UNIT I FUNDAMENTALS OF GIS

Introduction to GIS - Basic spatial concepts - Coordinate Systems - GIS and Information Systems – Definitions – History of GIS - Components of a GIS – Hardware, Software, Data, People, Methods – Proprietary and open source Software - Types of data – Spatial, Attribute data- types of attributes – scales/ levels of measurements.

INTRODUCTION TO GIS:

A geographic information system (GIS) is a computer system for capturing, storing, querying, analyzing and displaying geospatial data. One of many applications of GIS is disaster management.

On March 11, 2011, a magnitude 9.0 earthquake struck off the east coast of Japan, registering as the most powerful earthquake to hit Japan on record. The earthquake triggered powerful tsunami waves that reportedly reached heights of up to 40 meters and traveled up to 10 kilometers inland. In the aftermath of the earthquake and tsunami, GIS played an important role in helping responders and emergency managers to conduct rescue operations, map severely damaged areas and infrastructure, prioritize medical needs, and locate temporary shelters. GIS was also linked with social media such as Twitter, YouTube, and Flickr so that people could follow events in near real time and view map overlays of streets, satellite imagery, and topography.

GEOGRAPHIC INFORMATION SYSTEM:

Geospatial data describe both the locations and characteristics of spatial features. To describe a road, for example, we refer to its location (i.e., where it is) and its characteristics (e.g., length, name, speed limit, and direction), as shown in below figure.

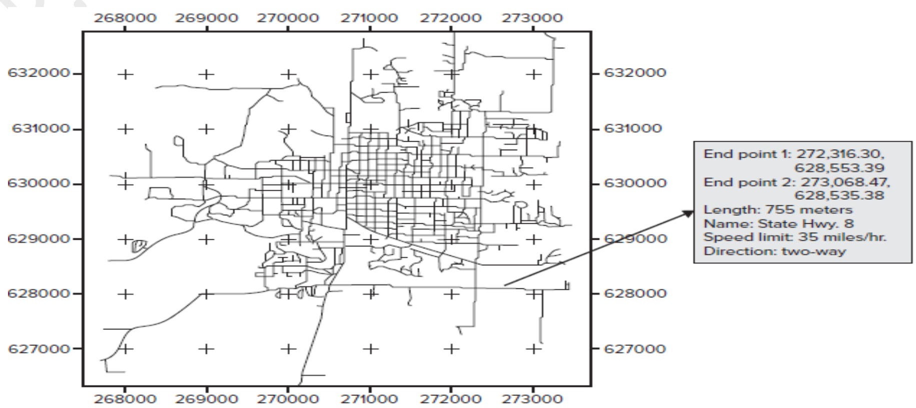


Figure: An example of geospatial data. The street network is based on a plane coordinate system. The box on the right lists the x and y coordinates of the end points and other attributes of a street segment.

The ability of a GIS to handle and process geospatial data distinguishes GIS from other information systems and allows GIS to be used for integration of geospatial data and other data.

HISTORY OF GIS:

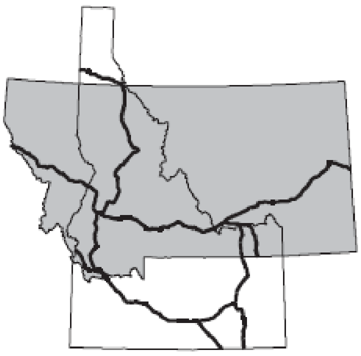
The first operational GIS is reported to have been developed by Roger Tomlinson in the early 1960s for storing, manipulating, and analyzing data collected for the Canada Land Inventory (Tomlinson 1984). In 1964, Howard Fisher founded the Harvard Laboratory for Computer Graphics, where several well known computer programs of the past such as SYMAP, SYMVU, GRID, and ODESSEY were developed and distributed throughout 1970s. These earlier programs were run on mainframes and minicomputers, and maps were made on line printers and pen plotters. In the 1980s, commercial and free GIS packages appeared in the market.

As GIS continually evolves, two trends have emerged in recent years. One, as the core of geospatial technology, GIS has increasingly been integrated with other geospatial data such as satellite images and GPS data. Two, GIS has been linked with Web services, mobile technology, social media and cloud computing.

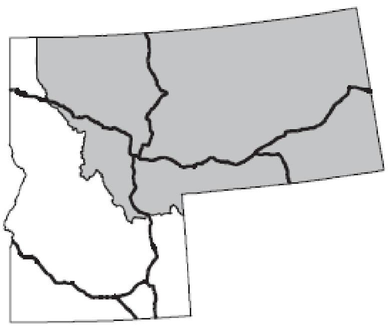
COORDINATE SYSTEMS:

A basic principle in geographic information system (GIS) is that map layers to be used together must align spatially. Obvious mistakes can occur if they do not. For example, below figure shows the interstate highway maps of Idaho and Montana downloaded separately from the Internet. The two maps do not register spatially. To connect the highway networks across the shared state border, we must convert them to a common spatial reference system. The coordinate system provides spatial reference.

GIS users typically work with map features on a plane (flat surface). These map features represent spatial features on the Earth's surface. The locations of map features are based on a plane coordinate system expressed in x and y coordinates, whereas the locations of spatial features on the Earth's surface are based on a geographic coordinate system expressed in longitude and latitude values. A map projection bridges the two types of coordinate systems. The process of projection transforms the Earth′s surface to a plane, and the outcome is a map projection, ready to be used for a projected coordinate system.



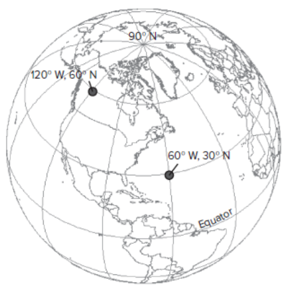
The map shows the interstate highways in Idaho and Montana based on different coordinate systems.



The map shows the connected interstate networks based on the same coordinate system.

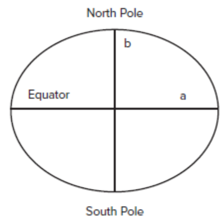
Geographic Coordinate System:

The geographic coordinate system is the reference system for locating spatial features on the Earth's surface. The geographic coordinate system is defined by longitude and latitude. Both longitude and latitude are angular measures: longitude measures the angle east or west from the prime meridian, and latitude measures the angle north or south of the equatorial plane. For example, the longitude at point X is the angle a west of the prime meridian, and the latitude at point Y is the angle b north of the equator.



The geographic coordinate system.

Meridians are lines of equal longitude. The prime meridian passes through Greenwich, England, and has the reading of 0°. Using the prime meridian as a reference, we can measure the longitude value of a point on the Earth′s surface as 0° to 180° east or west of the prime meridian. Meridians are therefore used for measuring location in the E–W direction. Parallels are lines of equal latitude.



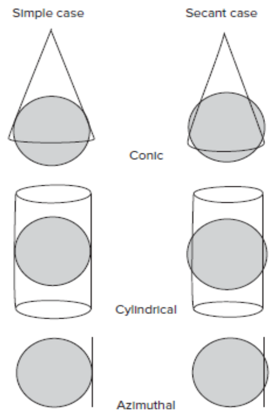
The flattening is based on the difference between the semimajor axis a and the semiminor axis b.

The angular measures of longitude and latitude may be expressed in degrees-minutes-seconds (DMS), decimal degrees (DD), or radians (rad). Given that 1 degree equals 60 minutes and 1 minute equals 60 seconds, we can convert between DMS and DD. For example, a latitude value of 45°52'30" would be equal to 45.875° (45 + 52/60 + 30/3600). Radians are typically used in computer programs. One radian equals 57.2958°, and one degree equals 0.01745 rad.

Map Projections:

A map projection transforms the geographic coordinates on an ellipsoid into locations on a plane. The outcome of this transformation process is a systematic arrangement of parallels and meridians on a flat surface representing the geographic coordinate system. A map projection provides a couple of distinctive advantages. First, a map projection allows us to use two-dimensional maps, either paper or digital. Second, a map projection allows us to work with plane coordinates rather than longitude and latitude values.

Map projections can be grouped by either the preserved property or the projection surface. Cartographers group map projections by the preserved property into the following four classes: conformal, equal area or equivalent, equidistant, and azimuthal or true direction. A conformal projection preserves local angles and shapes. An equivalent projection represents areas in correct relative size. An equidistant projection maintains consistency of scale along certain lines. And an azimuthal projection retains certain accurate directions. The preserved property of a map projection is often included in its name, such as the Lambert conformal conic projection or the Albers equal-area conic projection.

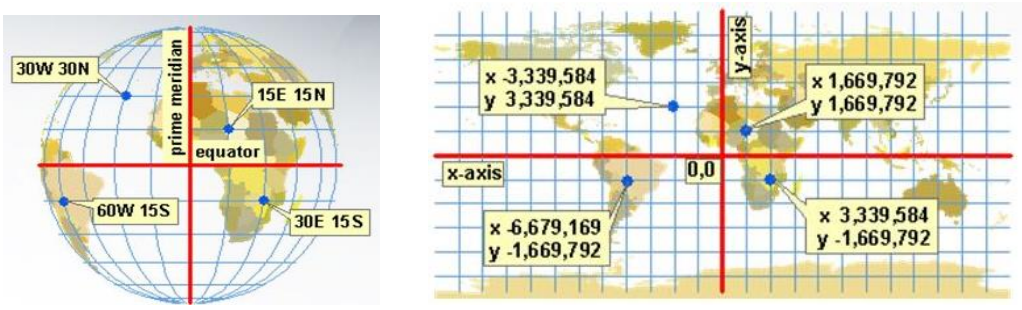


Case and projection

A map projection is defined by its parameters. Typically, a map projection has five or more parameters. A *standard line* refers to the line of tangency between the projection surface and the reference globe. The *standard line* is called the standard parallel if it follows a parallel, and the standard meridian if it follows a meridian. The *principal scale*, or the scale of the reference globe, can be derived from the ratio of the globe's radius to the Earth's radius (3963 miles or 6378 kilometers). The *scale factor* is the normalized local scale, defined as the ratio of the local scale to the principal scale. The *false easting* is the assigned x-coordinate value and the false northing is the assigned y-coordinate value. Essentially, the *false easting* and *false northing* create a false origin so that all points fall within the NE quadrant and have positive coordinates. The following are the commonly used map projections: Transverse Mercator, Lambert Conformal Conic, Albers Equal-Area Conic, Equidistant Conic, Web Mercator.

Projected Coordinate Systems:

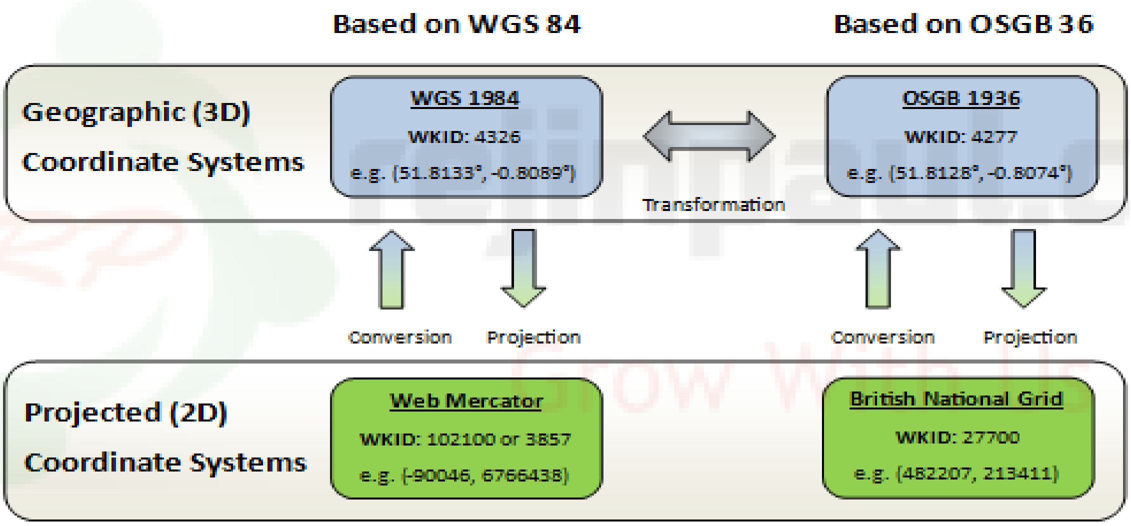
A projected coordinate system is built on a map projection. Projected coordinate systems and map projections are often used interchangeably. For example, the Lambert conformal conic is a map projection but it can also refer to a coordinate system. In practice, however, projected coordinate systems are designed for detailed calculations and positioning, and are typically used in large-scale mapping such as at a scale of 1:24,000 or larger. Accuracy in a feature's location and its position relative to other features is therefore a key consideration in the design of a projected coordinate system. To maintain the level of accuracy desired for measurements, a projected coordinate system is often divided into different zones, with each zone defined by a different projection center.



(a) *(b)*

The Projected Coordinate System (a): Representation of points in Geographic Coordinate System (b): Equivalent representation in Projected coordinate system

Three coordinate systems are commonly used in the United States: the Universal Transverse Mercator (UTM) grid system, the Universal Polar Stereographic (UPS) grid system, and the State Plane Coordinate (SPC) system.



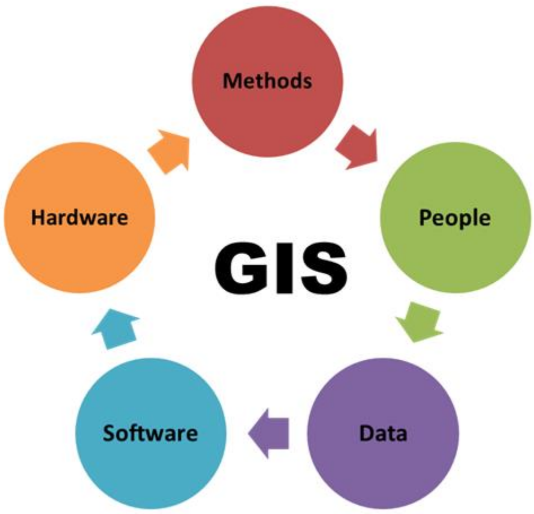
Example Coordinate Systems

World Geodetic System (WGS-84) is familiar to many non-geographers because it is used by GPS devices to describe locations all over the Earth. A different GCS, called OSGB-36, which is more accurate for describing locations in Britain but not as good for other countries, is used specifically for British data. Web Mercator is a PCS based on WGS-84 used for global maps, and British National Grid is a PCS based on OSGB-36 used for British maps. Converting between coordinate systems that are based on the same GCS is relatively straightforward, but when converting, for example, GPS (WGS-84) coordinates to BNG, a mathematical transformation is required. The "Petroleum" transformation is an accurate transformation from WGS-84 to OSGB-36.

COMPONENTS OF GIS:

A GIS is an organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information. GIS technology integrates common database operations, such as query and statistical analysis, with the unique visualization and geographic analysis benefits offered by maps. A working GIS integrates the following key components: hardware, software, data, people, and methods.

- *Hardware* - GIS hardware includes computers for data processing, data storage, and input/output; printers and plotters for reports and hard-copy maps; digitizers and scanners for digitization of spatial data; and GPS (Global Positioning System) and mobile devices for fieldwork.
- *Software* - GIS software, either commercial or open source, includes programs and applications to be executed by a computer for data management, data analysis, data display, and other tasks. Additional applications, written in Python, JavaScript, VB.NET, or C++, may be used in GIS for specific data analyses.
- Method - A successful GIS operates according to a well-designed plan and business rules, which are the models and operating practices unique to each organization. Any organization has documented their process plan for GIS operation. These document address number question about the GIS methods: number of GIS expert required, GIS software and hardware, Process to store the data, what type of DBMS (database management system) and more. Well designed plan will address all these questions.
- *People* - GIS technology is of limited value without the people who manage the system and to develop plans for applying it. GIS users range from technical specialists who design and maintain the system, to those who use it to help them do their everyday work.

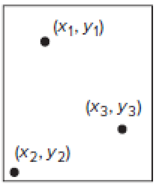


- *Data* - Maybe the most important component of a GIS is the data. Geographic data and related tabular data can be collected in-house or bought from a commercial data provider. Most GIS employ a DBMS to create and maintain a database to help organize and manage data. The data that a GIS operates on consists of any data bearing a definable relationship to space, including any data about things and events that occur in nature. At one time this consisted of hard-copy data, like traditional cartographic maps, surveyor's logs, demographic statistics, geographic reports, and descriptions from the field. Advances in spatial data collection, classification, and accuracy have allowed more and more standard digital base-maps to become available at different scales.
- *Organization* - GIS operations exist within an organizational environment; therefore, they must be integrated into the culture and decision-making processes of the organization for such matters as the role and value of GIS, GIS training, data collection and dissemination, and data standards.

WORKING OF GIS:

GIS consists of the following elements i.e. geospatial data, data acquisition, data management, data display, data exploration, and data analysis.

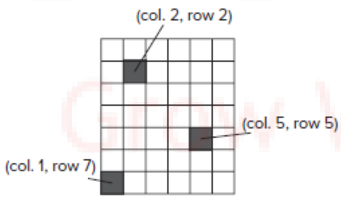
- ***Geospatial Data:*** By definition, geospatial data cover the location of spatial features. To locate spatial features on the Earth's surface, we can use either a geographic or a projected coordinate system. A geographic coordinate system is expressed in longitude and latitude and a projected coordinate system in x, y coordinates. Many projected coordinated systems are available for use in GIS. A GIS represents geospatial data as either vector data or raster data.



The vector data model uses x, y coordinates to represent point features

The *vector data model* uses points, lines, and polygons to represent spatial features with a clear spatial location and boundary such as streams, land parcels, and vegetation stands. Each feature is assigned an ID so that it can be associated with its attributes.

The *raster data model* uses a grid and grid cells to represent spatial features: point features are represented by single cells, line features by sequences of neighbouring cells, and polygon features by collections of contiguous cells. The cell value corresponds to the attribute of the spatial feature at the cell location. Raster data are ideal for continuous features such as elevation and precipitation.



The raster data model uses cells in a grid to represent point features

A *vector data model* can be georelational or object-based, with or without topology, and simple or composite. The georelational model stores geometries and attributes of spatial features in separate systems, whereas the object-based model stores them in a single system. Topology explicitly expresses the spatial relationships between features, such as two lines meeting perfectly at a point.

- ***Data Acquisition:*** Data acquisition is usually the first step in conducting a GIS project. The need for geospatial data by GIS users has been linked to the development of data clearinghouses and geoportals. Since the early 1990s, government agencies at different levels in the United States as well as many other countries have set up websites for sharing public data and for directing users to various data sources.

Data acquisition involves compilation of existing and new data. To be used in a GIS, a newly digitized map or a map created from satellite images requires geometric transformation (i.e., geo-referencing). Additionally, both existing and new spatial data must be edited if they contain digitizing and/or topological errors.

- ***Attribute Data Management:*** A GIS usually employs a database management system (DBMS) to handle attribute data, which can be large in size in the case of vector data. Each polygon in a soil map, for example, can be associated with dozens of attributes on the physical and chemical soil properties and soil interpretations. Attribute data are stored in a relational database as a collection of tables. These tables can be prepared, maintained, and edited separately, but they can also be linked for data search and retrieval.

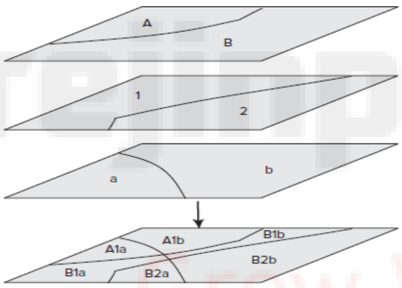
- ***Data Display:*** A routine GIS operation is mapmaking because maps are an interface to GIS. Mapmaking can be informal or formal in GIS. It is informal when we view geospatial data on maps, and formal when we produce maps for professional presentations and reports. A professional map combines the title, map body, legend, scale bar, and other elements together to convey geographic information to the map reader.

  To make a "good" map, we must have a basic understanding of map symbols, colors, and typology, and their relationship to the mapped data. Additionally, we must be familiar with map design principles such as layout and visual hierarchy. After a map is composed in a GIS, it can be printed or saved as a graphic file for presentation. It can also be converted to a KML file, imported into Google Earth, and shared publicly on a web server.

