, and is performed in both vector and raster domain.

Vector Overlay

During vector overlay, map features and the associated attributes are integrated to produce new composite map. Logical rules can be applied to how the maps are combined. Vector overlay can be performed on different type of map feature: viz., polygon-on-polygon overlay, line-on-polygon overlay, point-on-polygon overlay (figure 7.5). During the process of overlay, the attribute data associated with each feature type is merged. The resulting table will contain both the attribute data.

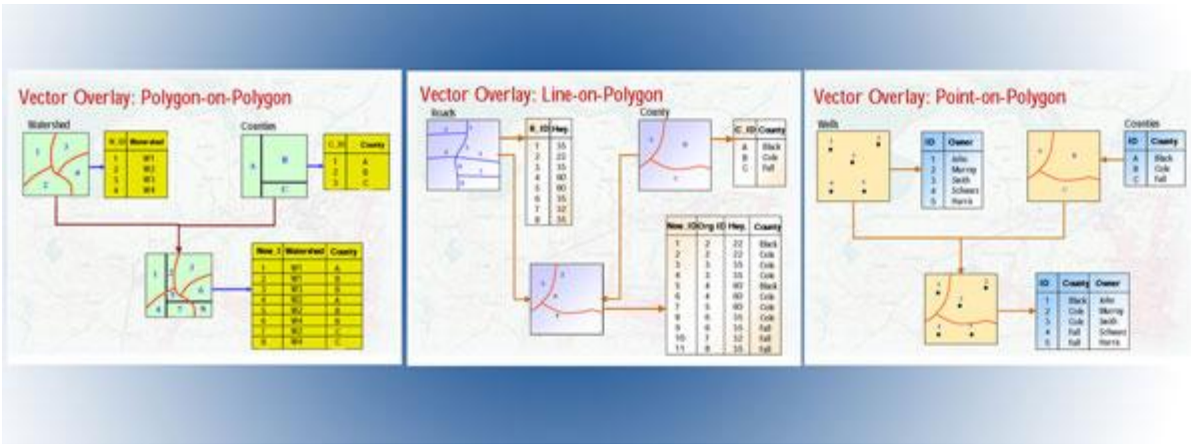


Figure 7.5 Vector overlay

Raster Overlay

In raster overlay, the pixel or grid cell values in each map are combined using arithmetic and Boolean operators to produce a new value in the composite map. The maps can be treated as arithmetic variables and perform complex algebraic functions. The method is often described as map algebra (figure 7.6). The raster GIS provides the ability to perform map layers mathematically.
The map algebraic function uses mathematical expressions to create new raster layers by comparing them.

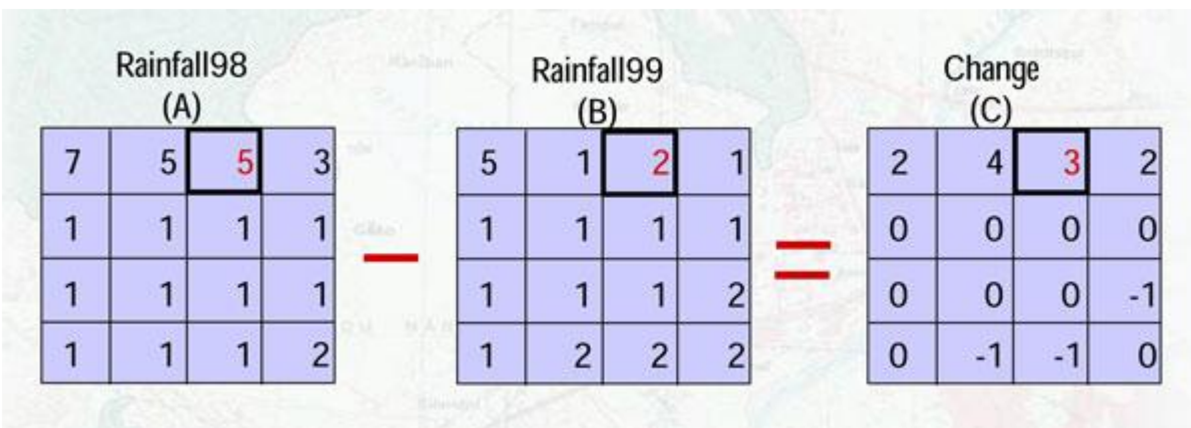


Figure 7.6 Map algebra

There are three groups of mathematical operators in the Map Calculator: Arithmetic, Boolean, and Relational.

Arithmetic Operators - The Arithmetic operators (*, /, -, +) allow for the addition, subtraction, multiplication, and division of two raster maps, or numbers, or combination of the two.
Boolean Operators - The Boolean operators (And, Not, Or, and Xor) use Boolean logic (TRUE or FALSE) on the input values. Output values of TRUE are written as 1 and FALSE as 0.
Relational Operators - The Relational operators (<, <=, <>, =, >, and >=) evaluate specific relational conditions. If the condition is TRUE, the output is assigned 1; if the condition is FALSE, the output is assigned 0.

The figure 7.7 shows examples of simple raster overlay using different logical operators.

The following GIS application illustrates the land use and land cover changes over time in the Kathmandu Valley (figure 7.8). The analysis is done by overlaying land use/cover data of different dates as discussed above. The figure shows the land use/cover data of 1978 and 1995 of the Kathmandu valley, and the changes between 1978 to 1995 derived from the 1978 and 1995 land use/cover data.