- ***Data Exploration:*** Data exploration refers to the activities of visualizing, manipulating, and querying data using maps, tables, and graphs. These activities offer a close look at the data and function as a precursor to formal data analysis. Data exploration in GIS can be map or feature-based. Map-based exploration includes data classification, data aggregation, and map comparison.

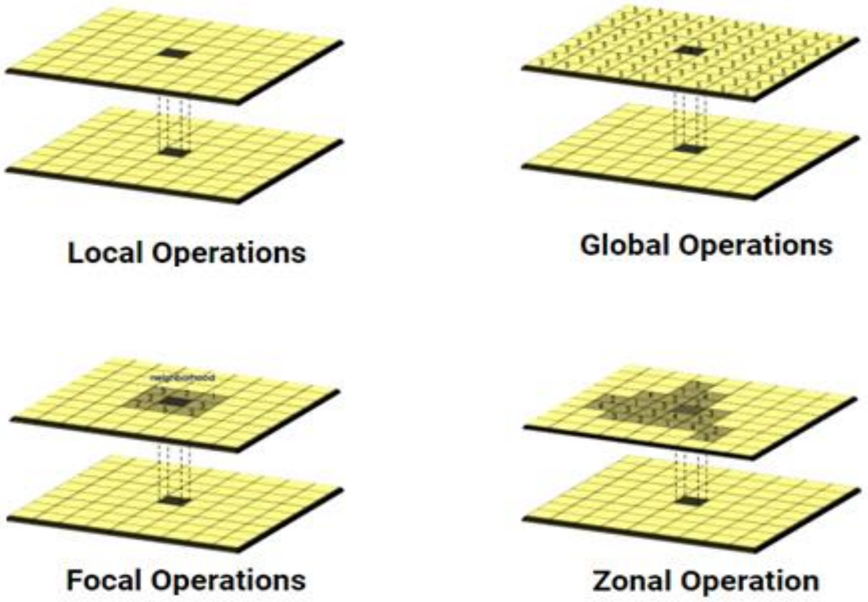
Feature-based query can involve either attribute or spatial data. Attribute data query is basically the same as database query using a DBMS. In contrast, spatial data query allows GIS users to select features based on their spatial relationships such as containment, intersect, and proximity. A combination of attribute and spatial data queries provides a powerful tool for data exploration.

- ***Data Analysis:*** A GIS has a large number of tools for data analysis. Some are basic tools, meaning that they are regularly used by GIS users. Other tools tend to be discipline or application specific. Two basic tools for vector data are buffering and overlay: buffering creates buffer zones from select features, and overlay combines the geometries and attributes of the input layers.



A vector-based overlay operation combines geometries and attributes from different layers to create the output.

Four basic tools for raster data are local, neighbourhood, zonal, and global operations, depending on whether the operation is performed at the level of individual cells, or groups of cells, or cells within an entire raster.



Basic operation of Raster Data

GIS SOFTWARE PRODUCTS:

The below table shows a select list of commercial GIS software in the left column and free and open source software (FOSS) for GIS in the right column.

Commercial	Free and Open Source
• Environmental Systems Research Institute (Esri) (**http://www.esri.com/): ArcGIS**	• Center for Spatial Data Science, University of Chicago (**http://spatial.uchicago.edu/): GeoDa**
• Autodesk Inc. (**http://www.autodesk.com/): AutoCAD Map3D and Autodesk Geospatial**	• Open Source Geospatial Foundation (**http://grass .osgeo.org/): GRASS**
• Bentley Systems, Inc. (**http://www.bentley.com/): Bentley Map**	• gvSIG Community (**http://www.gvsig.com/en): gvSIG**
• Intergraph/Hexagon Geospatial (**http://www .intergraph.com/): GeoMedia**	• International Institute for Aerospace Survey and Earth Sciences, the Netherlands (**http://www.itc .nl/ilwis/): ILWIS**
• Blue Marble (**http://www.bluemarblegeo.com/): Global Mapper**	• MapWindow GIS Project (**http://mapwindow .org/): MapWindow**
• Manifold (**http://www.manifold.net/): Manifold System**	• Open Jump (**http://www.openjump.org/): OpenJump**
• Pitney Bowes (**http://www.mapinfo.com/): MapInfo**	• Quantum GIS Project (**http://www.qgis.org/): QGIS**
• Caliper Corporation (**http://www.caliper.com/): Maptitude**	• SAGA User Group (**http://www.saga-gis.org): SAGA GIS**
• General Electric (**https://www.gegridsolutions. com/GIS.htm): Smallworld**	• Refractions Research (**http://udig.refractions .net/): uDig**
• Clark Labs (**http://www.clarklabs.org/): TerrSet/IDRISI**	

ArcGIS is composed of applications and extensions at three license levels. The applications include ArcMap,ArcGIS Pro, ArcCatalog, ArcScene, and ArcGlobe, and the extensions include 3D Analyst, Network Analyst, Spatial Analyst, Geostatistical Analyst, and others.

GRASS GIS (Geographic Resources Analysis Support System), the first FOSS for GIS, was originally developed by the U.S. Army Construction Engineering Research Laboratories in the 1980s. Well known for its analysis tools, GRASS GIS is currently maintained and developed by a worldwide network of users. Academicians, government agencies (NASA, NOAA, USDA and USGS) and GIS practitioners use this open source software because its code can be inspected and tailored to their needs.

SAGA GIS (System for Automated Geoscientific Analyses) is one of the classics in the world of free GIS software. It started out primarily for terrain analysis such as hillshading, watershed extraction and visibility analysis. Now, SAGA GIS is a powerhouse because it delivers a fast growing set of geoscientific methods to the geoscientific community.

GeoDa is a free GIS software program primarily used to introduce new users into spatial data analysis. Its main functionality is data exploration in statistics. One of the nicest things about it is how it comes with sample data for you to give a test-drive. From simple box-plots all the way to regression statistics, GeoDa has complete arsenal of statistics to do nearly anything spatially.

APPLICATION OF GIS:

GIS is a useful tool because a high percentage of information we routinely encounter has a spatial component. An often cited figure among GIS users is that 80 percent of data is geographic. Since its beginning, GIS has been important for land use planning, natural hazard assessment, wildlife habitat analysis, riparian zone monitoring, timber management, and urban planning. The list of fields that have benefited from the use of GIS has expanded significantly for the past three decades.

In the United States, the U.S. Geological Survey (USGS) is a leading agency in the development and promotion of GIS. The USGS website provides case studies as well as geospatial data for applications in climate and land use change, ecosystem analysis, geologic mapping, petroleum resource assessment, watershed management, coastal zone management, natural hazards (volcano, flood, and landslide), aquifer depletion, and ground water management.

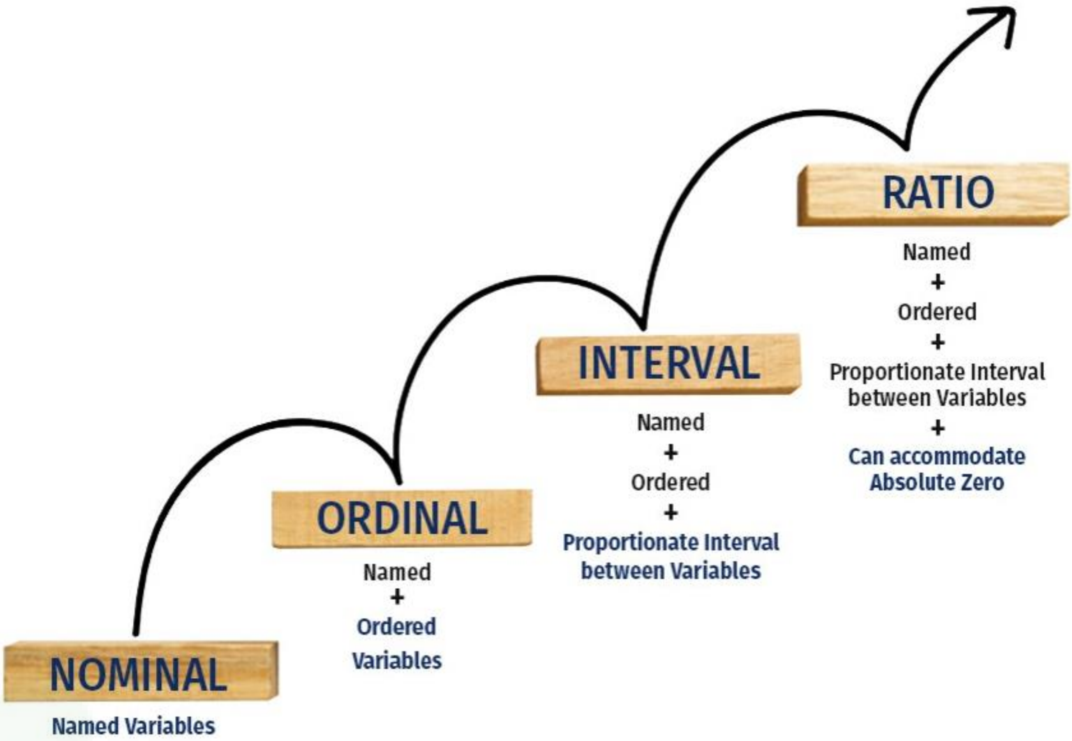
In the private sector, most GIS applications are integrated with the Internet, GPS, wireless technology, and Web services. The following shows some of these applications:

- Online mapping websites offer locators for finding real estate listings, vacation rentals, banks, restaurants, coffee shops, and hotels.
- Location-based services allow mobile phone users to search for nearby banks, restaurants, and taxis; and to track friends, dates, children, and the elderly.
- Mobile GIS allows field workers to collect and access geospatial data in the field.
- Mobile resource management tools track and manage the location of field crews and mobile assets in real time.
- Automotive navigation systems provide turn by-turn guidance and optimal routes based on precise road mapping using GPS and camera.
- Augmented reality lets a smart phone user look through the phone's camera with superimposed data or images (e.g., 3-D terrain from a GIS, monsters in Pokemon Go) about the current location.

SCALES/LEVELS OF MEASUREMENTS:

Scales of Measurement or level of measurement is a system for classifying attribute data into four categories namely nominal, ordinal, interval and ratio.

- *Nominal:* In this level of measurement, the numbers in the variable are used only to classify the data. In this level of measurement, words, letters, and alpha-numeric symbols can be used. Suppose there are data about people belonging to three different gender categories. In this case, the person belonging to the female gender could be classified as F, the person belonging to the male gender could be classified as M, and transgendered classified as T. This type of assigning classification is nominal level of measurement.
- *Ordinal:* This level of measurement depicts some ordered relationship among the variable's observations. Suppose a student scores the highest grade of 100 in the class. In this case, he would be assigned the first rank. Then, another classmate scores the second highest grade of an 92; she would be assigned the second rank. A third student scores a 81 and he would be assigned the third rank, and so on. The ordinal level of measurement indicates an ordering of the measurements.



Levels of Measurements

- *Interval:* The interval level of measurement not only classifies and orders the measurements, but it also specifies that the distances between each interval on the scale are equivalent along the scale from low interval to high interval. For example, an interval level of measurement could be the measurement of anxiety in a student between the score of 10 and 11, this interval is the same as that of a student who scores between 40 and 41. A popular example of this level of measurement is temperature in centigrade, where, for example, the distance between 940C and 960C is the same as the distance between 1000C and 1020C.
- *Ratio:* In this level of measurement, the observations, in addition to having equal intervals, can have a value of zero as well. A common geographic example of ratio data is density (i.e. population, ethnicity, etc.). Any percent value from 0 to 100 will have a meaningful zero.

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UNIT II SPATIAL DATA MODELS

Database Structures – Relational, Object Oriented – ER diagram - spatial data models – Raster Data Structures – Raster Data Compression - Vector Data Structures - Raster vs Vector Models- TIN and GRID data models - OGC standards - Data Quality.

DATABASE MODEL:

Data model defines the logical structure of a database. Data Models are fundamental entities to introduce abstraction in a DBMS. Data models define how data is connected to each other and how they are processed and stored inside the system. There are a number of different database data models. Amongst those that have been used for attribute data in GIS are the hierarchical, network, relational, object-relational and object-oriented data models. Of these the relational data model has become the most widely used model.

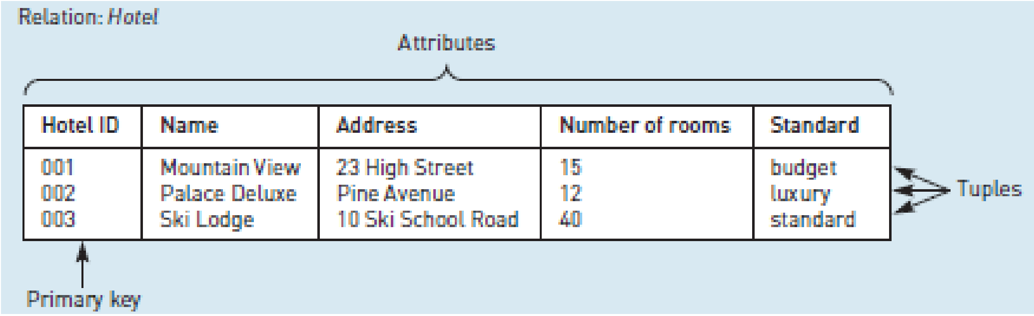
Relational Data Model:

Data are organized in a series of two-dimensional tables, each of which contains records for one entity. These tables are linked by common data known as keys. Queries are possible on individual tables or on groups of tables. For the Happy Valley data, the below figure illustrates an example of one such table.

Hotel ID	Name	Address	Number of rooms	Standard
001	Mountain View	23 High Street	15	budget
002	Palace Deluxe	Pine Avenue	12	luxury
003	Ski Lodge	10 Ski School Road	40	standard

Relational database table data for Happy Valley

The data in a relational database are stored as a set of base tables with the characteristics described above. Other tables are created as the database is queried and these represent virtual views. The table structure is extremely flexible and allows a wide variety of queries on the data. Queries are possible on one table at a time (for example, you might ask ‘which hotels have more than 14 rooms?’ or ‘which hotels are luxury standard?’), or on more than one table by linking through key fields (for instance, ‘which passengers originating from the UK are staying in luxury hotels?’ or ‘which ski lessons have pupils who are over 50 years of age?'). Queries generate further tables, but these new tables are not usually stored. There are few restrictions on the types of query possible.



Database terminology applied to Happy Valley table

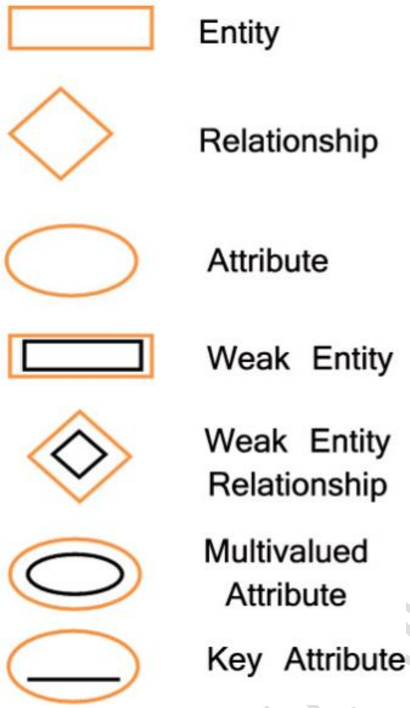
With many relational databases querying is facilitated by menu systems and icons, or 'query by example' systems. Frequently, queries are built up of expressions based on relational algebra, using commands such as SELECT (to select a subset of rows), PROJECT (to select a subset of columns) or JOIN (to join tables based on key fields). SQL (standard query language) has been developed to facilitate the querying of relational databases. The advantages of SQL for database users are its completeness, simplicity, pseudo English-language style and wide application. However, SQL has not really developed to handle geographical concepts such as 'near to', 'far from' or'connected to'.

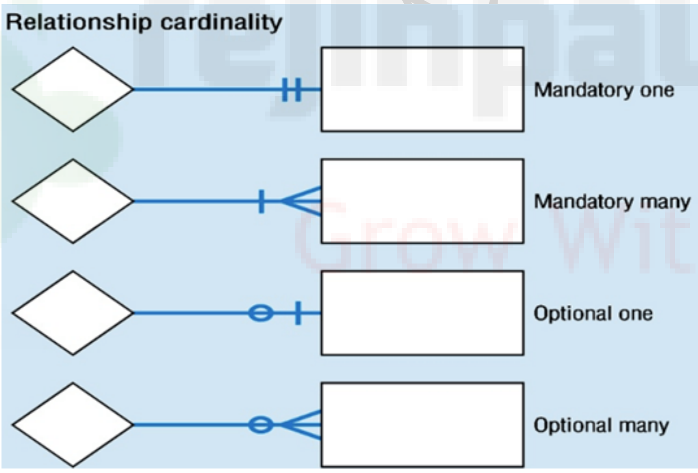
ER Diagram:

An Entity–relationship model (ER model) describes the structure of a database with the help of a diagram, which is known as Entity Relationship Diagram (ER Diagram). An ER model is a design or blueprint of a database that can later be implemented as a database. ER Model is best used for the conceptual design of a database. The main components of E-R model are:

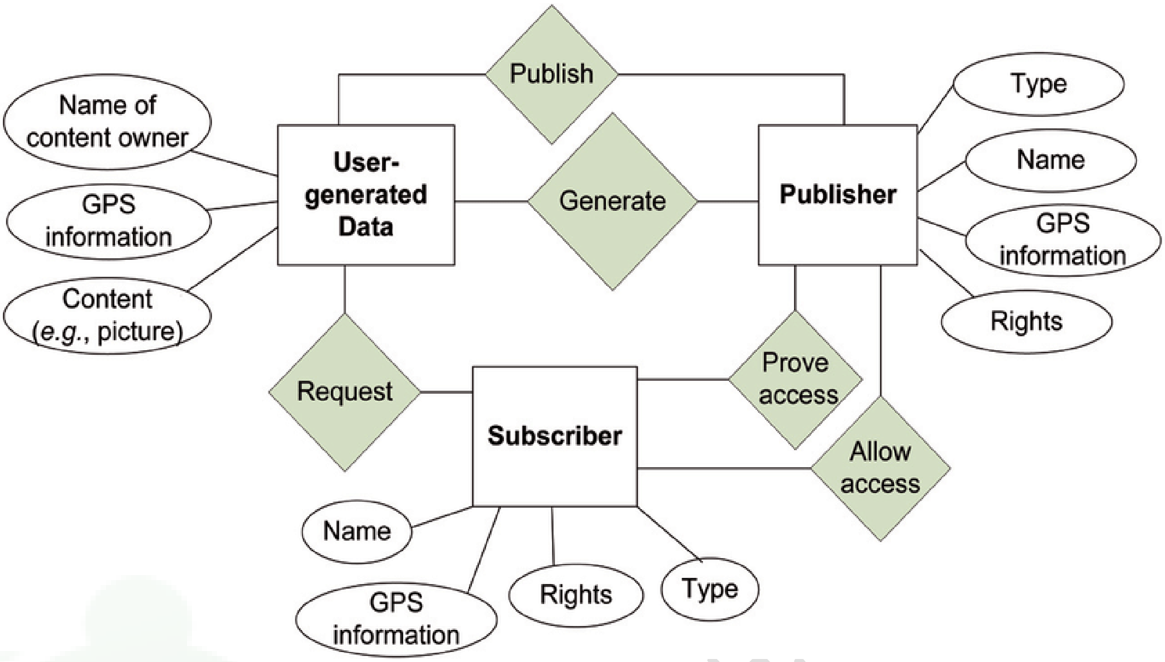
- Entity – An entity in an ER Model is a real-world entity having properties called attributes. Every attribute is defined by its set of values called domain. For example, in a school database, a student is considered as an entity. Student has various attributes like name, age, class, etc.
- Relationship – The logical association among entities is called relationship. Relationships are mapped with entities in various ways. Mapping cardinalities define the number of association between two entities. The following are the Mapping cardinalities - one to one, one to many, many to one & many to many.

The following are the various symbols used in ER diagram:





The figure shows the ER diagram for the GPS tracking system. The design has three entities namely User-generated Data, Publisher and Subscriber.



ER Diagram of GPS System

SPATIAL DATA MODEL:

Raster Data Model:

The raster spatial data model is one of a family of spatial data models described as tessellations. In the raster world individual cells are used as the building blocks for creating images of point, line, area, network and surface entities. In the raster world the basic building block is the individual grid cell, and the shape and character of an entity is created by the grouping of cells. The size of the grid cell is very important as it influences how an entity appears.

Representation of Spatial Features:

The vector data model uses the geometric objects of point, line, and polygon to represent spatial features. A point has zero dimension and has only the property of location. A point feature is made of a point or a set of points. Wells, benchmarks, and gravel pits on a topographic map are examples of point features. A line is one-dimensional and has the property of length, in addition to location. A line has two end points and may have additional points in between to mark the shape of the line. polygon is two-dimensional and has the properties of area (size) and perimeter, in addition to location. Made of connected, closed, nonintersecting lines, the perimeter or the boundary defines the area of a polygon.

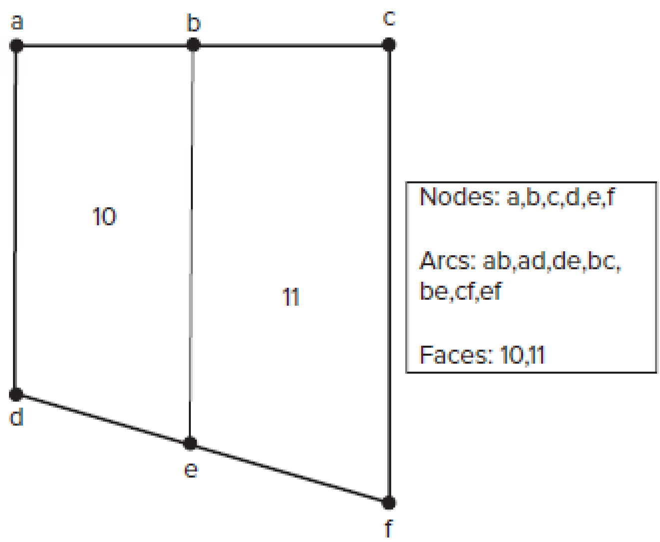
Topology:

Topology refers to the study of those properties of geometric objects that remain invariant under certain transformations such as bending or stretching. An example of a topological map is a subway map.

A subway map depicts correctly the connectivity between the subway lines and stations on each line but has distortions in distance and direction. In GIS, vector data can be topological or non-topological, depending on whether topology is built into the data or not. Topology can be explained through directed graphs (digraphs), which show the arrangements of geometric objects and the relationships among objects. An edge or arc is a directed line with a starting point and an ending point. The end points of an arc are nodes, and intermediate points, if any, are vertices. And a face refers to a polygon bounded by arcs. If an arc joins two nodes, the nodes are said to be adjacent and incident with the arc.

TIGER:

An early application example of topology is the Topologically Integrated Geographic Encoding and Referencing (TIGER) data base from the U.S. Census Bureau. The TIGER database links statistical area boundaries such as counties, census tracts, and block groups to roads, railroads, rivers, and other features by topology.



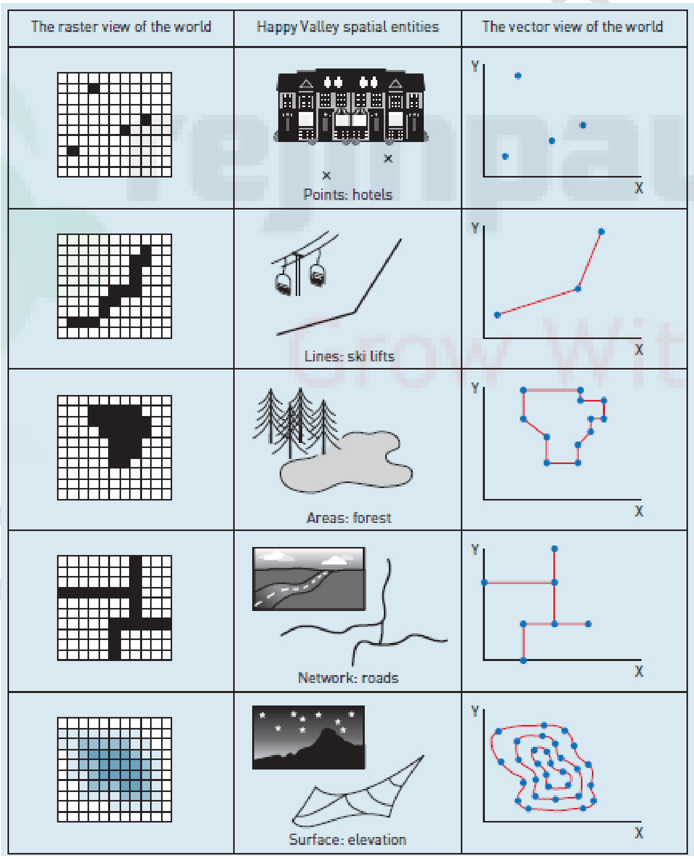
Topology in the TIGER database involves nodes, arcs and faces.

Topology has three main advantages. First, it ensures data quality and integrity. Second, topology can enhance GIS analysis. Third, topological relationships between spatial features allow GIS users to perform spatial data query.

Vector Data Model:

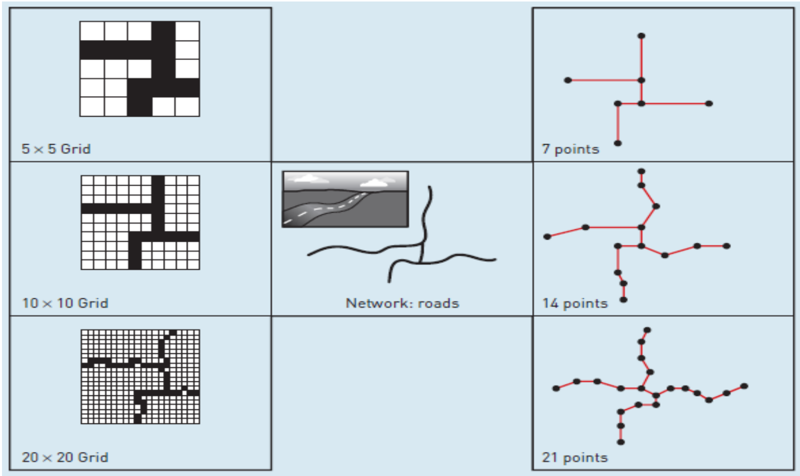
A vector spatial data model uses two-dimensional Cartesian (x,y) co-ordinates to store the shape of a spatial entity. In the vector world the point is the basic building block from which all spatial entities are constructed. The simplest spatial entity, the point, is represented by a single (x,y) co-ordinate pair. Line and area entities are constructed by connecting a series of points into chains and polygons.

The more complex the shape of a line or area feature the greater the number of points required to represent it. Selecting the appropriate number of points to construct an entity is one of the major dilemmas when using the vector approach.



Raster and vector spatial data

If too few points are chosen the character, shape and spatial properties of the entity (for example, area, length, perimeter) will be compromised. If too many points are used, unnecessary duplicate information will be stored and this will be costly in terms of data capture and computer storage.



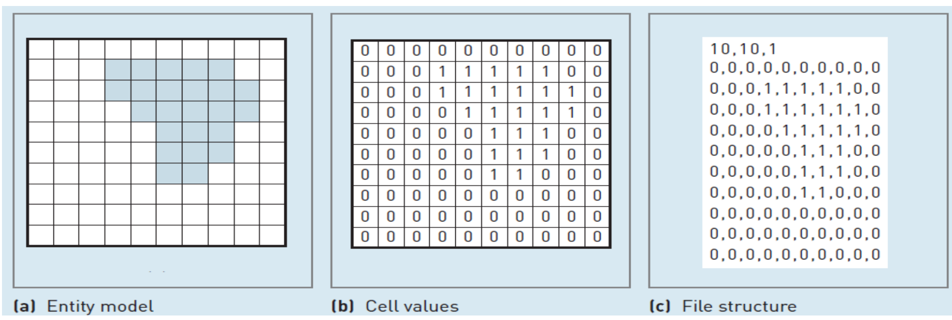
Effect of changing resolution in the vector and raster worlds

SPATIAL DATA STRUCTURES:

Data structures provide the information that the computer requires to reconstruct the spatial data model in digital form. There are many different data structures in use in GIS. This diversity is one of the reasons why exchanging spatial data between different GIS software can be problematic. However, despite this diversity data structures can be classified according to whether they are used to structure raster or vector data.

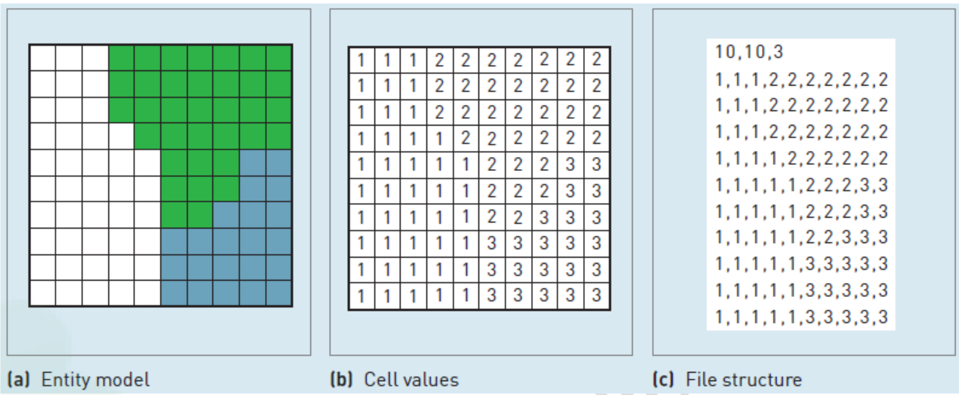
Raster data structures:

In the raster world a range of different methods is used to encode a spatial entity for storage and representation in the computer. The below figure shows the most straightforward method of coding raster data. The cells in each line of the image (Figure: a) are mirrored by an equivalent row of numbers in the file structure (Figure: c). The first line of the file tells the computer that the image consists of 10 rows and 10 columns and that the maximum cell value is 1. In this example, a value of 0 has been used to record cells where the entity is not present and a value of 1 for cells where the entity is present (Figure: b).



A simple raster data structure

In a simple raster data structure, such as illustrated in the above figure, different spatial features must be stored as separate data layers. Thus, to store more raster entities, separate data files would be required, each representing a different layer of spatial data. However, if the entities do not occupy the same geographic location (or cells in the raster model), then it is possible to store them all in a single layer, with an entity code given to each cell. This code informs the user which entity is present in which cell.



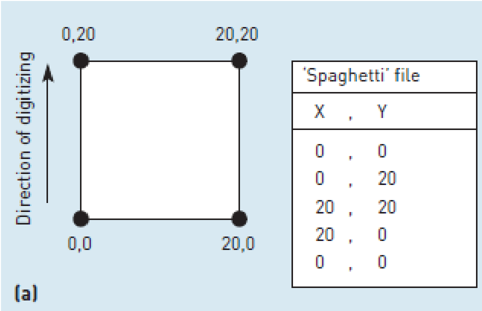
Feature coding of cells in the raster world

Above figure shows how different land uses can be coded in a single raster layer. The values 1, 2 and 3 have been used to classify the raster cells according to the land use present at a given location. The value 1 represents residential area; 2, forest; and 3, farmland.

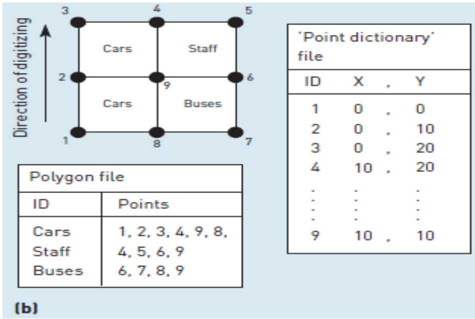
One of the major problems with raster data sets is their size, because a value must be recorded and stored for each cell in an image. Thus, a complex image made up of a mosaic of different features (such as a soil map with 20 distinct classes) requires the same amount of storage space as a similar raster map showing the location of a single forest. To address this problem a range of data compaction methods have been developed.

Vector Data Structure:

There are many potential vector data structures that can be used to store the geometric representation of entities in the computer. The simplest vector data structure that can be used to reproduce a geographical image in the computer is a file containing (*x*,*y*) co-ordinate pairs that represent the location of individual point features (or the points used to construct lines or areas).



Data structures in the vector world: simple data structure



point dictionary

The above figure shows such a vector data structure for the Happy Valley car park. Note how a closed ring of co-ordinate pairs defines the boundary of the polygon. The limitations of simple vector data structures start to emerge when more complex spatial entities are considered. For example, consider the Happy Valley car park divided into different parking zones (Figure: b). The car park consists of a number of adjacent polygons. If the simple data structure, illustrated in Figure: a, were used to capture this entity then the boundary line shared between adjacent polygons would be stored twice. This may not appear too much of a problem in the case of this example, but consider the implications for a map of the 50 states in the USA.

The amount of duplicate data would be considerable. This method can be improved by adjacent polygons sharing common co-ordinate pairs (points). To do this all points in the data structure must be numbered sequentially and contain an explicit reference which records which points are associated with which polygon. This is known as a point dictionary. The data structure in Figure: b, shows how such an approach has been used to store data for the different zones in the Happy Valley car park.

There is a considerable range of topological data structures in use by GIS. All the structures available try to ensure that:

- no node or line segment is duplicated;
- line segments and nodes can be referenced to more than one polygon;
- all polygons have unique identifiers; and
- island and hole polygons can be adequately represented.

RASTER DATA COMPRESSION:

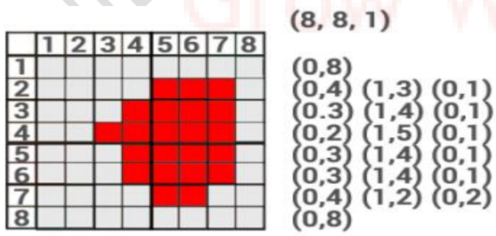
Data compression refers to the reduction of data volume, a topic particularly important for data delivery and Web mapping. Data compression is related to how raster data are encoded. Quadtree and RLE, because of their efficiency in data encoding, can also be considered as data compression methods.

A variety of techniques are available for data compression. They can be lossless or lossy. A lossless compression preserves the cell or pixel values and allows the original raster or image to be precisely reconstructed. Therefore, lossless compression is desirable for raster data that are used for analysis or deriving new data. RLE is an example of lossless compression. Other methods include LZW (Lempel—Ziv-Welch) and its variations (e.g., LZ77,LZMA).

A lossy compression cannot reconstruct fully the original image but can achieve higher compression ratios than a lossless compression. Lossy compression is therefore useful for raster data that are used as background images rather than for analysis. Image degradation through lossy compression can affect GIS-related tasks such as extracting ground control points from aerial photographs or satellite images for the purpose of georeferencing.

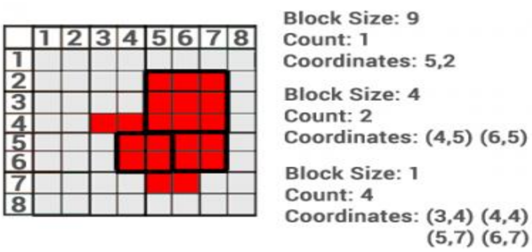
Run length encoding:

Run length encoding stores cells on a row-by-row basis. Instead of recording each individual cell's values, run length encoding groups cell values by row.



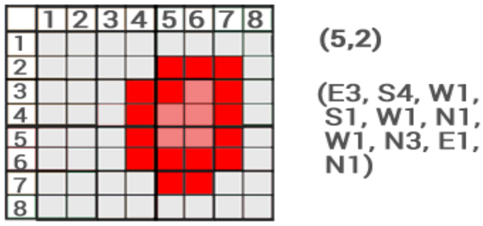
Block coding:

The block coding raster storage technique assigns areas that are blocks to reduce redundancy. The block coding raster image compression method subdivides an entire raster image into hierarchical blocks. It's an extension of the run length encoding technique, but extends it to two dimensions.



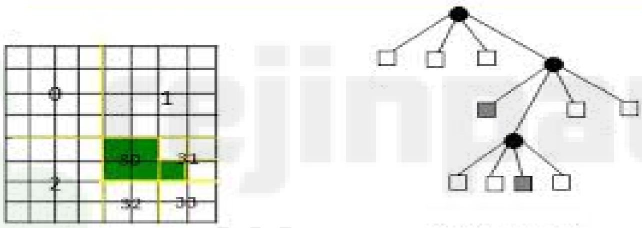
Chain Coding:

Chain coding defines the outer boundary using relative positions from a start point. The sequence of the exterior is stored where the endpoint finishes at the start point. During the encoding, the direction is stored as an integer. However, in this example we use cardinal directions for simplicity. For example, the value 0 is north and 1 is east.

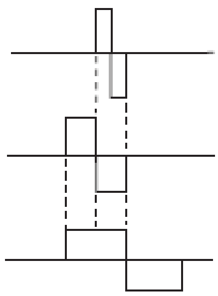


Quadtree encoding:

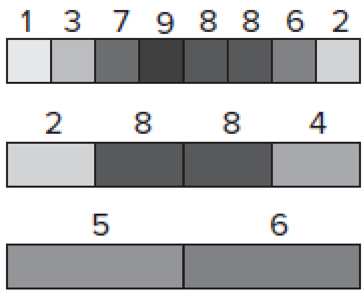
Quadtrees are raster data structures based on the successive reduction of homogeneous cells. It recursively subdivides a raster image into quarters. The subdivision process continues until each cell is classed.



MrSID uses the wavelet transform for data compression. The wavelet-based compression is also used by JPEG 2000 and ECW (Enhanced Compressed Wavelet). The wavelet transform treats an image as a wave and progressively decomposes the wave into simpler wavelets (Addison 2002). Using a wavelet (mathematical) function, the transform repetitively averages groups of adjacent pixels (e.g., 2, 4, 6, 8, or more) and, at the same time, records the differences between the original pixel values and the average. The differences, also called wavelet coefficients, can be 0, greater than 0, or less than 0. In parts of an image that have few significant variations, most pixels will have coefficients of 0 or very close to 0. To save data storage, these parts of the image can be stored at lower resolutions by rounding off low coefficients to 0, but storage at higher resolutions is required for parts of the same image that have significant variations (i.e., more details). Box 4.4 shows a simple example of using the Haar function for the wavelet 3transform.



(a)



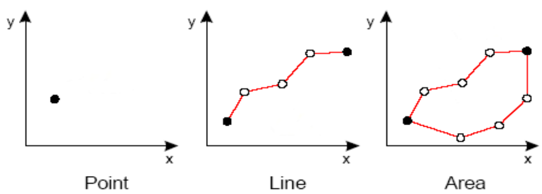
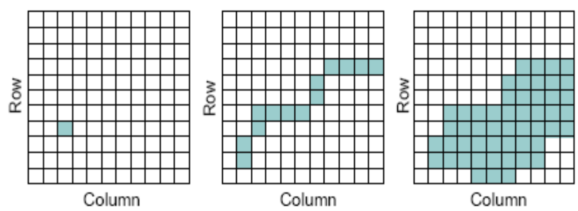
(b)

The Haar wavelet and the wavelet transform.

(a) Three Haar wavelets at three scales (resolutions).

(b) A simple example of the wavelet transform.

VECTOR vs RASTER:

Vector	Raster
Usually Complex.	Usually Simple.
Difficult for overlay operation.	Efficient for overlay operation.
High spatial variability is inefficiently represented.	High spatial variability is efficiently represented.
Small file size.	Large file size.
Vector data model is often used for representing discrete features with definable boundaries.	Raster data model is widely used for representing continuous spatial features.
Example: 	Example: 

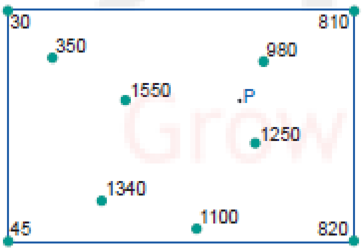
DIGITAL TERRAIN MODELLING:

The abbreviation DTM is used to describe a digital data set which is used to model a topographic surface (a surface representing height data). To model a surface accurately it would be necessary to store an almost infinite number of observations. Since this is impossible, a surface model approximates a continuous surface using a finite number of observations. Thus, an appropriate number of observations must be selected, along with their geographical location.