This is the analysis of connectivity between points, lines and polygon in terms of distance, area, travel time, optimum paths etc. Connectivity analysis consists of the following analyses:

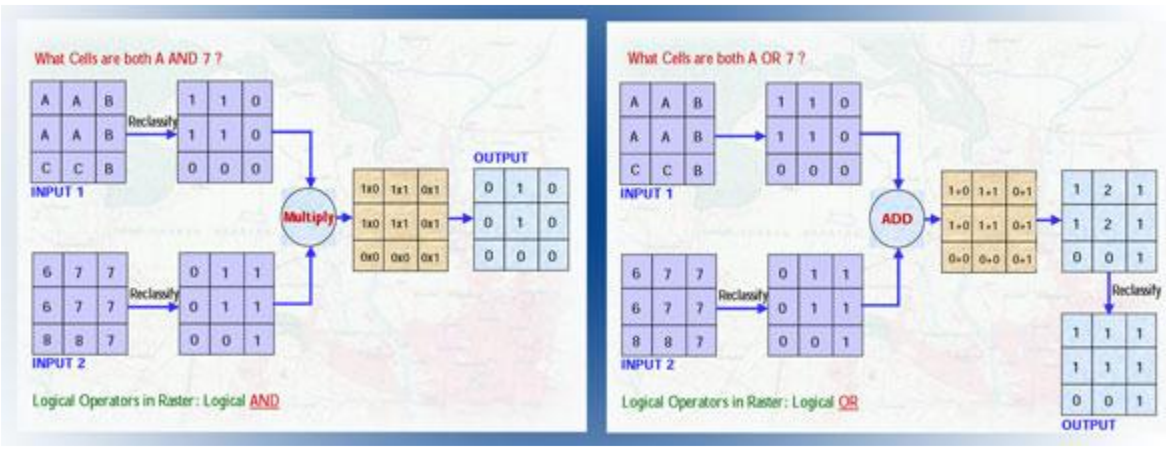


Figure 7.7 Raster overlay using 'and' and 'or' logical operators

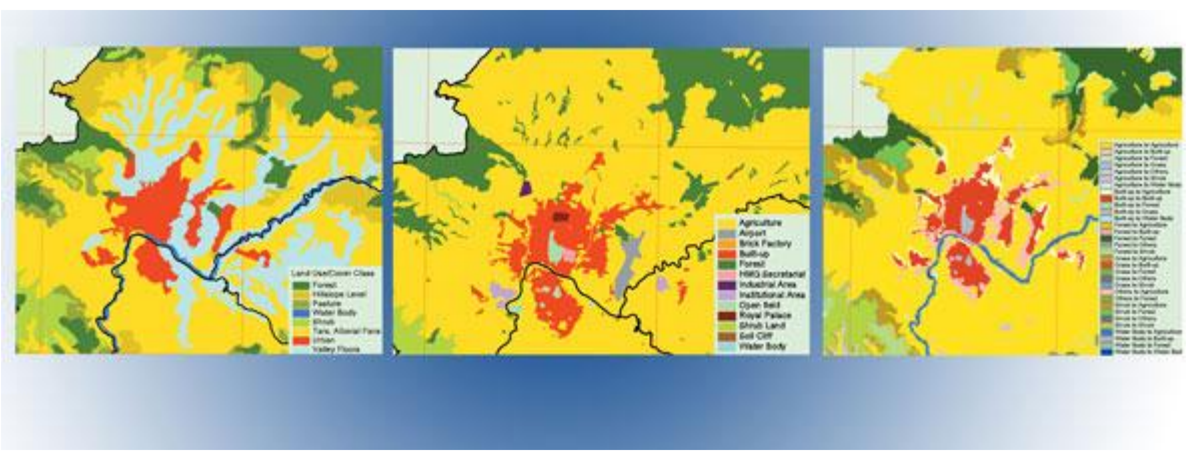


Figure 7.8 Land-cover change in the Kathmandu valley between 1978 and 1995

Proximity Analysis/ Buffering

Proximity analysis is measurement of distances from points, lines and boundaries of polygons. One of the most popular proximity analysis is based on "buffering", by which a buffer can be generated around a point, line and area with a given distance as shown in the figure 7.9. Buffering is easier to generate for raster data than for vector data.

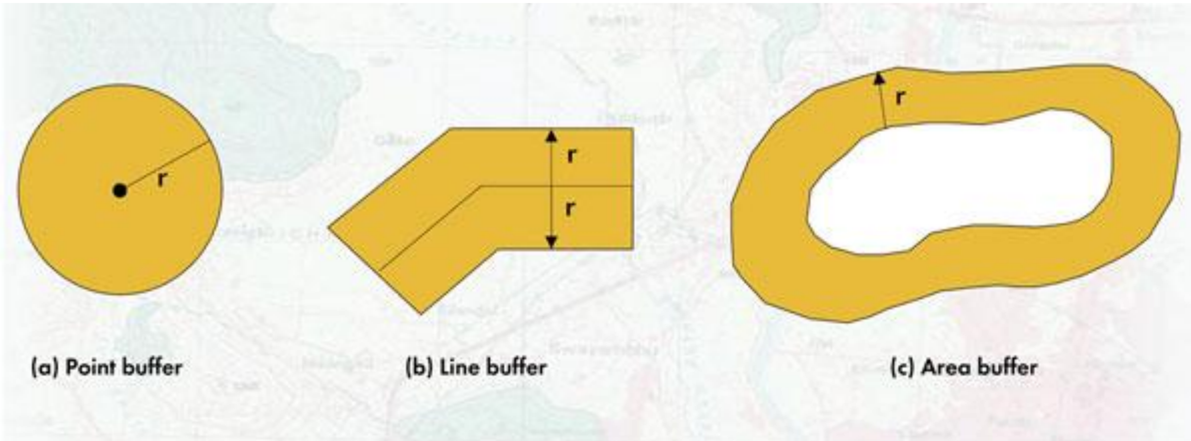


Figure 7.9 Buffer operations

The following figure 7.10 shows walking distance from ICIMOD building.