The 'resolution' of a DTM is determined by the frequency of observations used. DTMs are created from a series of either regularly or irregularly spaced (x,y,z) data points (where x and y are the horizontal co-ordinates and z is the vertical or height co-ordinate). DTMs may be derived from a number of data sources. These include contour and spot height information found on topographic maps, stereoscopic aerial photography, satellite images and field surveys.

Triangulated Irregular Networks:

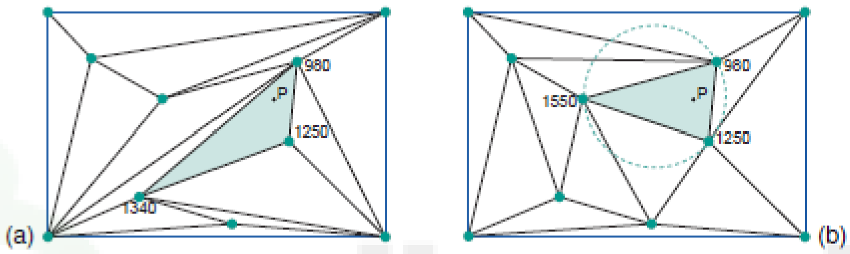
A commonly used data structure in GIS software is the triangulated irregular network (TIN). It is on the standard implementation techniques for digital terrain models, but it can be used to represent any continuous field. The principles behind a TIN are simple. It is built from a set of locations for which we have a measurement for instance an elevation. The locations can be arbitrarily scattered in space and are usually not on a nice regular grid. Any location together with its elevation value can be viewed as a point in three dimensional space. This is illustrated in below figure. From these 3D points, we can construct an irregular tessellation made of triangles.



Input locations and their (elevation) values for a TIN construction.

In three-dimensional space, three points uniquely determine a plane, as long as they not collinear, i.e. they must not be positioned on the same line. A plane fitted through these points has a fixed aspect and gradient and can be used to compute an approximation f elevation of other locations. Since we pick many triples of points, we can construct many such planes and therefore we can have many elevation approximations for a single location such as `*P*`. So, it is wise to restrict the use of a plane to the triangular area between the three points.

If we restrict the use of a plane to the area between its three anchor points, we obtain a triangular tessellation of the complete study space. Unfortunately, there are many different tessellations for a given input set of anchor points. Some tessellations are better than others, in the sense that they make smaller errors of elevation approximation. For instance, it we base our elevation computation for location `P` on the left hand shaded triangle, we will get another value than from the right hand shaded triangle. The second will provide a better approximation because the average distance from `P` to the three triangle anchors is smaller. The triangulation shown in below figure happens to be a Delaunay triangulation, which in a sense is an optimal triangulation. There are multiple ways of defining what such a triangulation is, but we suffice here to state two important properties. The first is that the triangles are as equilateral ('equal-sided') as they can be, given the set of anchor points. The second property is that for each triangle, the circumcircle through its three anchor points does not contain any other anchor point. One such circumcircle is depicted on the right of Figure (b).



Two triangulations based on the input locations (a) one with many 'stretched' triangles; (b) the triangles are more equilateral – Delaunay triangulation.

A TIN clearly is a vector representation: each anchor point has a stored georeference. Yet, we might also call it an irregular tessellation, as the chosen triangulation provides a partitioning of the entire study space. However, in this case, the cells do not have an associated stored value as is typical of tessellations, but rather a simple interpolation function that uses the elevation values of its three anchor points.

GIS DATA STANDARDS:

The number of formats available for GIS data is almost as large as the number of GIS packages on the market. This makes the sharing of data difficult and means that data created on one system is not always easily read by another system. This problem has been addressed in the past by including data conversion functions in GIS software. These conversion functions adopt commonly used exchange formats such as DXF and E00.

Open Geospatial Consortium (OGC):

There is still no universally accepted GIS data standard, although the Open Geospatial Consortium (OGC), formed in 1994 by a group of leading GIS software and data vendors, is working to deliver spatial interface specifications that are available for global use (OGC, 2001). The OGC has proposed the Geography Markup Language (GML) as a new GIS data standard.

The Geography Markup Language (GML) is a non-proprietary computer language designed specifically for the transfer of spatial data over the Internet. GML is based on XML (eXtensible Markup Language), the standard language of the Internet, and allows the exchange of spatial information and the construction of distributed spatial relationships.

GML has been proposed by the Open Geospatial Consortium as a universal spatial data standard. GML is likely to become very widely used because it is:

- Internet friendly;
- not tied to any proprietary GIS;
- specifically designed for feature-based spatial data;
- open to use by anyone;
- compatible with industry-wide IT standards.

It is also likely to set the standard for the delivery of spatial information content to PDA and WAP devices, and so form an important component of mobile and location-based (LBS) GIS technologies. The collection of geoportals and various other compliemntary services, create a Spatial Data Infrastructure (SDI).

Spatial Data Infrastructure (SDI):

An SDI is used to represent all the components that enable access to spatial data including relevant technologies, policies and institutional arrangements. Using electronic media, SDIs connect nationally distributed repositories of geospatial information and make them available on a device through a single entry point often referred to as a 'geoportal'. They facilitate data providers and users to participate in the digital spatial community at a national scale and provide a basis for spatial data discovery, evaluation and application for users within government, commercial and non-profit sectors, and academia and by citizens in general. The Global Spatial Data Infrastructure (GSDI) Association links national SDIs to establish a connection for all users in the world to share and reuse the available datasets.

Data Accuracy:

In GIS, *data quality* is used to give an indication of how good data are. It describes the overall fitness or suitability of data for a specific purpose or is used to indicate data free from errors and other problems. Examining issues such as *error*, *accuracy*, *precision* and *bias* can help to assess the quality of individual data sets. In addition, the *resolution* and *generalization* of source data, and the data model used, may influence the portrayal of features of interest. Data sets used for analysis need to be *complete*, *compatible* and *consistent*, and *applicable* for the analysis being performed.

Accuracy is the extent to which an estimated data value approaches its true value (Aronoff, 1989). If a GIS database is accurate, it is a true representation of reality. It is impossible for a GIS database to be 100 per cent accurate, though it is possible to have data that are accurate to within specified tolerances. For example, a ski lift station co-ordinate may be accurate to within plus or minus 10 metres.

Several types of error can arise when accuracy and/or precision requirements are not met during data capture and creation. The five types of error in a geospatial dataset are related to -

Positional Accuracy:

The identification of positional accuracy is important. This includes consideration of inherent error (source error) and operational error (introduced error). A more detailed review is provided in the next section.

Attribute Accuracy:

Consideration of the accuracy of attributes also helps to define the quality of the data. This quality component concerns the identification of the reliability, or level of purity (homogeneity), in a data set.

Logical Consistency:

This component is concerned with determining the faithfulness of the data structure for a data set. This typically involves spatial data inconsistencies such as incorrect line intersections, duplicate lines or boundaries, or gaps in lines. These are referred to as spatial or topological errors.

Completeness:

The final quality component involves a statement about the completeness of the data set. This includes consideration of holes in the data, unclassified areas, and any compilation procedures that may have caused data to be eliminated.

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UNIT III DATA INPUT AND TOPOLOGY

Scanner - Raster Data Input – Raster Data File Formats – Vector Data Input –Digitiser – Topology - Adjacency, connectivity and containment – Topological Consistency rules – Attribute Data linking – ODBC – GPS - Concept GPS based mapping.

Introduction:

Data encoding is the process of getting data into the computer. It is a process that is fundamental to almost every GIS project. For example:

- An archaeologist may encode aerial photographs of ancient remains to integrate with newly collected field data.
- A planner may digitize outlines of new buildings and plot these on existing topographical data.
- An ecologist may add new remotely sensed data to a GIS to examine changes in habitats.
- A historian may scan historical maps to create a virtual city from the past.
- A utility company may encode changes in pipeline data to record changes and upgrades to their pipe network.

Once in a GIS, data almost always need to be corrected and manipulated to ensure that they can be structured according to the required data model. Problems that may have to be addressed at this stage of a GIS project include:

- the re-projection of data from different map sources to a common projection;
- the generalization of complex data to provide a simpler data set; or
- the matching and joining of adjacent map sheets once the data are in digital form.

This unit looks in detail at the range of methods available to get data into a GIS. These include keyboard entry, digitizing, scanning and electronic data transfer. Then, methods of data editing and manipulation are reviewed, including re-projection, transformation and edge matching. The whole process of data encoding and editing is often called the 'data stream'.

Analogue data are normally in paper form, and include paper maps, tables of statistics and hard-copy (printed) aerial photographs. These data all need to be converted to digital form before use in a GIS, thus the data encoding and correction procedures are longer than those for digital data. Digital data are already in computer-readable formats and are supplied on CD-ROM or across a computer network. Map data, aerial photographs, satellite imagery, data from databases and automatic data collection devices (such as data loggers and GPS) are all available in digital form.

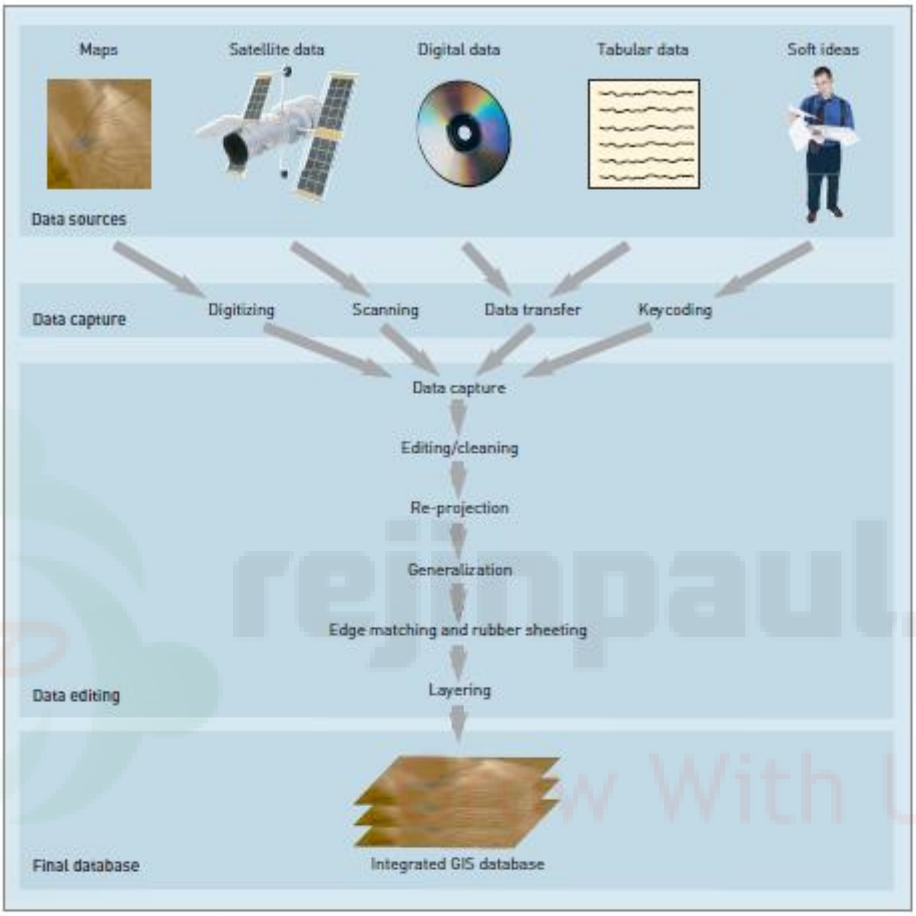


Figure: The Data Stream

SCANNER:

Scanning coverts paper maps into digital format by capturing features as individual cells, or pixels, producing an automated image. Maps are generally considered the backbone of any GIS activity. But many a time paper maps are not easily available in a form that can be readily used by the computers. Most of the paper maps had been prepared on the basis of old conventional surveys. New maps can be produced using improved technologies but this requires time as it increases the volume of work. Thus, we have to resort to the available maps. These paper maps have to be first converted into a digital format usable by the computer. This is a critical step as the quality of the analog document must be preserved in the transition to the computer domain.

The technology used for this kind of conversions is known as scanning and the instrument used for this kind of operation is known as a scanner. A scanner can be thought of as an electronic input device that converts analog information of a document like a map, photograph or an overlay into a digital format that can be used by the computer. Scanning automatically captures map features, text, and symbols as individual cells, or pixels, and produces an automated image.

Working of a Scanner:

The most important component inside a scanner is the scanner head which can move along the length of the scanner. The scanner head contains either a charged-couple device (CCD) sensor or a contact image (CIS) sensor. A CCD consists of a number of photosensitive cells or pixels packed together on a chip. The most advanced large format scanners use CCD's with 8000 pixels per chip for providing a very good image quality.

While scanning a bright white light from the scanner strikes the image to be scanned and is reflected onto the photosensitive surface of the sensor placed on the scanner head. Each pixel transfers a gray tone value (values given to the different shades of black in the image ranging from 0 (black) – 255 (white) i.e. 256 values to the scan board (software). The software interprets the value in terms of 0 (Black) or 1 (white), thereby, forming a monochrome image of the scanned portion. As the head moves ahead, it scans the image in tiny strips and the sensor continues to store the information in a sequential fashion. The software running the scanner pierces together the information from the sensor into a digital form of the image. This type of scanning is known as one pass scanning.

Scanning a colour image is slightly different in which the scanner head has to scan the same image for three different colours i.e. red, green, blue. In older colour scanners, this was accomplished by scanning the same area three times over for the three different colours. This type of scanner is known as three-pass scanner. However, most of the colour scanners now scan in one pass scanning all the three colours in one go by using colour filters. In principle, a colour CCD works in the same way as a monochrome CCD. But in this each colour is constructed by mixing red, green and blue. Thus, a 24-bit RGB CCD presents each pixel by 24 bits of information. Usually, a scanner using these three colours (in full 24 RGB mode) can create up to 16.8 million colours.

Types of Scanners:

Hand-held scanners although portable, can only scan images up to about four inches wide. They require a very steady hand for moving the scan head over the document. They are useful for scanning small logos or signatures and are virtually of no use for scanning maps and photographs.

The most commonly used scanner is a *flatbed scanner* also known as desktop scanner. It has a glass plate on which the picture or the document is placed. The scanner head placed beneath the glass plate moves across the picture and the result is a good quality scanned image. For scanning large maps or top sheets wide format flatbed scanners can be used.

Figure: Types of Scanners

Then there are the *drum scanners* which are mostly used by the printing professionals. In this type of scanner, the image or the document is placed on a glass cylinder that rotates at very high speeds around a centrally located sensor containing photo-multiplier tube instead of a CCD to scan. Prior to the advances in the field of sheet fed scanners, the drum scanners were extensively used for scanning maps and other documents.

RASTER GIS FILE FORMATS:

Raster data is made up of pixels (also referred to as grid cells). They are usually regularly-spaced and square but they don't have to be. Rasters have pixel that are associated with a value (continuous) or class (discrete).

Extension	File Type	Description
ERDAS Imagine (IMG)	*.IMG*	ERDAS Imagine IMG files is a proprietary file format developed by Hexagon Geospatial. IMG files are commonly used for raster data to store single and multiple bands of satellite data. IMG files use a hierarchical format (HFA) that are optional to store basic information about the file. For example, this can include file information, ground control points and sensor type. Each raster layer as part of an IMG file contains information about its data values. For example, this includes projection, statistics, attributes, pyramids and whether or not it's a continuous or discrete type of raster.
American Standard Code for Information Interchange ASCII Grid	*.ASC*	ASCII uses a set of numbers (including floats) between 0 and 255 for information storage and processing. They also contain header information with a set of keywords. In their native form, ASCII text files store GIS data in a delimited format. This could be comma, space or tab-delimited format. Going from non-spatial to spatial data, you can run a conversion process tool like ASCII to raster.
GeoTIFF	*.TIF* *.TIFF* *.OVR*	The GeoTIFF has become an industry image standard file for GIS and satellite remote sensing applications. GeoTIFFs may be accompanied by other files: ▪ TFW is the world file that is required to give your raster geolocation. ▪ XML optionally accompany GeoTIFFs and are your metadata. ▪ AUX auxiliary files store projections and other information. ▪ OVR pyramid files improves performance for raster display.

IDRISI Raster	*.RST* *.RDC*	IDRISI assigns RST extensions to all raster layers. They consist of numeric grid cell values as integers, real numbers, bytes and RGB24. The raster documentation file (RDC) is a companion text file for RST files. They assign the number of columns and rows to RST files. Further to this, they record the file type, coordinate system, reference units and positional error.
Envi RAW Raster	*.BIL* *.BIP* *.BSQ*	Band Interleaved files are a raster storage extension for single/multi-band aerial and satellite imagery. ▪ Band Interleaved for Line (BIL) stores pixel information based on rows for all bands in an image. ▪ Whereas Band interleaved by pixel (BIP) assigns pixel values for each band by rows. ▪ Finally, Band sequential format (BSQ) stores separate bands by rows. BIL files consist of a header file (HDR) that describes the number of columns, rows, bands, bit depth and layout in an image.
Esri Grid		Grid files are a proprietary format developed by Esri. Grids have no extension and are unique because they can hold attribute data in a raster file. But the catch is that you can only add attributes to integer grids. Attributes are stored in a value attribute tables (VAT) – one record for each unique value in the grid, and the count representing the number of cells. The two types of Esri Grid files are integer and floating point grids. Land cover would be an example of a discrete grid. Each class has a unique integer cell value. Elevation data is an example of a floating point grid. Each cell represents an elevation floating value.

VECTOR GIS FILE FORMATS:

Vector data is not made up of grids of pixels. Instead, vector graphics are comprised of vertices and paths. The three basic symbol types for vector data are points, lines and polygons (areas).

Extension	File Type	Description
Esri Shapefile	.SHP, .DBF, .SHX	The shapefile is BY FAR the most common geospatial file type you'll encounter. All commercial and open source accept shapefile as a GIS format. It's so ubiquitous that it's become the industry standard. But you'll need a complete set of three files that are mandatory to make up a shapefile. The three required files are: • SHP is the feature geometry. • SHX is the shape index position. • DBF is the attribute data.
Geographic JavaScript Object Notation (GeoJSON)	.GEOJSON .JSON	The GeoJSON format is mostly for web-based mapping. GeoJSON stores coordinates as text in JavaScript Object Notation (JSON) form. This includes vector points, lines and polygons as well as tabular information. GeoJSON store objects within curly braces {} and in general have less markup overhead (compared to GML). GeoJSON has straightforward syntax that you can modify in any text editor. Webmaps browsers understand JavaScript so by default GeoJSON is a common web format. But JavaScript only understands binary objects. Fortunately, JavaScript can convert JSON to binary.
Geography Markup Language (GML)	.GML	GML allows for the use of geographic coordinates extension of XML. And eXtensible Markup Language (XML) is both human-readable and machine-readable. GML stores geographic entities (features) in the form of text. Similar to GeoJSON, GML can be updated in any text editor. Each feature has a list of properties, geometry (points, lines, curves, surfaces and polygons) and spatial reference system. There is generally more overhead when compare GML with GeoJSON. This is because GML results in more data for the same amount of information.

Google Keyhole Markup Language (KML/KMZ)	*.KML* *.KMZ*	KML stands for Keyhole Markup Language. This GIS format is XML-based and is primarily used for Google Earth. KML was developed by Keyhole Inc which was later acquired by Google. KMZ (KML-Zipped) replaced KML as being the default Google Earth geospatial format because it is a compressed version of the file. KML/KMZ became an international standard of the Open Geospatial Consortium in 2008. The longitude, latitude components (decimal degrees) are as defined by the World Geodetic System of 1984 (WGS84). The vertical component (altitude) is measured in meters from the WGS84 EGM96 Geoid vertical datum.
GPS eXchange Format (GPX)	*.GPX*	GPS Exchange format is an XML schema that describes waypoints, tracks and routes captured from a GPS receiver. Because GPX is an exchange format, you can openly transfer GPS data from one program to another based on its description properties. The minimum requirement for GPX are latitude and longitude coordinates. In addition, GPX files optionally stores location properties including time, elevation and geoid height as tags.
IDRISI Vector	.VCT .VDC	IDRISI vector data files have a VCT extension along with an associated vector documentation file with a VDC extension. VCT format are limited to points, lines, polygons, text and photos. Upon the creation of an IDRISI vector file, it automatically creates a documentation file for building metadata. Attributes are stored directly in the vector files. But you can optionally use independent data tables and value files.

DIGITIZING:

Digitizing in GIS is the process of converting geographic data either from a hardcopy or a scanned image into vector data by tracing the features. During the digitzing process, features from the traced map or image are captured as coordinates in either point, line, or polygon format.

Types of Digitizing in GIS:

The most common method of encoding spatial features from paper maps is manual digitizing. It is an appropriate technique when selected features are required from a paper map. Manual digitizing requires a digitizing table that is linked to a computer workstation. The digitizing table is essentially a large flat tablet, the surface of which is underlain by a very fine mesh of wires. Attached to the digitizer via a cable is a cursor (puck) that can be moved freely over the surface of the table. Buttons on the cursor allow the user to send instructions to the computer. The position of the cursor on the table is registered by reference to its position above the wire mesh.

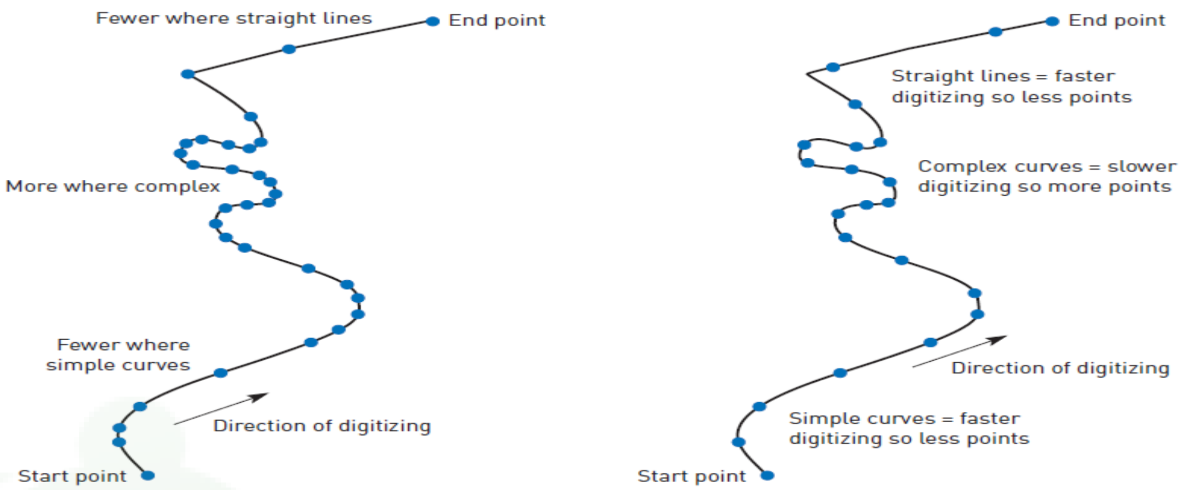
Figure: Manual Digitizer

Heads up digitizing (also referred to as on-screen digitizing) is the method of tracing geographic features from another dataset (usually an aerial, satellite image, or scanned image of a map) directly on the computer screen. Automated digitizing involves using image processing software that contains pattern recognition technology to generated vectors.

The procedure followed when digitizing a paper map using a manual digitizer has the following five stages:

- *Registration:* The map to be digitized is fixed firmly to the table top with sticky tape. Five or more control points are identified (usually the four corners of the map sheet and one or more grid intersections in the middle). The geographic co-ordinates of the control points are noted and their locations digitized by positioning the cross-hairs on the cursor exactly over them and pressing the 'digitize' button on the cursor. This sends the co-ordinates of a point on the table to the computer and stores them in a file as 'digitizer co-ordinates'.
- Digitizing point features: Point features, for example spot heights, hotel locations or meteorological stations, are recorded as a single digitized point. A unique code number or identifier is added so that attribute information may be attached later. For instance, the hotel with ID number '1' would later be identified as 'Mountain View'.
- *Digitizing line features:* Line features (such as roads or rivers) are digitized as a series of points that the software will join with straight line segments. In some GIS packages lines are referred to as arcs, and their start and end points as nodes. This gives rise to the term arc–node topology, used to describe a method of structuring line features.
- *Digitizing area (polygon) features:* Area features or polygons, for example forested areas or administrative boundaries, are digitized as a series of points linked together by line segments in the same way as line features. Here it is important that the start and end points join to form a complete area. Polygons can be digitized as a series of individual lines, which are later joined to form areas. In this case it is important that each line segment is digitized only once.
- *Adding attribute information:* Attribute data may be added to digitized polygon features by linking them to a centroid (or seed point) in each polygon. These are either digitized manually (after digitizing the polygon boundaries) or created automatically once the polygons have been encoded. Using a unique identifier or code number, attribute data can then be linked to the polygon centroids of appropriate polygons. In this way, the forest stand may have data relating to tree species, tree ages, tree numbers and timber volume attached to a point within the polygon.

Manual digitizers may be used in one of two modes: point mode or stream mode. In point mode the user begins digitizing each line segment with a start node, records each change in direction of the line with a digitized point and finishes the segment with an end node. Thus, a straight line can be digitized with just two points, the start and end nodes. For more complex lines, a greater number of points are required between the start and end nodes. Smooth curves are problematic since they require an infinite number of points to record their true shape.



(a) Point mode - person digitizing decides where to place each individual point such as to most accurately represent the line within the accepted tolerances of the digitizer.
(b) Stream mode – person digitizing decides on time or distance interval between the digitizing hardware registering each point as the person digitizing moves the cursor along the line.

In stream mode the digitizer is set up to record points according to a stated time interval or on a distance basis. Once the user has recorded the start of a line the digitizer might be set to record a point automatically every 0.5 seconds and the user must move the cursor along the line to record its shape. An end node is required to stop the digitizer recording further points. The speed at which the cursor is moved along the line determines the number of points recorded. Thus, where the line is more complex and the cursor needs to be moved more slowly and with more care, a greater number of points will be recorded. Conversely, where the line is straight, the cursor can be moved more quickly and fewer points are recorded.

The choice between point mode and stream mode digitizing is largely a matter of personal preference. Stream mode digitizing requires more skill than point mode digitizing, and for an experienced user may be a faster method. Stream mode will usually generate more points, and hence larger files, than point mode.

TOPOLOGY:

Topology is the mathematical representation of the physical relationships that exists between the geographical elements. Topology has long been a key GIS requirement for data management and integrity. In general, a topological data model manages spatial relationships by representing spatial objects (point, line, and area features) as an underlying graph of topological primitives—nodes, faces, and edges. These primitives, together with their relationships to one another and to the features whose boundaries they represent, are defined by representing the feature geometries in a planar graph of topological elements.

Topology is useful in GIS because many spatial modeling operations don't require coordinates, only topological information. For example, to find an optimal path between two points requires a list of the arcs that connect to each other and the cost to traverse each arc in each direction. Coordinates are only needed for drawing the path after it is calculated.

The topological structure supports three major topological concepts:

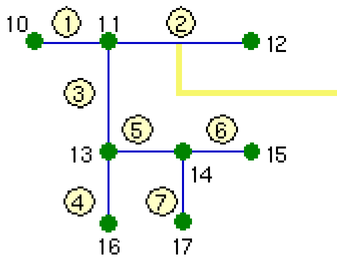
- Connectivity: Arcs connect to each other at nodes.
- Area definition: Arcs that connect to surround an area define a polygon.
- Contiguity: Arcs have direction and left and right sides.

Connectivity

Connectivity is defined through arc-node topology. This is the basis for many network tracing and path finding operations. Connectivity allows you to identify a route to the airport, connect streams to rivers, or follow a path from the water treatment plant to a house.

In the arc-node data structure, an arc is defined by two endpoints: the from-node indicating where the arc begins and a to-node indicating where it ends. This is called arc-node topology.

Arc-Node Topology



Arc-Node List

Arc	From Node	To Node
1	10	11
2	11	12
3	11	13
4	13	16
5	13	14
6	14	15
7	14	17

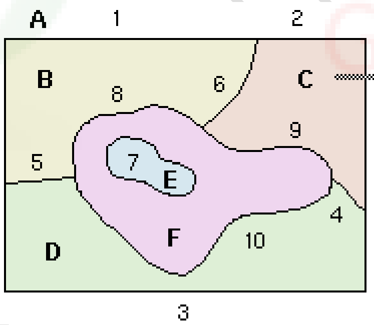
Figure: Arc-Node topology example

Arc-node topology is supported through an arc-node list. The list identifies the from- and to-nodes for each arc. Connected arcs are determined by searching through the list for common node numbers. In the above example, it is possible to determine that arcs 1, 2, and 3 all intersect because they share node 11. The computer can determine that it is possible to travel along arc 1 and turn onto arc 3 because they share a common node (11), but it's not possible to turn directly from arc 1 onto arc 5 because they don't share a common node.

Containment:

Many of the geographic features that may be represented cover a distinguishable area on the surface of the earth, such as lakes, parcels of land, and census tracts. An area is represented in the vector model by one or more boundaries defining a polygon. Although this sounds counterintuitive, consider a lake with an island in the middle. The lake actually has two boundaries: one that defines its outer edge and the island that defines its inner edge. In the terminology of the vector model, an island defines an inner boundary (or hole) of a polygon.

The arc-node structure represents polygons as an ordered list of arcs rather than a closed loop of x,y coordinates. This is called polygon-arc topology. In the illustration below, polygon F is made up of arcs 8, 9, 10, and 7 (the 0 before the 7 indicates that this arc creates an island in the polygon).



Polygon-Arc Topology

Polygon	Arc List
B	1, 6, 8, 5
C	2, 4, 9, 6
D	3, 5, 10, 4
E	7
F	8, 9, 10, 0, 7

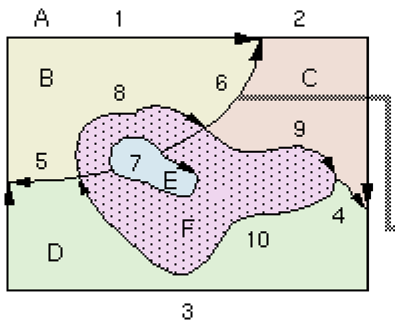
Figure: Polygon-Arc topology example

Each arc appears in two polygons (in the above example, arc 6 appears in the list for polygons B and C). Since the polygon is simply the list of arcs defining its boundary, arc coordinates are stored only once, thereby reducing the amount of data and ensuring that the boundaries of adjacent polygons don't overlap.

Contiguity:

Two geographic features that share a boundary are called adjacent. Contiguity is the topological concept that allows the vector data model to determine adjacency. Polygon topology defines contiguity. Polygons are contiguous to each other if they share a common arc. This is the basis for many neighbor and overlay operations.

Recall that the from-node and to-node define an arc. This indicates an arc's direction so the polygons on its left and right sides can be determined. Left-right topology refers to the polygons on the left and right sides of an arc. In the below example, polygon B is on the left of arc 6, and polygon C is on the right. Thus we know that polygons B and C are adjacent.



Left-Right Topology

Arc	Left Polygon	Right Polygon
1	A	B
2	A	C
3	A	D
4	C	D
5	D	B
6	B	C
7	F	E
8	B	F
9	C	F
10	D	F

Figure: Left-Right topology example

Notice that the label for polygon A is outside the boundary of the area. This polygon is called the external, or universe, polygon and represents the world outside the study area. The universe polygon ensures that each arc always has a left and right side defined.

Topology Rules:

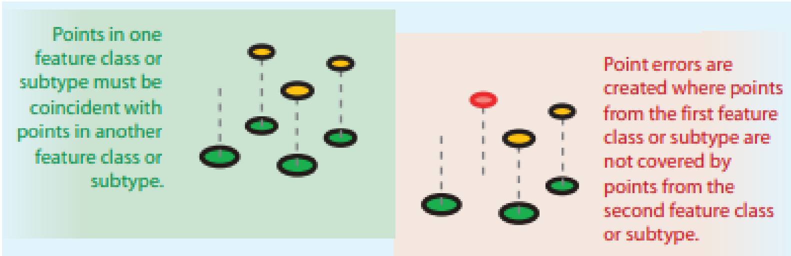
There are many topology rules you can implement in your geodatabase, depending on the spatial relationships that are most important for your organization to maintain. You should carefully plan the spatial relationships you will enforce on your features. Some topology rules govern the relationships of features within a given feature class, while others govern the relationships between features in two different feature classes or subtypes. Topology rules can be defined between sub types of features in one or another feature class. This could be used, for example, to require street features to be connected to other street features at both ends, except in the case of streets belonging to the cul-de-sac or dead-end subtypes.

Many topology rules can be imposed on features in a geodatabase. A well-designed geodatabase will have only those topology rules that define key spatial relationships needed by an organization. Most topology violations have fixes that you can use to correct errors.

Topology rules based on points:

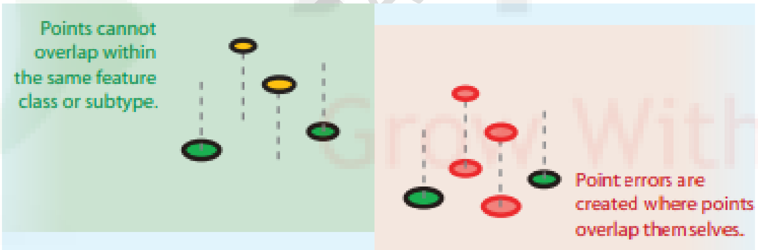
Must Coincide With:

Requires that points in one feature class (or subtype) be coincident with points in another feature class (or subtype). This is useful for cases where points must be covered by other points, such as transformers must coincide with power poles in electric distribution networks and observation points must coincide with stations.



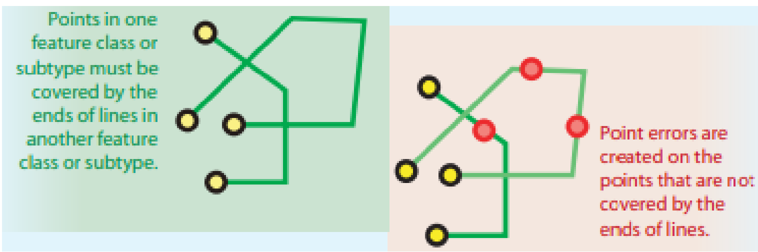
Must Be Disjoint:

Requires that points be separated spatially from other points in the same feature class (or subtype). Any points that overlap are errors. This is useful for ensuring that points are not coincident or duplicated within the same feature class, such as in layers of cities, parcel lot ID points, wells, or streetlamp poles.



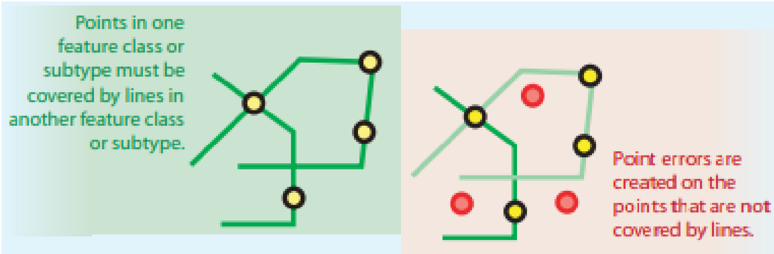
Must Be Covered By Endpoint of:

Requires that points in one feature class must be covered by the endpoints of lines in another feature class. This rule is similar to the line rule Endpoint Must Be Covered By except that, in cases where the rule is violated, it is the point feature that is marked as an error rather than the line. Boundary corner markers might be constrained to be covered by the endpoints of boundary lines.



Point Must Be Covered By Line:

Requires that points in one feature class be covered by lines in another feature class. It does not constrain the covering portion of the line to be an endpoint. This rule is useful for points that fall along a set of lines, such as highway signs along highways.

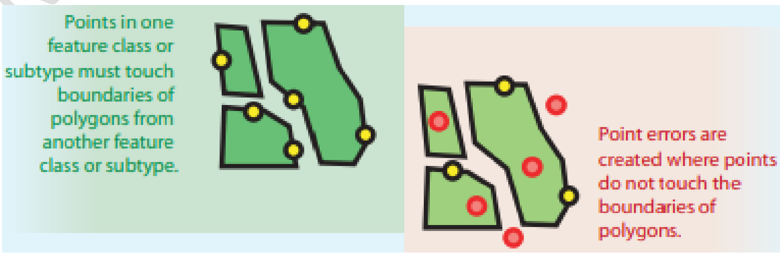


Must Be Properly Inside Polygons:

Requires that points fall within area features. This is useful when the point features are related to polygons, such as wells and well pads or address points and parcels.

Must Be Covered By Boundary of:

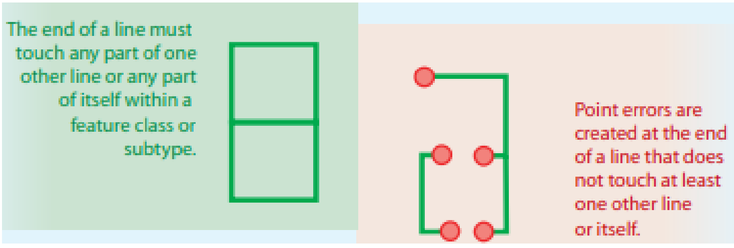
Requires that points fall on the boundaries of area features. This is useful when the point features help support the boundary system, such as boundary markers, which must be found on the edges of certain areas.



Topology rules based on Lines:

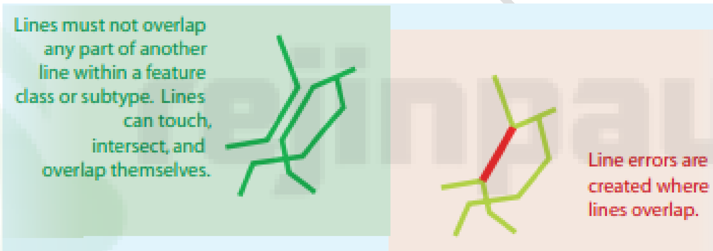
Must Not Have Dangles:

Requires that a line feature must touch lines from the same feature class (or subtype) at both endpoints. An endpoint that is not connected to another line is called a dangle. This rule is used when line features must form closed loops, such as when they are defining the boundaries of polygon features. It may also be used in cases where lines typically connect to other lines, as with streets. In this case, exceptions can be used where the rule is occasionally violated, as with cul-de-sac or dead-end street segments.



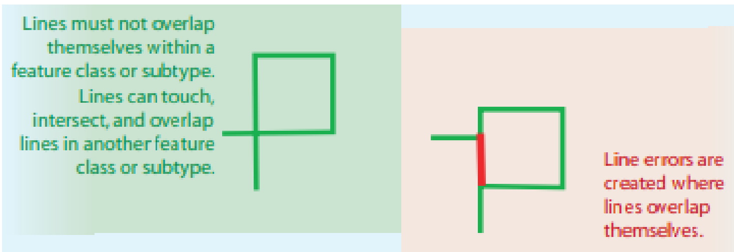
Must Not Overlap:

Requires that lines not overlap with lines in the same feature class (or subtype). This rule is used where line segments should not be duplicated, for example, in a stream feature class. Lines can cross or intersect but cannot share segments.



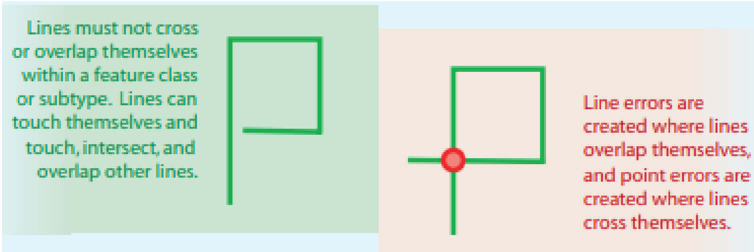
Must Not Self-Overlap:

Requires that line features not overlap themselves. They can cross or touch themselves but must not have coincident segments. This rule is useful for features, such as streets, where segments might touch in a loop but where the same street should not follow the same course twice.