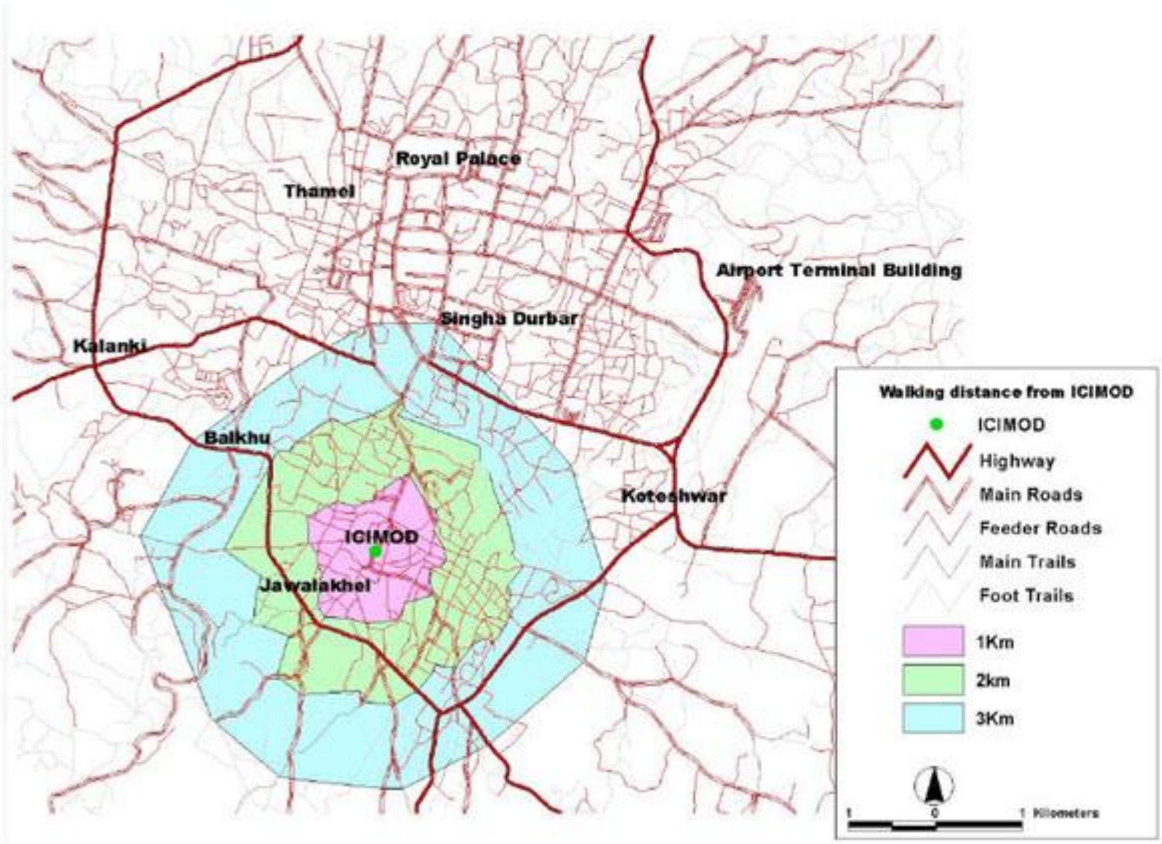


Figure 7.10 Walking distances from ICIMOD

Network Analysis

Network analysis is commonly used for the analysis of moving resources from one location to another through a set of interconnected features. It includes determination of optimum paths using specified decision rules. The decision rules are likely based on minimum time or distance, and so on. Figure 7.11 demonstrates an example of optimum paths based on minimum distance. In the figure, there are locations of number of main hospitals within the ring road of Kathmandu valley. If there has been an accident out of ring road (let's say: close to Bhaktapur), which is the closest hospital and the shortest route to that hospital for a ambulance. The network analysis identifies the closest hospital (Bir Hospital as you notice in the figure) in terms of distance and also indicates how to go there.

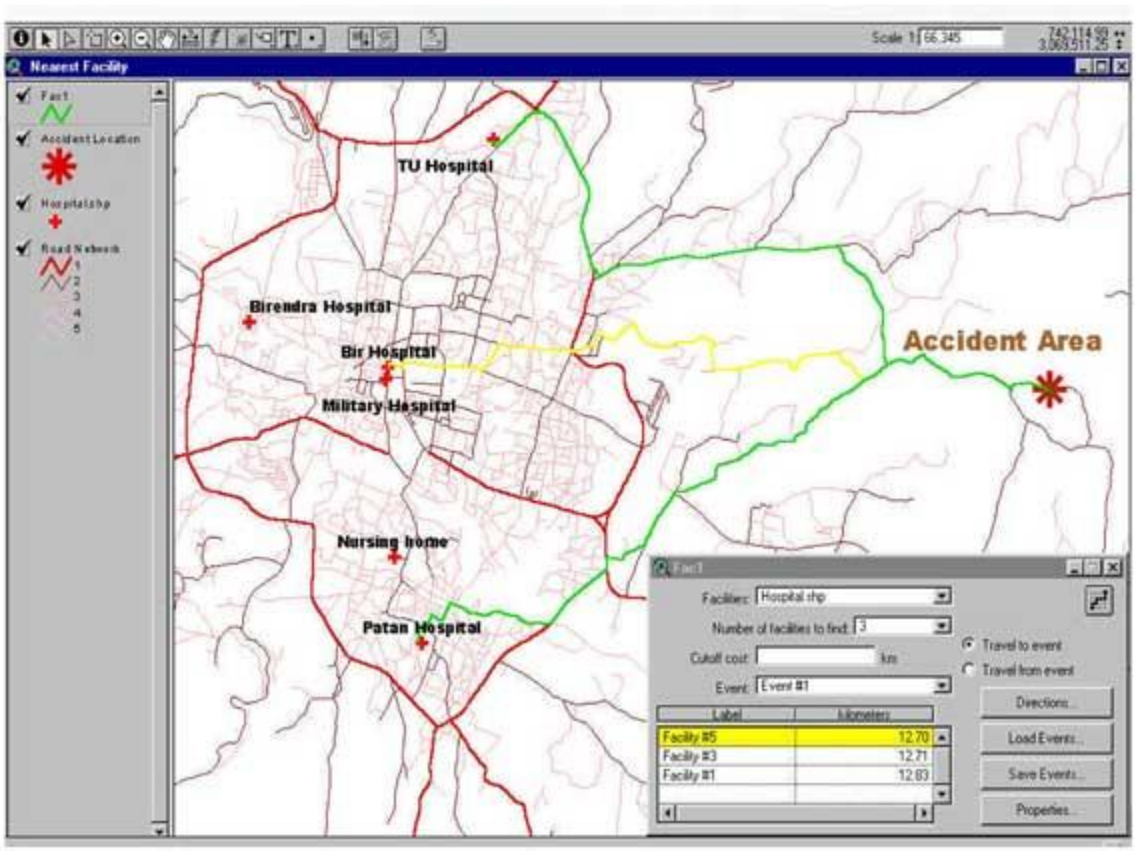


Figure 7.11 Network analysis

5.2 Map outputs and its basic elements

Visualization

Visualization is considered as the translation or conversion of spatial data from a database into graphics. These are in the form of maps, enabling the user to perceive the structure of the phenomenon or the area represented. The visualization process is guided by the saying "How do I say what to whom, and is it effective?" "How" refers to the cartographic methods that are used for making the graphics or the map. "I" refers to the cartographer, or the GIS user who is preparing the map for exploring the data or for presentation. "Say" refers to the semantics that represent the spatial data. "What" refers to the spatial data and its characteristics. "Whom" refers to the map audience and the purpose of the map.
The usefulness of a map depends upon the following factors.

WHO IS GOING TO USE THEM?

The map audience or the users will influences how a map should look like. A map made for school children will be very different from one made for scientists. Similarly, tourist maps and topographic maps of the same area are very much different in their contents and look as they are made for different users.

What is their purpose?

The purpose of the map determines what features are included and how they are represented. The different purposes such as orientation and navigation, physical planning, management, and education lead to different categories of maps.

WHAT IS THEIR CONTENT?

The usefulness also depends upon the contents of a map. The contents can be seen as primary content (main theme), secondary content (base map information) and supportive content (legends, scale, etc).

WHAT IS THE SCALE OF THE MAP?

The map scale is the ratio between a distance on a map and the corresponding distance in the terrain. Scale controls the amount of detail and extent of area that can be shown. Scale of the output map is based upon considerations such as - the purpose of the map, needs of the map user, map content, size of the area mapped, accuracy required etc.

WHAT IS THE PROJECTION OF THE MAP?

Every flat map of a curved surface is distorted. The choice of map projection determines how, where and how much the map is distorted. Normally, the selected map projection is that which is also used for topographic maps in a certain country.

ACCURACY

GIS has simplified the process of information extraction and communication. Combining or integrating various data sets has become possible. However, this has created the possibilities of integrating irrelevant or inconsistent data. The user should be aware with the aspects of data quality or accuracy, such as, "What is the source of data? Are the places at correct locations? Are the attribute values correct? Are the themes correctly labelled? Is the data complete?"

Map Design

Map making is both science and art. A beautiful map may become more popular even if it is less accurate than a plain map. Maps influence people's perception of space. This influence is partly because of convention and partly because of the graphics used. People understand the world differently, express this understanding differently in maps, and gain different understanding from the maps.

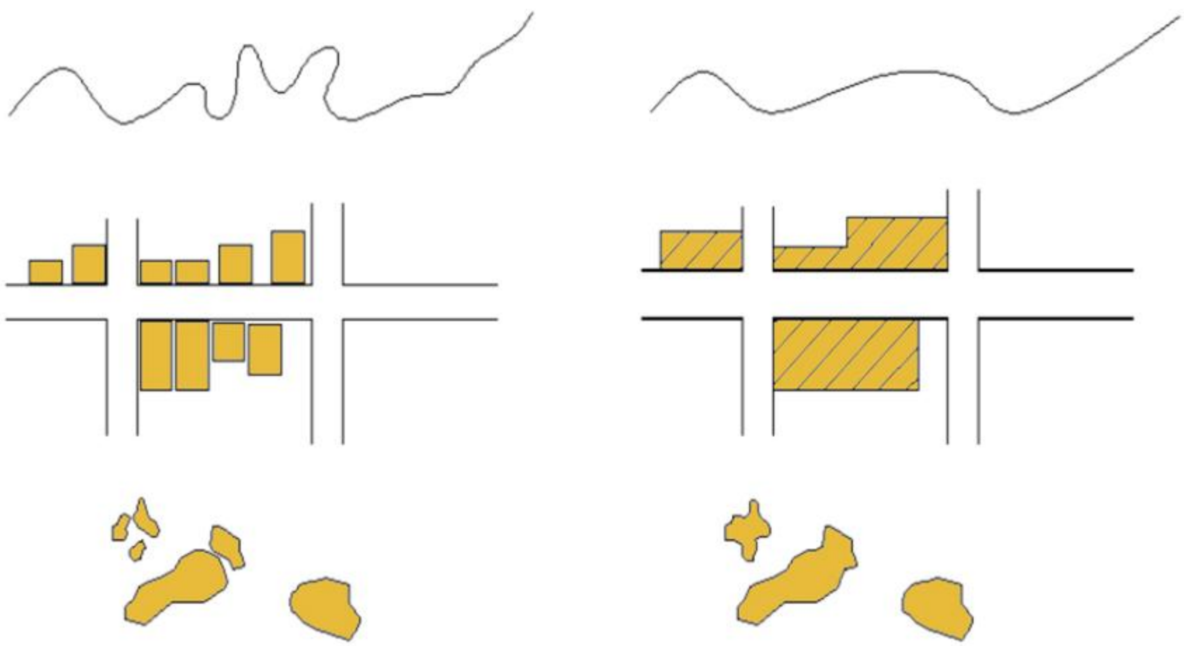


Figure 8.1 Generalisation

GENERALIZATION

Maps contain a certain level of detail depending upon its scale and purpose. Large scale maps usually contain more detail than small scale maps. Cartographers often generalize the data simplifying the information so that the map is easier to read (figure 8.1). The process of reducing the amount of detail in a map in a meaningful way is called generalization. Generalization is done normally when the map scale has to be reduced. However, the essence of the contents of original map should be maintained. This implies maintaining geometric and attribute accuracy as well as the aesthetic quality of the map. There are two type of generalization –graphical and conceptual generalization. Graphic generalization involves simplification, enlargement, displacement or merging of the geometric symbols. Conceptual generalization mainly deals with the attributes and requires knowledge of the map contents and the principles of the themes mapped.