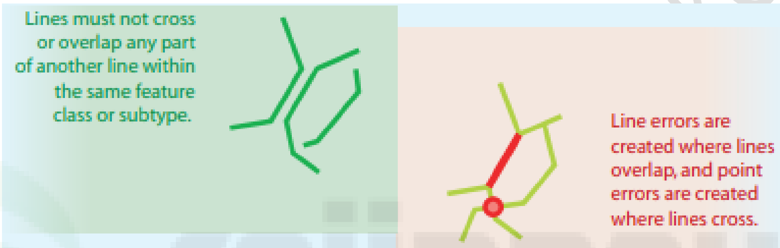
Must Not Self-Intersect:

Requires that line features not cross or overlap themselves. This rule is useful for lines, such as contour lines, that cannot cross themselves.



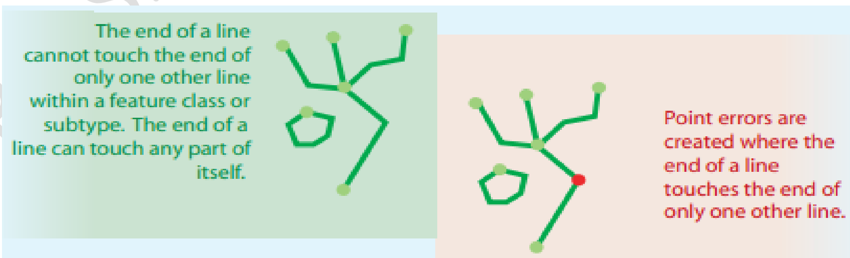
Must Not Intersect :

Requires that a line in one feature class (or subtype) must only touch other lines of the same feature class (or subtype) at endpoints. Any line segment in which features overlap or any intersection not at an endpoint is an error. This rule is useful where lines must only be connected at endpoints, such as in the case of plot lines, which must split (only connect to the endpoints of) back lot lines and cannot overlap each other.



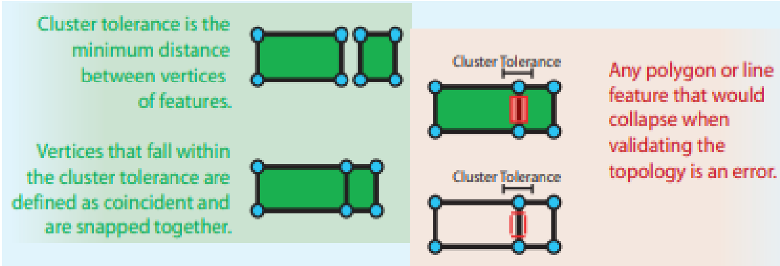
Must Not Have Pseudo Nodes:

Requires that a line connect to at least two other lines at each endpoint. Lines that connect to one other line (or to themselves) are said to have pseudo nodes. This rule is used where line features must form closed loops, such as when they define the boundaries of polygons or when line features logically must connect to two other line features at each end, as with segments in a stream network, with exceptions being marked for the originating ends of first-order streams.



Must Be Larger Than Cluster Tolerance:

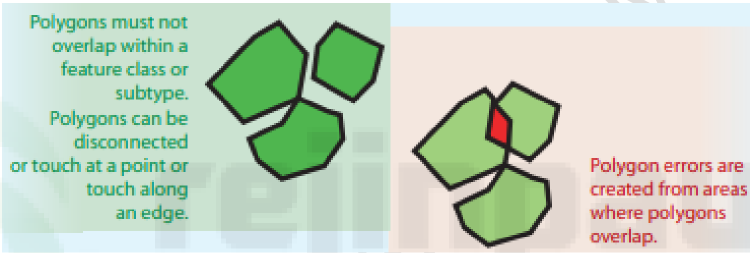
Requires that a feature does not collapse during a validate process. This rule is mandatory for a topology and applies to all line and polygon feature classes. In instances where this rule is violated, the original geometry is left unchanged.



Topology rules based on Polygons:

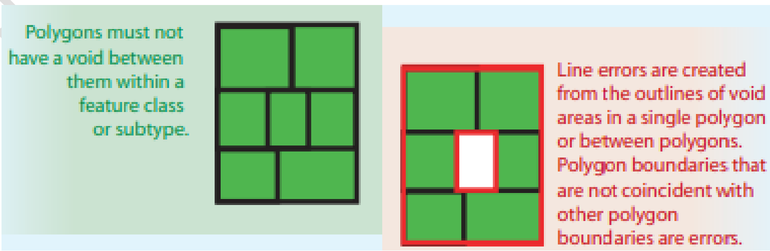
Must Not Overlap:

Requires that the interior of polygons not overlap. The polygons can share edges or vertices. This rule is used when an area cannot belong to two or more polygons. It is useful for modeling administrative boundaries, such as ZIP Codes or voting districts, and mutually exclusive area classifications, such as land cover or landform type.



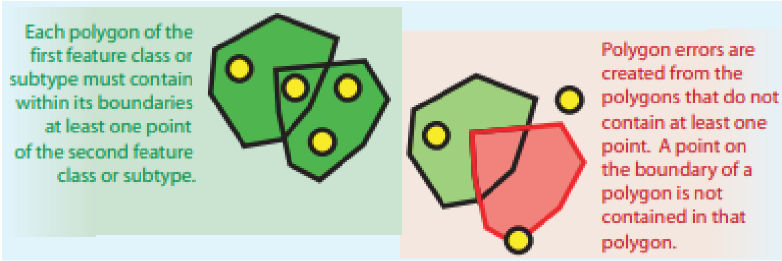
Must Not Have Gaps:

This rule requires that there are no voids within a single polygon or between adjacent polygons. All polygons must form a continuous surface. An error will always exist on the perimeter of the surface. You can either ignore this error or mark it as an exception. Use this rule on data that must completely cover an area. For example, soil polygons cannot include gaps or form voids—they must cover an entire area.



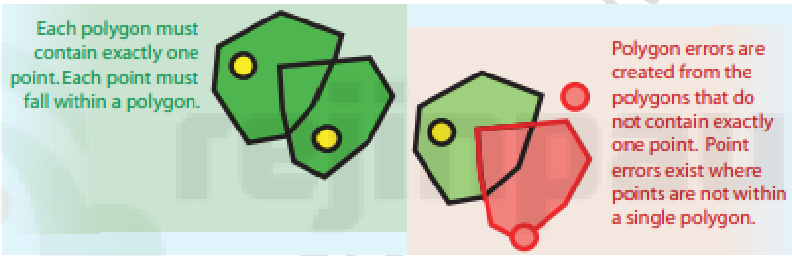
Contains Point:

Requires that a polygon in one feature class contain at least one point from another feature class. Points must be within the polygon, not on the boundary. This is useful when every polygon should have at least one associated point, such as when parcels must have an address point.



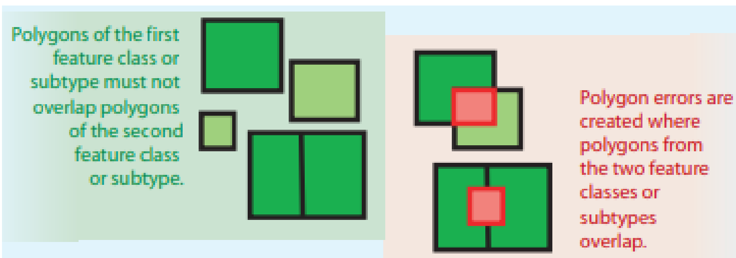
Contains One Point:

Requires that each polygon contains one point feature and that each point feature falls within a single polygon. This is used when there must be a one-to-one correspondence between features of a polygon feature class and features of a point feature class, such as administrative boundaries and their capital cities. Each point must be properly inside exactly one polygon and each polygon must properly contain exactly one point. Points must be within the polygon, not on the boundary.



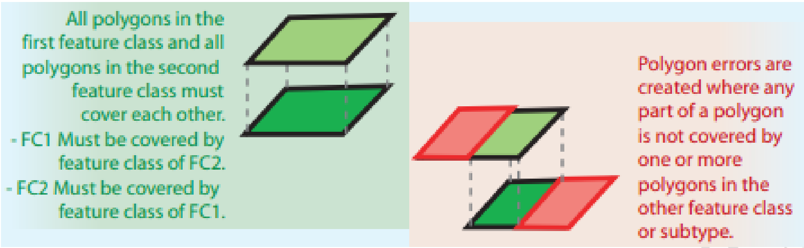
Must Not Overlap With:

Requires that the interior of polygons in one feature class (or subtype) must not overlap with the interior of polygons in another feature class (or subtype). Polygons of the two feature classes can share edges or vertices or be completely disjointed. This rule is used when an area cannot belong to two separate feature classes. It is useful for combining two mutually exclusive systems of area classification, such as zoning and water body type, where areas defined within the zoning class cannot also be defined in the water body class and vice versa.



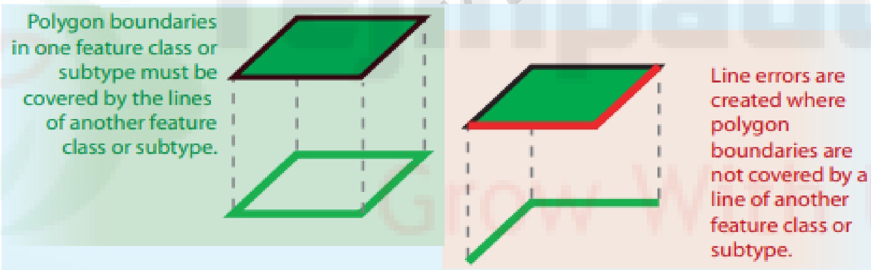
Must Cover Each Other:

Requires that the polygons of one feature class (or subtype) must share all of their area with the polygons of another feature class (or subtype). Polygons may share edges or vertices. Any area defined in either feature class that is not shared with the other is an error. This rule is used when two systems of classification are used for the same geographic area, and any given point defined in one system must also be defined in the other. One such case occurs with nested hierarchical datasets, such as census blocks and block groups or small watersheds and large drainage basins. The rule can also be applied to non-hierarchically related polygon feature classes, such as soil type and slope class.



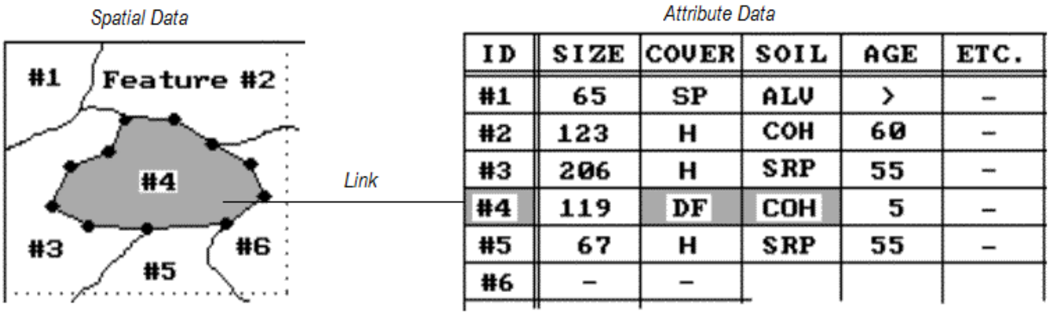
Area Boundary Must Be Covered By Boundary of:

Requires that boundaries of polygon features in one feature class (or subtype) be covered by boundaries of polygon features in another feature class (or subtype). This is useful when polygon features in one feature class, such as subdivisions, are composed of multiple polygons in another class, such as parcels, and the shared boundaries must be aligned.



ATTRIBUTE DATA LINKING:

There are two types of GIS data: spatial data (coordinate and projection information for spatial features) and attribute data. Attribute data is additional information appended in tabular format linked with spatial features. The attribute data is linked with spatial data through unique id (i.e. feature ID). The spatial data contains information about where and attribute data can contain information about what, where, and why. Attribute data provides characteristics about spatial data.



ID	SIZE	COVER	SOIL	AGE	ETC.
#1	65	SP	ALV	>	–
#2	123	H	COH	60	–
#3	206	H	SRP	55	–
#4	119	DF	COH	5	–
#5	67	H	SRP	55	–
#6	–	–			

Figure: Attribute data and Spatial data linking

Joins:

When our data was all in a single table, we could easily retrieve a particular row from that table. But if the data we are looking for is available in two or more tables then joins can be used to retrieve those data. Join is used to fetch data from two or more tables, which is joined to appear as single set of data. It is used for combining column from two or more tables by using values common to both tables.

There are several types of JOINs: INNER, LEFT OUTER and RIGHT OUTER; they all do slightly different things, but the basic theory behind them all is the same.

Inner Join:

An INNER JOIN returns a result set that contains the common elements of the tables, i.e. the intersection where they match on the joined condition. An INNER JOIN focuses on the commonality between two tables. When using an INNER JOIN, there must be at least some matching data between two (or more) tables that are being compared. INNER JOINs are the most frequently used JOIN operation.

location

fid	city	state	country
101	Chennai	TN	IND
102	Coimbatore	TN	IND
103	Nellore	AP	IND
104	Vellore	TN	IND
105	Tirupathi	AP	IND

city details

city	population	area	rainfall
Chennai	122345	9205.56	55.32
Coimbatore	122344	1234.36	120.36
Vellore	354212	1002.36	75.64
Kanchepuram	564321	4561.89	80.64
Nellore	123456	6455.45	98.65

Inner join

fid	city	state	country	city	populatio	area	rainfall
101	Chennai	TN	IND	Chennai	122345	9205.56	55.32
102	Coimbatore	TN	IND	Coimbatore	122344	1234.36	120.36
103	Nellore	AP	IND	Nellore	123456	6455.45	98.65
104	Vellore	TN	IND	Vellore	354212	1002.36	75.64

Left Outer Join:

A LEFT JOIN or a LEFT OUTER JOIN takes all the rows from one table, defined as the left table, and joins it with a second table. A LEFT JOIN will always include the rows from the LEFT table, even if there are no matching rows in the table it is JOINed with.

location

fid	city	state	country
101	Chennai	TN	IND
102	Coimbatore	TN	IND
103	Nellore	AP	IND
104	Vellore	TN	IND
105	Tirupathi	AP	IND

city details

city	population	area	rainfall
Chennai	122345	9205.56	55.32
Coimbatore	122344	1234.36	120.36
Vellore	354212	1002.36	75.64
Kanchepuram	564321	4561.89	80.64
Nellore	123456	6455.45	98.65

Left outer join

fid	city	state	country	city	populatio	area	rainfall
101	Chennai	TN	IND	Chennai	122345	9205.56	55.32
102	Coimbatore	TN	IND	Coimbatore	122344	1234.36	120.36
103	Nellore	AP	IND	Nellore	123456	6455.45	98.65
104	Vellore	TN	IND	Vellore	354212	1002.36	75.64
105	Tirupathi	AP	IND	NIL	NIL	NIL	NIL

Right Outer Join:

A RIGHT OUTER JOIN is similar to a LEFT OUTER JOIN except that the roles between the two tables are reversed, and all the rows on the second table are included along with any matching rows from the first table i.e. A RIGHT JOIN will always include the rows from the RIGHT table, even if there are no matching rows in the table it is JOINed with.

location

fid	city	state	country
101	Chennai	TN	IND
102	Coimbatore	TN	IND
103	Nellore	AP	IND
104	Vellore	TN	IND
105	Tirupathi	AP	IND

city details

city	population	area	rainfall
Chennai	122345	9205.56	55.32
Coimbatore	122344	1234.36	120.36
Vellore	354212	1002.36	75.64
Kanchepuram	564321	4561.89	80.64
Nellore	123456	6455.45	98.65

fid	city	state	country	city	populatio	area	rainfall
101	Chennai	TN	IND	Chennai	122345	9205.56	55.32
102	Coimbatore	TN	IND	Coimbatore	122344	1234.36	120.36
104	Vellore	TN	IND	Vellore	354212	1002.36	75.64
103	Nellore	AP	IND	Nellore	123456	6455.45	98.65
NIL	NIL	NIL	NIL	Kanchepuram	564321	4561.89	80.64

Relates:

Relates can help us to discover specific information within our data. A relate (also called a table relate) is a property of a layer. We can create a table relate so that we can query and select features in one layer and see all the related features in another layer or table. Unlike joining tables, relating tables simply defines a relationship between two tables. The associated data isn't appended to the layer's attribute table like it is with a join. Instead, we can access the related data through selected features or records in your layer or table.

Relation Class:

A relationship class is an object in a geo-database that stores information about a relationship between two feature classes, between a feature class and a non-spatial table, or between two non-spatial tables. Both participants in a relationship class must be stored in the same geo-database.

A relationship class stores information about associations among features and records in a geo-database and can help ensure your data's integrity. Relates that are added to a layer or table in a map are essentially the same as simple relationship classes defined in a geo-database, except that they are saved with the map instead of in a geo-database.

Open Database Connectivity (ODBC):

An Open Database Connectivity (ODBC) is an interface that allows applications to access data in database management systems (DBMS) using SQL as a standard for accessing the data. ODBC permits maximum interoperability, which means a single application can access different DBMS. Application end users can then add ODBC database drivers to link the application to their choice of DBMS. Application end users can then add ODBC database drivers to link the application to their choice of DBMS.

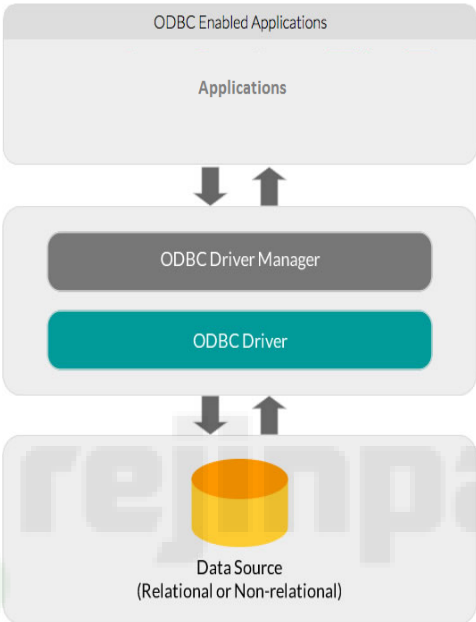


Figure: Architecture of ODBC

The ODBC solution for accessing data led to ODBC database drivers, which are dynamic-link libraries on Windows and shared objects on Linux/UNIX. These drivers allow an application to gain access to one or more data sources. ODBC provides a standard interface to allow application developers and vendors of database drivers to exchange data between applications and data sources.

ODBC Driver Manager:

The ODBC Driver Manager loads and unloads ODBC drivers on behalf of an application. The Windows platform comes with a default Driver Manager, while non-windows platforms have the choice to use an open source ODBC Driver Manager like unixODBC and iODBC. The ODBC Driver Manager processes ODBC function calls, or passes them to an ODBC driver and resolves ODBC version conflicts.

ODBC Driver:

The ODBC driver processes ODBC function calls, submits SQL requests to a specific data source and returns results to the application. The ODBC driver may also modify an application's request so that the request conforms to syntax supported by the associated database. A framework to easily build an ODBC drivers is available from Simba Technologies, as are ODBC drivers for many data sources, such as Salesforce, MongoDB, Spark and more.

The following are the steps involved in connecting application programs with the database using ODBC API:

- Load ODBC driver: The forName() method of Class class is used to register the driver class. This method is used to dynamically load the driver class.
- Establish Connection: The getConnection() method of DriverManager class is used to establish connection with the database.
- Prepare and Execute SQL Statement: The createStatement() method of Connection interface is used to create statement. The executeQuery() and execute() method is used to execute queries to the database.
- Process the result: The executeQuery() method returns the object of ResultSet that can be used to get all the records of a table.
- Close connection: The *close()* method is used to close the connection in order to free the allocated resource used by the connection.

The below java code is used for connecting with mysql database using ODBC application programming interface.

```
Class.forName("org.gjt.mm.mysql.Driver");
Connection conn=null;
conn = DriverManager.getConnection(connectionURL, "root", "admin");
String sql = "SELECT * FROM STUDENTS";
PreparedStatement  pst = connection.prepareStatement(sql);
conn.open();
ResultSet=pst.executeQuery();
conn.close();
```

Global Positioning System:

The Global Positioning System (GPS) is a U.S.-owned utility that provides users with positioning, navigation, and timing (PNT) services. This system consists of three segments: the space segment, the control segment, and the user segment. The U.S. Air Force develops, maintains, and operates the space and control segments. GPS technology was first used by the United States military in the 1960s and expanded into civilian use over the next few decades.