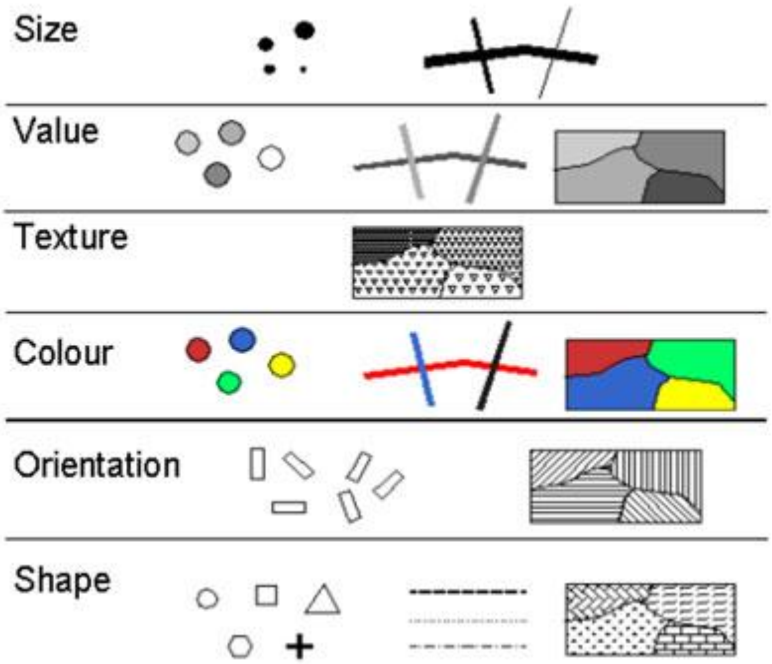


Figure 8.2 Graphic variables

GRAPHIC VARIABLES

The differences in the graphic character of symbols give different perceptions to the map reader. These graphic characteristics are termed as graphic variables which can be summarised as size, Lightness or grey value, Grain or texture, Colour, Orientation, and Shape or form (figure 8.2). Knowledge of these basic graphical variables and their perceptual characteristics help the map designers in selecting those variables that provide a sensation which matches the data or the objectives of the map.

USE OF COLOUR

Colour perception has psychological, physiological and conventional aspects. It has been noted that it is difficult to perceive colour in small areas, and more contrast is perceived between some colours than between others. In addition to distinguishing nominal categories, colour differences are also used to show deviations or gradation.

Note: The basic elements of the maps have already been described in earlier chapters.

Unit 6: introduction to spatial data infrastructure

6.1 SDI concepts and its current trend

The explosive growth of the Internet continues to revolutionize the way modern day business is conducted and services provided. In recent years geographical information systems (GIS) and enterprises have continued to evolve towards distributed models in order to better exploit the potentials presented by the Internet computing paradigm. GIS systems have exhibited sustained evolution from stand alone, data-centric stovepipes to distributed models composed of open interoperable services while GI enterprises continue to pursue edible models in order to leverage advances in business networking and e-commerce. Meanwhile the spatial data infrastructure (SDI) concept which emerged in the 1980s to advance spatial data sharing by taking advantage of the ubiquity of the Internet and its ease of use has matured and is evolving into an infrastructure for the delivery of geoprocessing services, the so called geographical services infrastructure (GSI).

The term "Spatial Data Infrastructure" (SDI) is often used to denote the relevant base collection of technologies, policies and institutional arrangements that facilitate the availability of and access to spatial data. The SDI provides a basis for spatial data discovery, evaluation, and application for users and providers within all levels of government, the commercial sector, the non-profit sector, academia and by citizens in general.

Spatial data infrastructure encompasses the resources, systems, network linkages, standards and institutional issues involved from many different sources in delivering geo-spatially related information to the widest possible group of potential users. Also, adopting this definition with general definition of infrastructures, it could be concluded that SDI has following characteristics:

- Is a set of base capabilities;
- Is a general comprehensive system;
- Has multiple effective aspects in ICT utilization;
- Includes some stable and dynamic physical components;
- Provides important, fundamental and irreplaceable services.

SDI Evolution

1906: Created U. S. Geographic Board.

1919: Created a new Board of Surveys and Maps that took over the responsibilities of U.S. Geographic Board.

1953: Describes responsibilities of Federal agencies with regard to the coordination of surveying and mapping activities.

1967: Better describes responsibilities of Federal Agencies (leadership and coordination).

1983: Establishes coordination of Federal digital cartographic data programs.

1990: Establishes Federal Geographic Data Committee and links more programs.