Today, GPS receivers are included in many commercial products, such as automobiles, smart phones, exercise watches, and GIS devices.

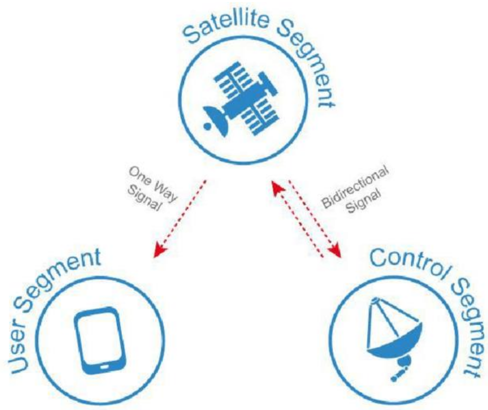


Figure: Three Segments of GPS

Space Segment:

The GPS space segment consists of a constellation of satellites transmitting radio signals to users. The United States is committed to maintaining the availability of at least 24 operational GPS satellites, 95% of the time. To ensure this commitment, the Air Force has been flying 31 operational GPS satellites for the past few years. GPS satellites fly in medium Earth orbit (MEO) at an altitude of approximately 20,200 km (12,550 miles). Each satellite circles the Earth twice a day. The satellites in the GPS constellation are arranged into six equally-spaced orbital planes surrounding the Earth. Each plane contains four "slots" occupied by baseline satellites. This 24-slot arrangement ensures users can view at least four satellites from virtually any point on the planet.

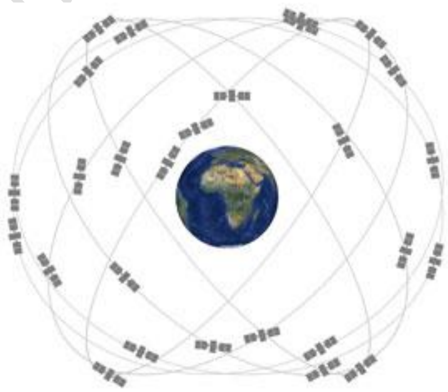


Figure: Constellation of satellites

The Air Force normally flies more than 24 GPS satellites to maintain coverage whenever the baseline satellites are serviced or decommissioned. The extra satellites may increase GPS performance but are not considered part of the core constellation. In June 2011, the Air Force successfully completed a GPS constellation expansion known as the "Expandable 24" configuration. Three of the 24 slots were expanded, and six satellites were repositioned, so that three of the extra satellites became part of the constellation baseline. As a result, GPS now effectively operates as a 27-slot constellation with improved coverage in most parts of the world.

Control Segments:

The GPS control segment consists of a global network of ground facilities that track the GPS satellites, monitor their transmissions, perform analyses, and send commands and data to the constellation. The current Operational Control Segment (OCS) includes a master control station, an alternate master control station, 11 command and control antennas, and 16 monitoring sites. The locations of these facilities are shown in the map above.

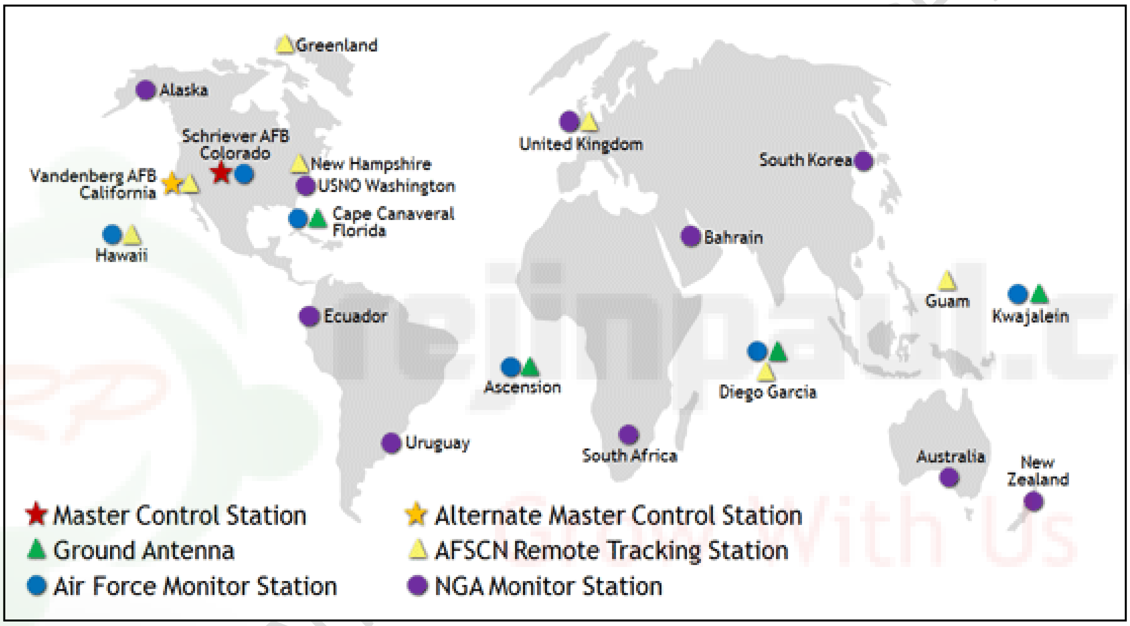


Figure: GPS Control Segments

The GPS constellation delivers consistently high performance thanks to the dedicated efforts of its operators — the men and women of the U.S. Air Force's 2nd Space Operations Squadron (2SOPS) and the Air Force Reserve's 19th Space Operations Squadron (19SOPS) at Schriever Air Force Base, Colorado.

User Segments:

Like the Internet, GPS is an essential element of the global information infrastructure. The free, open, and dependable nature of GPS has led to the development of hundreds of applications affecting every aspect of modern life. GPS technology is now in everything from cell phones and wristwatches to bulldozers, shipping containers, and ATM's.

GPS BASED MAPPING:

The surveying and mapping community was one of the first to take advantage of GPS because it dramatically increased productivity and resulted in more accurate and reliable data. Today, GPS is a vital part of surveying and mapping activities around the world. When used by skilled professionals, GPS provides surveying and mapping data of the highest accuracy. GPS-based data collection is much faster than conventional surveying and mapping techniques, reducing the amount of equipment and labor required. A single surveyor can now accomplish in one day what once took an entire team weeks to do. GPS supports the accurate mapping and modeling of the physical world — from mountains and rivers to streets and buildings to utility lines and other resources. Features measured with GPS can be displayed on maps and in geographic information systems (GIS) that store, manipulate, and display geographically referenced data.

Governments, scientific organizations, and commercial operations throughout the world use GPS and GIS technology to facilitate timely decisions and wise use of resources. Any organization or agency that requires accurate location information about its assets can benefit from the efficiency and productivity provided by GPS positioning. Unlike conventional techniques, GPS surveying is not bound by constraints such as line-of-sight visibility between survey stations. The stations can be deployed at greater distances from each other and can operate anywhere with a good view of the sky, rather than being confined to remote hilltops as previously required.

GPS is especially useful in surveying coasts and waterways, where there are few land-based reference points. Survey vessels combine GPS positions with sonar depth soundings to make the nautical charts that alert mariners to changing water depths and underwater hazards. Bridge builders and offshore oil rigs also depend on GPS for accurate hydrographic surveys.
Land surveyors and mappers can carry GPS systems in backpacks or mount them on vehicles to allow rapid, accurate data collection. Some of these systems communicate wirelessly with reference receivers to deliver continuous, real-time, centimeter-level accuracy and unprecedented productivity gains. To achieve the highest level of accuracy, most survey-grade receivers use two GPS radio frequencies: L1 and L2. Currently, there is no fully functional civilian signal at L2, so these receivers leverage a military L2 signal using "codeless" techniques.

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UNIT IV DATA ANALYSIS

Vector Data Analysis tools - Data Analysis tools - Network Analysis - Digital Elevation models - 3D data collection and utilisation.

VECTOR DATA ANALYSIS:

The vector data model uses points and their *x*-, *y*-coordinates to construct spatial features of points, lines, and polygons. These spatial features are used as inputs in vector data analysis. Therefore, the accuracy of data analysis depends on the accuracy of these features in terms of their location and shape and whether they are topological or not. Additionally, it is important to note that an analysis may apply to all, or selected, features in a layer. The following are the types of analysis used with vector data.

- Buffering
- Overlay
- Distance Measurement
- Pattern Analysis
- Feature Manipulation

Buffering:

Based on the concept of proximity, buffering creates two areas: one area that is within a specified distance of select features and the other area that is beyond. The area within the specified distance is the buffer zone. A GIS typically varies the value of an attribute to separate the buffer zone (e.g., 1) from the area beyond the buffer zone (e.g., 0). Besides the designation of the buffer zone, no other attribute data are added or combined.

Features for buffering may be points, lines, or polygons (refer below figure). Buffering around points creates circular buffer zones. Buffering around lines creates a series of elongated buffer zones around each line segment. And buffering around polygons creates buffer zones that extend outward from the polygon boundaries.

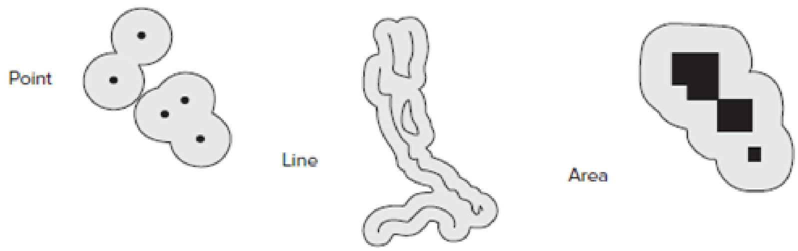
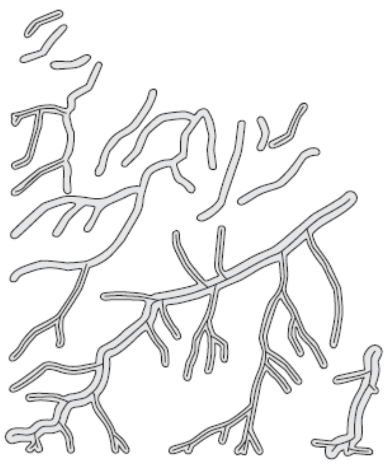


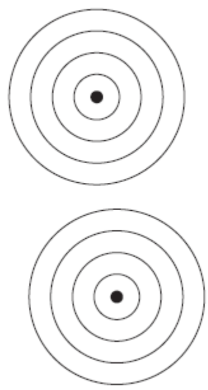
Figure: Buffering around points, Lines and polygons

Variations in Buffering:

The buffer distance or buffer size does not have to be constant; it can vary according to the values of a given field (refer below figure). For example, the width of the riparian buffer can vary depending on its expected function and the intensity of adjacent land use. A feature may have more than one buffer zone. As an example, a nuclear power plant may be buffered with distances of 5, 10, 15, and 20 miles, thus forming multiple rings around the plant. Although the interval of each ring is the same at 5 miles, the rings are not equal in area. The second ring from the plant, in fact, covers an area about three times larger than the first ring. One must consider this area difference if the buffer zones are part of an evacuation plan. Likewise, buffering around line features does not have to be on both sides of the lines; it can be on either the left side or the right side of the line feature. (The left or right side is determined by the direction from the starting point to the end point of a line.) Likewise, buffer zones around polygons can be extended either outward or inward from the polygon boundaries. Boundaries of buffer zones may remain intact so that each buffer zone is a separate polygon for further analysis.



Buffering with different buffer distance



Buffering with four levels

Regardless of its variations, buffering uses distance measurements from select features to create the buffer zones. Because buffering uses distance measurements from spatial features, the positional accuracy of spatial features in a data set also determines the accuracy of buffer zones.

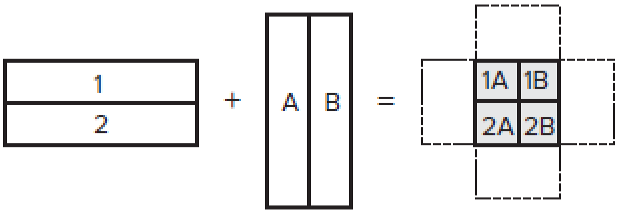
Applications of Buffering:

Most applications of buffering are based on buffer zones. A buffer zone is often treated as a protection zone and is used for planning or regulatory purposes:

- Government regulations may set 2-mile buffer zones along streams to minimize sedimentation from logging operations.
- A national forest may restrict oil and gas well drilling within 500 feet of roads or highways.
- A planning agency may set aside land along the edges of streams to reduce the effects of nutrient, sediment, and pesticide runoff; to maintain shade to prevent the rise of stream temperature; and to provide shelter for wildlife and aquatic life
- A planning agency may create buffer zones around geographic features such as water, wetlands, critical habitats, and wells to be protected and exclude these zones from landfill consideration.
- Sometimes buffer zones may represent the inclusion zones in GIS applications. For example, the criteria for an industrial park may stipulate that a potential site must be within 1 mile of a heavy-duty road. In this case, the 1-mile buffer zones of all heavy-duty roads become the inclusion zones.
- Buffer zones can also be used as indicators of the positional accuracy of point and line features. This application is particularly relevant for historical data that do not include geographic coordinates or data that are generated from poor-quality sources.

OVERLAY:

An overlay operation combines the geometries and attributes of two feature layers to create the output. The geometry of the output represents the geometric intersection of features from the input layers. Below figure illustrates an overlay operation with two simple polygon layers. Each feature on the output contains a combination of attributes from the input layers, and this combination differs from its neighbours. Feature layers to be overlaid must be spatially registered and based on the same coordinate system.

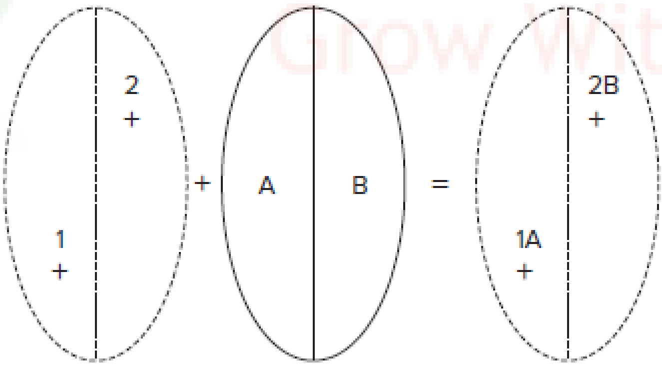


Overlay combines the geometries and attributes from two layers into a single layer. The dashed lines are for illustration only and are not included in the output.

Feature Type and Overlay:

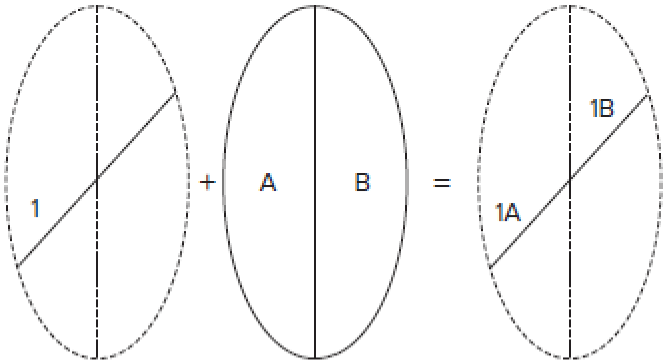
Overlay operations can take polygon, line, or point layers as the inputs and create an output of a lower-dimension feature type. For example, given the inputs of polygon and line layers, the output will be a line layer. Without going through all different combinations of feature types, this section covers three common overlay operations: point-in polygon, line-in-polygon, and polygon-on-polygon. To distinguish the layers in the following discussion, the layer that may be a point, line, or polygon layer is called the input layer, and the layer that is a polygon layer is called the overlay layer.

In a point-in-polygon overlay operation, the same point features in the input layer are included in the output but each point is assigned with attributes of the polygon within which it falls. For example, a point-in-polygon overlay can find the association between wildlife locations and vegetation types.



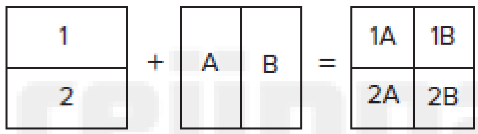
Point-in-polygon overlay. The input is a point layer. The output is also a point layer but has attribute data from the polygon layer.

In a line-in-polygon overlay operation, the output contains the same line features as in the input layer but each line feature is dissected by the polygon boundaries on the overlay layer. Thus the output has more line segments than does the input layer. Each line segment on the output combines attributes from the input layer and the underlying polygon. For example, a line-in-polygon overlay can find soil data for a proposed road. The input layer includes the proposed road. The overlay layer contains soil polygons.



Line-in-polygon overlay. The input is a line layer. The output is also a line layer.

The most common overlay operation is polygon-on-polygon, involving two polygon layers. The output combines the polygon boundaries from the input and overlay layers to create a new set of polygons. Each new polygon carries attributes from both layers, and these attributes differ from those of adjacent polygons. For example, a polygon-on-polygon overlay can analyze the association between elevation zones and vegetation types.



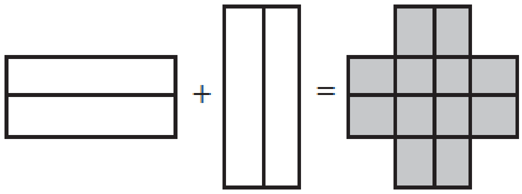
Polygon-on-polygon overlay. In the illustration, the two layers for overlay have the same area extent. The output combines the geometries and attributes from the two layers into a single polygon layer.

Overlay Methods:

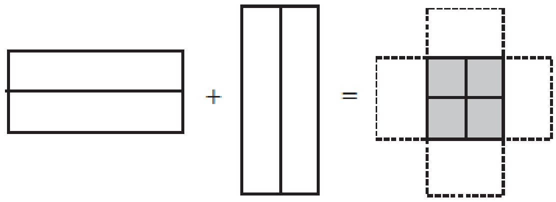
The overlay methods are based on the Boolean connectors AND, OR, and XOR. Intersect uses the AND connector. Union uses the OR connector. Symmetrical Difference or Difference uses the XOR connector. Identity or Minus uses the following expression: [(input layer) AND (identity layer)] OR (input layer). The following explains in more detail these four common overlay methods by using two polygon layers as the inputs.

Union preserves all features from the inputs. The area extent of the output combines the area extents of both input layers.

Intersect preserves only those features that falls within the area extent common to the inputs. Intersect is often a preferred method of overlay because any feature on its output has attribute data from both of its inputs. For example, a forest management plan may call for an inventory of vegetation types within riparian zones. Intersect will be a more efficient overlay method than Union in this case because the output contains only riparian zones with vegetation types.



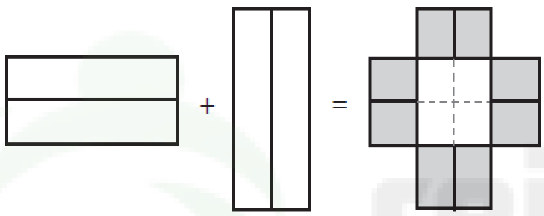
The Union method keeps all the areas of the two input layers in the output.



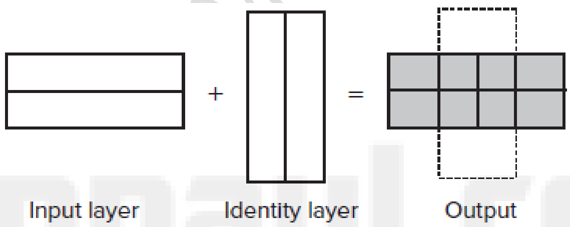
The Intersect method preserves only the area common to the two input layers in the output.

Symmetrical Difference preserves features that fall within the area extent that is common to only one of the inputs. In other words, Symmetrical Difference is opposite to Intersect in terms of the output's area extent.

Identity preserves only features that fall within the area extent of the layer defined as the input layer. The other layer is called the identity layer.



The Symmetrical Difference method preserves areas common to only one of the input layers in the output.