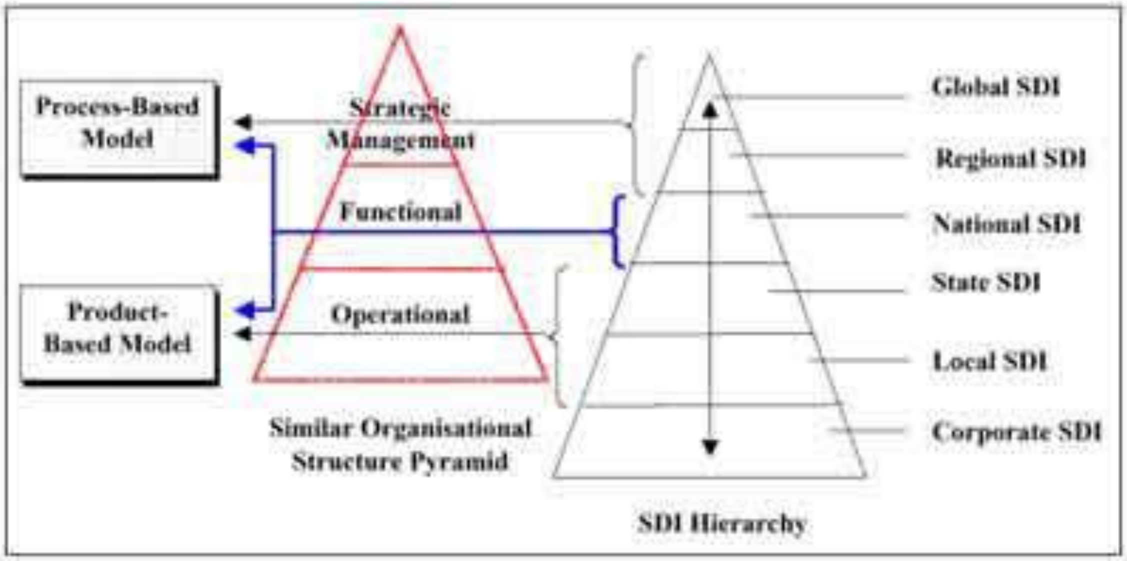
1994: Establishes the National Spatial Data Infrastructure (NSDI).

An infrastructure is a kind of organization, which is the main basis for other organizing activity developments, contributes necessary and different activities in sustainable development. In this process new and adoptive nature is created for each activity, preserving their usual specification through strategies and policies injection and integration assuring their effectiveness.

Tracing SDI trend, after one decade of its emergence (1990s), its concepts have been fulfilled considerably. Balancing the GI (Geographic Information) generation and utilization concentration is the main evolution resulted new SDI definitions as follow:

- Product-based model, which represents one of the main aims of an SDI development initiative, can be used to link existing and upcoming databases of the respective political/administrative levels of the community.
- Process-based model, which presents one of the other main aims of an SDI development initiative, defining a framework to facilitate the management of information assets.

Also, a hierarchical structure is defined for SDI, which comes from especial nature of geo-spatial data as they depend on scale and application. Regarding this structure, SDI treats in a pyramid, which its base (corporate level) is very similar to current foundation used for desktop GIS applications development and by its promotion to the peak, SDI converts to a global infrastructure (Figure below).



Considering this structure, the following points could be illustrated:

- From each level we could navigate to its upper and lower levels.
- Each lower level provides the building blocks of upper levels.
- Each upper level transfers its overall definitions and backgrounds (strategy, policy) to lower level;
- The levels relationship fastens as they come closer.

These specifications and tangibility of this structure for societies, has clarified and simplified SDI concepts and developments more.

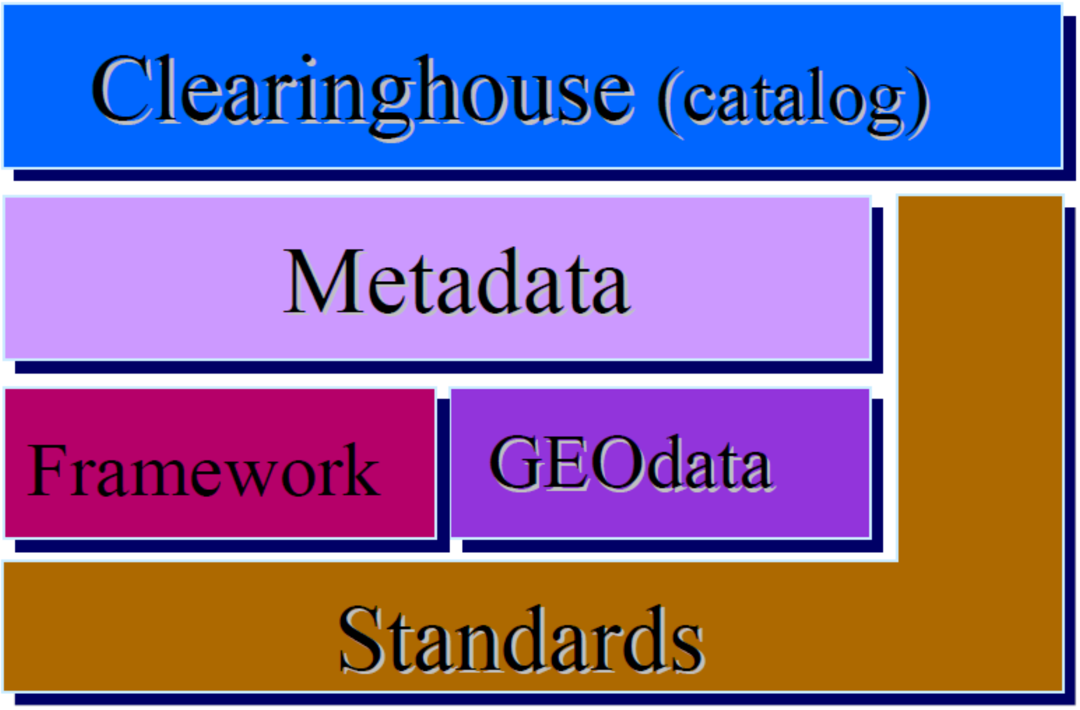
What is a National Spatial Data Infrastructure (NSDI)

To encourage the collection, processing, archiving, integration, and sharing of geospatial data and information using common standards and interoperable systems and techniques and accessible via the web.

The Vision of the NSDI:

To assure that spatial data from multiple sources (Federal, State, and local governments, academia, and the private sector) are widely available and easily integrated to enhance knowledge and understanding of our physical and cultural world.

6.2 The concept of metadata and clearing house



Clearinghouse

A (spatial data) clearinghouse is a distributed network of spatial data producers, managers and users that are linked electronically together. It is a system of software and institutions that are to facilitate the discovery, evolution and downloading of digital spatial data and provides means to inventory, document and data sharing. The clearinghouse concept is a useful one in building a Geographic Information Infrastructure (GII). The objective is to minimize unnecessary duplication of effort for data capture, and to maximize the benefit of geographic information sharing. Data providers nowadays are fully aware of the importance of advertising and making available their metadata describing their databases, to facilitate the use of their products. This explains the current level of activity of building these clearinghouses.

Data Clearinghouse!!

- Institutional view
  People and infrastructure to facilitate discovery of who has what geographic information.
- Technical view
  A set of information services that use hardware, software, and telecommunications networks provide searchable access to information.

How does a clearinghouse work?

A clearinghouse allows data providers to register their geographic data sets, the quality of these data and also the instructions for accessing them. Each data provider provides an electronic description of each spatial data set. In addition, the provider may also provide access to the spatial data set itself. The clearinghouse thus functions as a detailed catalogue service with support for links to spatial data and browsing capabilities. The data described in the clearinghouse may be located at the site of the data producers or at sites of designated data disseminators located elsewhere in the country. Obviously computer network facilitates are the key factors to success.

Metadata Concepts and functionality

Metadata is defined as background information that describes the content, quality, condition and other appropriate characteristics of the data. So metadata is a simple mechanism to inform others of the existence of the data sets, their purpose and scope. In essence metadata answer who, what, when, where, why and how questions (WH Questions) about all facets of the data made available. Metadata can be used internally be the data provider to monitor the status of data sets, and externally to advertise to potential users through a national clearinghouse. Metadata are important in the production of a digital spatial data clearinghouse, where potential users can search for the data they need.

Roles of metadata:

Applicability: information needed to determine the data sets that exists for a geographic location,

Fitness for use: information needed to determine whether a data set meets a specified need,

Access: information needed to acquire an identified data set,

Transfer: information needed to process and use a data set,

Administration: information needed to document the status of existing data (data model, quality, completeness, temporal validity etc…) to define internal policy for update operations from different data sources.

Metadata Standards

For metadata to be easily read and understood, standards create a common language for users and producers. Metadata standards provide appropriate and adequate information for the design of metadata. The key development in metadata standards are the ISO STANDARD 1504615 METADATA, the federal geographic data committee’s content standard for Digital Geospatial Metadata FGDC.

A standard provides a common terminology and definitions for the documentation of spatial data.

Metadata management & update

Just like ordinary data, metadata has to be kept up-to-date. The main concerns in metadata management include what to represent, how to represent, how to capture and how to use it; and all these depend on the purpose of metadata; For internal (data provider) use, we will refer to local metadata which contains the detailed information about data sets stored on local hardware and managed by the data provider. For external use we refer to global metadata which contains a short description of the data sets (an abstraction of local metadata) as advertised in the clearinghouse to allow users to find relevant data efficiently. Data providers should register their data holding with the clearinghouse. Whenever changes occur in their data, each data provider reports the changes to the clearing authority. Updating the global metadata is the responsibility of clearinghouse.

6.3 Critical factors around SDIs

Geographic data exchange and sharing means the flow of digital data from one information system to the other. Advances in technology, data handling and data communication allow the user to think of the possibility of finding and accessing data that has been collected by different data providers. Their objective is to minimize the duplication of effort in spatial data collection and processing. Data sharing problems which can be viewed as critical factors in SDI can be briefly described as follows:

1. *Data standards*: It refers to an agreed upon way of representing data in a system in terms of content, type and format. Exchange of data between databases is difficult if they support different data standards or different query language. The development of common data architecture and the support for a single data exchange format, commonly known as *standard for data exchange* may provide a sound basis for data sharing. Examples of these standards are the DIGEST (Digital Geographic Information Exchange Standard) Spatial Data Transfer Standard (SDTS) etc...

2. *Heterogeneity:* it means being different in kind, quality and character. Spatial data may exists in a variety of locations, are possibly managed by a variety of database systems, were collected for different purposes and by different methods, and are stored in different structures. This brings about all kinds of inconsistency among these data sets (heterogeneity) and creates many problems when data is shared.
3. *Communication problems*: with advances in computer network communication and related technology, locating relevant information in a network of distributed information sources has become more important recently. The question is which communication technology is the best suitable for transfer of huge amounts of spatial data in a secure and reliable way. Efficient tools and communication protocols are necessary to provide search browse and delivery mechanisms.
4. *institutional and Economic problems*: these problems arise in the absence of policy concerning pricing, copyright, privacy, liability, conformity with standards, data quality etc… resolving these problems is essential to create the right environment for data sharing.

Unit 7: Open GIS

7.1 Introduction of open concept in GIS

An open source application by definition is software that you can freely access and modify the source code for. Open source projects typically are worked on by a community of volunteer programmers. Open source GIS programs are based on different base programming languages. Three main groups of open source GIS (outside of web GIS) in terms of programming languages are: "C" languages, Java, and .NET.

The first group would be the group that uses "C" language for its implementation. This is the more mature of the groups of open source GIS, probably for the simple reason that is the group that has been working on GIS software applications the longest and has a long history of resuse of code. The libraries in the "C" group, from the base infrastructure, and include some capabilities like coordinate reprojection that make them very useful and popular. Popular "C" based open source GIS software applications include GRASS, a project started in 1982 by the US Army but is now open source, and QGIS (otherwise known as Quantum GIS).

The second group of Open Source GIS would be the ones that use JAVA as the implementation language. JTS, central library for the Java GIS development, offers some geospatial functions that allow to compare objects and return a boolean true/false result indicating the existence (or absence) of any questioned spatial relationship. Other operators, like Union or Buffer, which are very hard to code, are offered in this group making it very appreciated by GIS developers. GeoTools, Geoserve, and OpenMap, are among the most popular open source GIS in this group of JAVA tools.

The third most influential group of Open Source GIS would be the one that integrates applications that use ".NET" as the implementation language. SharpMap and WorldWind are the most popular of these applications.

Outside of the three major language groups, open source web mapping is another group. Population open source web mapping includes OpenLayers and MapBuilder, widely used due to their simplicity and accessibility.

To learn GIS using open source software, read Sid Feygin's article How to Go from GIS Novice to Pro without Spending a Dime which provides tips and resources.

7.2 Open Source GIS and Freeware GIS Applications

Listed here are available open source GIS based applications you can download written for a variety of platforms and in various languages.

FlowMap

FlowMap is a freeware application designed to analyze and display flow data. This application was developed at the Faculty of Geographical Sciences of the Utrecht University in the Netherlands.

Platforms: Windows OS

GMT Mapping Tools

GMT is a free, public-domain collection of ~60 UNIX tools that allow users to manipulate (x,y) and (x,y,z) data sets (including filtering, trend fitting, gridding, projecting, etc.) and produce Encapsulated PostScript File (EPS) illustrations ranging from simple x-y plots through contour maps to artificially illuminated surfaces and 3-D perspective views in black and white, gray tone, hachure patterns, and 24-bit color.

Platforms: UNIX, Macintosh

GRASS

Geographic Resources Analysis Support System (GRASS) is the public domain GIS software application originally developed by the US Government. GRASS is probably the most well-known open source and original GIS software applications. GRASS is a raster-based GIS, vector GIS, image processing system, graphics production system, data management system, and spatial modeling system. GRASS can be downloaded for free.

Platforms: Linux, Macintosh, Sun Solaris, Silicon Graphics Irix, HP-UX, DEC-Alpha, and Windows OS

gvSIG

gvSIG is an open source GIS application written in Java.

Platforms: Windows, Macintosh, Linux, UNIX

MapWindow GIS

MapWindow GIS is open source GIS application that can be extended through plugins. The application is built using Microsoft's .NET

Platforms: Windows

OpenJUMP GIS

OpenJUMP GIS is an open source GIS written in Java through a collaborative effort by volunteers. Formerly known as JUMP GIS, the application can read shapefiles and GML format files.

Platforms: Windows, Macintosh, Linux, UNIX

Quantum GIS

Also referred to as QGIS, Quantum GIS is an Open Source Geographic Information System (GIS).

More: Getting Started With QGIS: Open Source GIS

Platforms: Linux, Unix, Mac OSX, and Windows.

SPRING

SPRING is a GIS and Remote Sensing Image Processing system with an object-oriented data model which provides for the integration of raster and vector data representations in a single environment.

Platform: Windows, Linux, UNIX, Macintosh

TNTLite

TNTLite MicroImages, Inc. provides TNTlite as a free version of TNTmips , the professional software for geospatial data analysis. The free TNTlite product has all the features of the professional version, except TNTlite limits the size of Project File objects, and TNTlite enables data sharing only with other copies of TNTlite (export processes are disabled). Can either be downloaded or ordered on CD.

Platforms: Windows

uDig GIS

uDig GIS is a free, open source GIS desktop application that runs on Windows, Linux and MacOS. uDig was designed to use OGC's OpenGIS standards such as WMS, WFS and more. One-click install allows you to view local shapefiles, remote WMS services and even directly edit your own spatial database geometries.

Platforms: Windows, Linux, Macintosh

Open Source Web Mapping

GeoMajas

Written in java, GeoMajas is an open source GIS framework for the web.

GeoServer

Java based open source server software that allows users to edit and share geospatial data and uses open standards to spublish GIS data.

MapGuide Open Source

First introduced as open source by Autodesk in 2005, MapGuide Open Source allows for the development of web based mapping.

MapFish

An open source mapping development framework for web mapping applications based on the Pylon Pythons web framework.

MapServer

MapServer is an Open Source development environment for building spatially enabled Internet applications. The software builds upon other popular Open Source or freeware systems like Shapelib, FreeType, Proj.4, libTIFF, Perl and others.

OpenLayers

Javascript library that is open source for displaying GIS data within a browser environment.   OpenStreetMap uses OpenLayers for its main map display (aka the "Slippy Map").

TileMill

Built on open source libraries (Mapnik, node.js, backbone.js,express and CodeMirror). The Chicago Tribune included TileMill in a series entitled Making Maps using PostGIS, Mapnik, TileMill, and Google Maps.

7.3 Web Based GIS system

Web-based GIS is becoming more and more prevalent as time passes. The following is a brief description of what web-based GIS is about.

The World-Wide-Web (WWW) is a useful tool for the gathering and manipulation. Most information that is available in the world is now available over the Internet. Now much the same is true concerning GIS information.

Where formerly an individual would have to buy an expensive software package to use and manipulate the data needed for GIS, the same is not so today. With the advent of Java based programming, software applications for web-based GIS work are now available. Some of these programs require the user to buy some software, and others require plug-ins to be added to web browsers, but some require no special software additions at all. These use only the capabilities of your existing web browsers

Because of these advancements, many people who were not able to easily get information they may want or need before can now have it at their fingertips. People who have an interest in gathering information cam find it accessible like never before. For the first time, the public can examine the same information as the policy makers, for hands-on examination of GIS material. Talk about citizen involvement.

Another useful facet of using web-based GIS is that the people giving the information are completely in charge of the amount of information made available to the public. If there were privacy issues surrounding certain bit of information, don't make it accessible to others. It is that simple. People cannot use or abuse information that they do not have. With web-based information distribution, you never need to worry about information falling into "the wrong hands".

With Internet connections getting faster and faster, the amount of information that can be transferred over the Internet is staggering. Soon people will be able to examine GIS data while in a foreign country in order to make a purchasing decision on property that he or she has never seen. Analysis of data by a widely scattered group can also be accomplished in a faster, more efficient manner when the information is available almost everywhere in the world.

Some web references

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