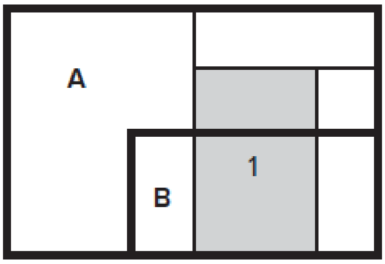


The Identity method produces an output that has the same extent as the input layer. But the output includes the geometry and attributes data from the identity layer.

Applications of Overlay:

The overlay methods play a central role in many querying and modeling applications. Suppose an investment company is looking for a land parcel that is zoned commercial, not subject to flooding, and not more than 1 mile from a heavy-duty road. The company can first create the 1-mile road buffer and overlay the buffer zone layer with the zoning and floodplain layers. A subsequent query of the overlay output can select land parcels that satisfy the company's selection criteria.

A more specific application of overlay is to help solve the areal interpolation problem. Areal interpolation involves transferring known data from one set of polygons (source polygons) to another (target polygons). For example, census tracts may represent source polygons with known populations in each tract from the U.S. Census Bureau, and school districts may represent target polygons with unknown population data. Using overlay the population of the school districts can be calculated using the population given in the census tract.



An example of areal interpolation.

Distance Measurement:

Distance measurement refers to measuring straight line (Euclidean) distances between features. Measurements can be made from points in a layer to points in another layer, or from each point in a layer to its nearest point or line in another layer. In both cases, distance measures are stored in a field. Distance measures can be used directly for data analysis.

Pattern Analysis:

Pattern analysis is the study of the spatial arrangements of point or polygon features in two dimensional space. Pattern analysis uses distance measurements as inputs and statistics (spatial statistics) for describing the distribution pattern. At the general (global) level, a pattern analysis can reveal if a point distribution pattern is random, dispersed, or clustered

A classic technique for point pattern analysis, nearest neighbour analysis uses the distance between each point and its closest neighbouring point in a layer to determine if the point pattern is random, regular, or clustered. The nearest neighbour statistic is the ratio (R) of the observed average distance between nearest neighbours (d_{obs}) to the expected average for a hypothetical random distribution (d_{exp}):

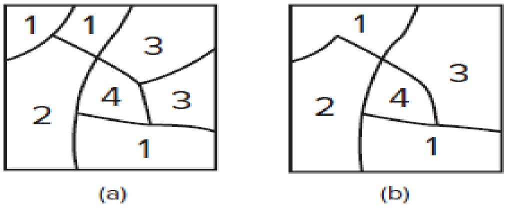
$$R = \frac{d_{\text{obs}}}{d_{\text{exp}}}$$

The R ratio is less than 1 if the point pattern is more clustered than random, and greater than 1 if the point pattern is more dispersed than random.

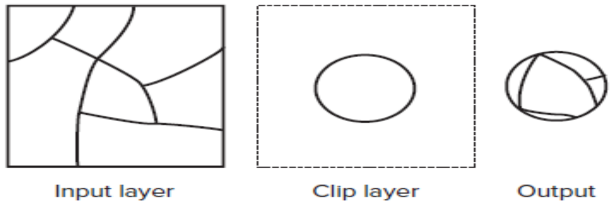
Feature Manipulation:

Tools are available in a GIS package for manipulating and managing features in one or more feature layers. When a tool involves two layers, the layers must be based on the same coordinate system. Like overlay, these feature tools are often needed for data preprocessing and data analysis; however, unlike overlay, these tools do not combine geometries and attributes from input layers into a single layer.

Dissolve aggregates features in a feature layer that have the same attribute value or values. For example, we can aggregate roads by highway number or counties by state. An important application of Dissolve is to simplify a classified polygon layer.



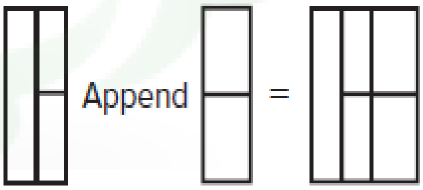
Dissolve removes boundaries of polygons that have the same attribute value in (a) and creates a simplified layer (b).



Clip creates an output that contains only those features of the input layer that fall within the area extent of the clip layer. The output has the same feature type as the input.

Clip creates a new layer that includes only those features of the input layer, including their attributes that fall within the area extent of the clip layer. Clip is a useful tool, for example, for cutting a map acquired elsewhere to fit a study area.

Append creates a new layer by piecing together two or more layers, which represent the same feature and have the same attributes. For example, Append can put together a layer from four input layers, each corresponding to the area extent of a USGS 7.5-minute quadrangle.



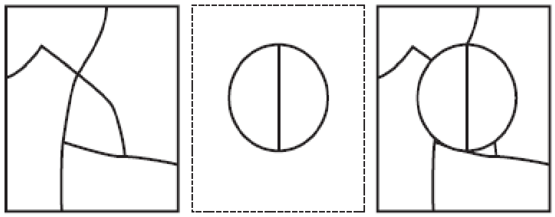
Append pieces together two adjacent layers into a single layer but does not remove the shared boundary between the layers.

Select creates a new layer (b) with selected features from the input layer (a).

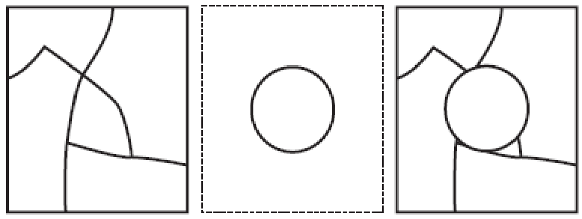
Select creates a new layer that contains features selected from a user-defined query expression. For example, we can create a layer showing high-canopy closure by selecting stands that have 60 to 80 percent closure from a stand layer.

Eliminate creates a new layer by removing features that meet a user-defined query expression. For example, Eliminate can implement the minimum mapping unit concept by removing polygons that are smaller than the defined unit in a layer.

Update uses a "cut and paste" operation to replace the input layer with the update layer and its features. As the name suggests, Update is useful for updating an existing layer with new features in limited areas.



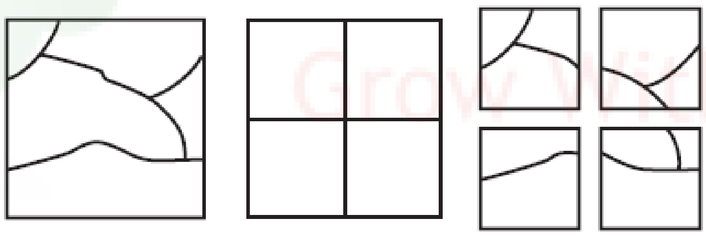
Update replaces the input layer with the update layer and its features.



Erase removes features from the input layer that fall within the area extent of the erase layer.

Erase removes from the input layer those features that fall within the area extent of the erase layer. Suppose a suitability analysis stipulates that potential sites cannot be within 300 meters of any stream. A stream buffer layer can be used in this case as the erase layer to remove itself from further consideration.

Split divides the input layer into two or more layers. A split layer, which shows area subunits, is used as the template for dividing the input layer. For example, a national forest can split a stand layer by district so that each district office can have its own layer.



Split uses the geometry of the split layer to divide the input layer into four separate layers.

RASTER DATA ANALYSIS:

The raster data model uses a regular grid to cover the space and the value in each grid cell to represent the characteristic of a spatial phenomenon at the cell location. This simple data structure of a raster with fixed cell locations not only is computationally efficient, but also facilitates a large variety of data analysis operations. This is why raster data are typically used in geographic information system (GIS), involving heavy computation such as building environmental models.

In contrast with vector data analysis, which uses points, lines, and polygons, raster data analysis uses cells and rasters. Raster data analysis can be performed at the level of individual cells, or groups of cells, or cells within an entire raster. Some raster data operations use a single raster; others use two or more rasters.

Data Analysis Environment:

Because a raster operation may involve two or more rasters, it is necessary to define the data analysis environment by specifying its area extent and output cell size. The area extent for analysis may correspond to a specific raster, or an area defined by its minimum and maximum x-, y-coordinates, or a combination of rasters. An analysis mask, either a feature layer or a raster, can also determine the area extent for analysis.

An analysis mask limits analysis to its area coverage. For example, to limit soil erosion analysis to only private lands, we can prepare a mask of either a feature layer showing private lands or a raster separating private lands (e.g., with a cell value of 1) from others (e.g., with a cell value of no data).

Local Operations:

Constituting the core of raster data analysis, local operations are cell-by-cell operations. A local operation can create a new raster from either a single input raster or multiple input rasters. The cell values of the new raster are computed by a function relating the input to the output or are assigned by a classification table.

Local Operations with a Single Raster:

Given a single raster as the input, a local operation computes each cell value in the output raster as a function of the cell value in the input raster at the same location. The function may involve a GIS tool, a mathematical operator, and/or a constant. A large number of mathematical operators are available in a GIS package.

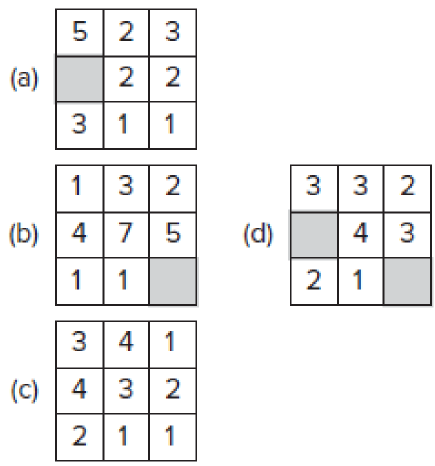
Reclassification:

A local operation, reclassification creates a new raster by classification. Reclassification is also referred to as recoding, or transforming, through lookup tables. Two reclassification methods may be used. The first method is a one-to-one change, meaning that a cell value in the input raster is assigned a new value in the output raster. For example, irrigated cropland in a land-use raster is assigned a value of 1 in the output raster. The second method assigns a new value to a range of cell values in the input raster. For example, cells with population densities between 0 and 25 persons per square mile in a population density raster are assigned a value of 1 in the output raster and so on. An integer raster can be reclassified by either method, but a floating-point raster can only be reclassified by the second method.

Reclassification serves three main purposes. First, reclassification can create a simplified raster. For example, instead of having continuous slope values, a raster can have 1 for slopes of 0 to 10 percent, 2 for 10 to 20 percent, and so on. Second, reclassification can create a new raster that contains a unique category or value such as slopes of 10 to 20 percent. Third, reclassification can create a new raster that shows the ranking of cell values in the input raster. For example, a reclassified raster can show the ranking of 1 to 5, with 1 being least suitable and 5 being most suitable.

Local Operations with Multiple Rasters:

Local operations with multiple rasters are also referred to as compositing, overlaying, or superimposing maps. Because local operations can work with multiple rasters, they are the equivalent of vector-based overlay operations. A greater variety of local operations have multiple input rasters than have a single input raster. Besides mathematical operators that can be used on individual rasters, other measures that are based on the cell values or their frequencies in the input rasters can also be derived and stored in the output raster. Some of these measures are, however, limited to rasters with numeric data. Summary statistics, including maximum, minimum, range, sum, mean, median, and standard deviation, are measures that apply to rasters with numeric data.



The cell value in (d) is the mean calculated from three input rasters (a, b, and c) in a local operation. The shaded cells have no data.

For example, above figure shows a local operation that calculates the mean from three input rasters. If a cell contains no data in one of the input rasters, the cell also carries no data in the output raster by default.

Some local operations do not involve statistics or computation. A local operation called Combine assigns a unique output value to each unique combination of input values. Suppose a slope raster has three cell values (0 to 20 percent, 20 to 40 percent, and greater than 40 percent slope), and an aspect raster has four cell values (north, east, south, and west aspects).

(a)

3	2	1
2	1	2
1	2	3

(b)

3	2	4
3	2	4
2	4	1

(c)

1	3	6
2	4	5
4	5	7

(d)

Combine code	1	2	3	4	5	6	7
(slope, aspect)	(3,3)	(2,3)	(2,2)	(1,2)	(2,4)	(1,4)	(3,1)

Each cell value in (c) represents a unique combination of cell values in (a) and (b). The combination codes and their representations are shown in (d).

The Combine operation creates an output raster with a value for each unique combination of slope and aspect, such as 1 for greater than 40 percent slope and the south aspect, 2 for 20 to 40 percent slope and the south aspect, and so on

Applications of Local Operations:

A change detection study of land cover, for example, can use the unique combinations produced by the Combine operation to trace the change of the land cover type. The land cover databases (2001, 2006, and 2011) from the U.S. Geological Survey (USGS)) are ideal for such a change detection study.

The Revised Universal Soil Loss Equation (RUSLE) uses six environmental factors in the equation:

A = R K L S C P, where

A is the predicted soil loss,

R is the rainfall–runoff erosivity factor,

K is the soil erodibility factor,

L is the slope length factor,

S is the slope steepness factor,

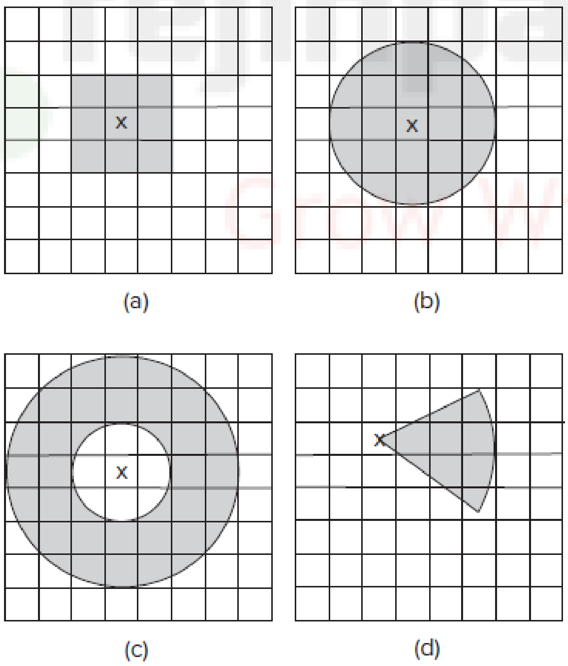
C is the crop management factor,

and P is the support practice factor.

With each factor prepared as an input raster, we can multiply the rasters in a local operation to produce the output raster of predicted soil loss.

Neighborhood Operations:

A neighborhood operation, also called a focal operation, involves a focal cell and a set of its surrounding cells. The surrounding cells are chosen for their distance and/or directional relationship to the focal cell. A required parameter for neighborhood operations is the type of neighborhood. Common neighbourhoods include rectangles, circles, annuluses, and wedges.



Four common neighborhood types: rectangle (a),circle (b), annulus (c), and wedge (d). The cell marked with an x is the focal cell.

A rectangle is defined by its width and height in cells, such as a 3-by-3 area centered at the focal cell. A circle extends from the focal cell with a specified radius. An annulus or doughnut-shaped neighborhood consists of the ring area between a smaller circle and a larger circle centered at the focal cell. And a wedge consists of a piece of a circle centered at the focal cell.

Applications of Neighborhood Operations:

An important application of neighborhood operations is data simplification. The moving average method, for instance, reduces the level of cell value fluctuation in the input raster. The method typically uses a 3-by-3 or a 5-by-5 rectangle as the neighborhood. As the neighborhood is moved from one focal cell to another, the average of cell values within the neighborhood is computed and assigned to the focal cell. The output raster of moving averages represents a generalization of the original cell values.

(a)

1	2	2	2	2
1	2	2	2	3
1	2	1	3	3
2	2	2	3	3
2	2	2	2	3

(b)

1.56	2.00	2.22
1.67	2.11	2.44
1.67	2.11	2.44

Neighborhood operations are common in image processing. These operations are variously called filtering, convolution, or moving window operations for spatial feature manipulation

Zonal Operations:

A zonal operation works with groups of cells of same values or like features. These groups are called zones. Zones may be contiguous or noncontiguous. A contiguous zone includes cells that are spatially connected, whereas a non-contiguous zone includes separate regions of cells. A watershed raster is an example of a contiguous zone, in which cells that belong to the same watershed are spatially connected. A land use raster is an example of a non-contiguous zone, in which one type of land use may appear in different parts of the raster.

Given two rasters in a zonal operation, one input raster and one zonal raster, a zonal operation produces an output raster, which summarize the cell values in the input raster for each zone in the zonal raster. The summary statistics and measures include area, minimum, maximum, sum, range, mean, standard deviation, median, majority, minority, and variety.

NETWORK:

A network is a system of linear features that has the appropriate attributes for the flow of objects. A road system is a familiar network. Other networks include railways, public transit lines, bicycle paths, and streams. A network is typically topology-based: lines meet at intersections, lines cannot have gaps, and lines have directions.

A link refers to a road segment defined by two end points. Also called edges or arcs, links are the basic geometric features of a network. Link impedance is the cost of traversing a link. A simple measure of the cost is the physical length of the link. But the length may not be a reliable measure of cost, especially in cities where speed limits and traffic conditions vary significantly along different streets.

A junction refers to a street intersection. A junction is also called a node. A turn is a transition from one street segment to another at a junction. Turn impedance is the time it takes to complete a turn, which is significant in a congested street network. Turn impedance is directional.

NETWORK ANALYSIS:

A network with the appropriate attributes can be used for a variety of applications. Some applications are directly accessible through GIS tools. Others require the integration of GIS and specialized software in operations research and management science.

Shortest Path Analysis:

Shortest path analysis finds the path with the minimum cumulative impedance between nodes on a network. Because the link impedance can be measured in distance or time, a shortest path may represent the shortest route or fastest route. Shortest path analysis typically begins with an impedance matrix in which a value represents the impedance of a direct link between two nodes on a network and an ∞ (infinity) means no direct connection. The problem is to find the shortest distances (least cost) from a node to all other nodes. A variety of algorithms can be used to solve the problem; among them, the most commonly used algorithm is the Dijkstra algorithm.

Dijkstra's Algorithm:

The idea of the algorithm is very simple.

1.It maintains a list of unvisited vertices.

2.It chooses a vertex (the source) and assigns a maximum possible cost (i.e. infinity) to every other vertex.

3.The cost of the source remains zero as it actually takes nothing to reach from the source vertex to itself.

4.In every subsequent step of the algorithm it tries to improve(minimize) the cost for each vertex. Here the cost can be distance, money or time taken to reach that vertex from the source vertex. The minimization of cost is a multi-step process.

a. For each unvisited neighbor (vertex 2, vertex 3, vertex 4) of the current vertex (vertex 1) calculate the new cost from the vertex (vertex 1).

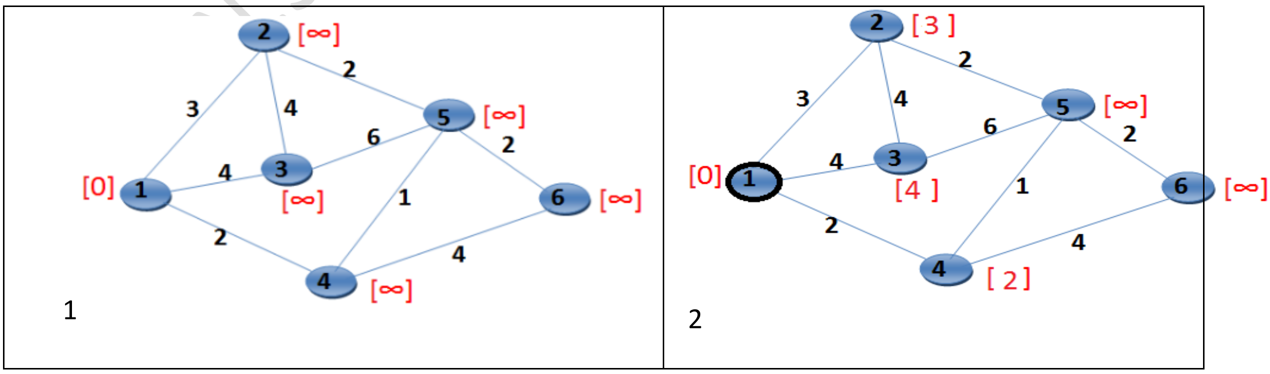
b. For e.g. the new cost of vertex 2 is calculated as the minimum of the two ((existing cost of vertex 2) or (sum of cost of vertex 1 + the cost of edge from vertex 1 to vertex 2))

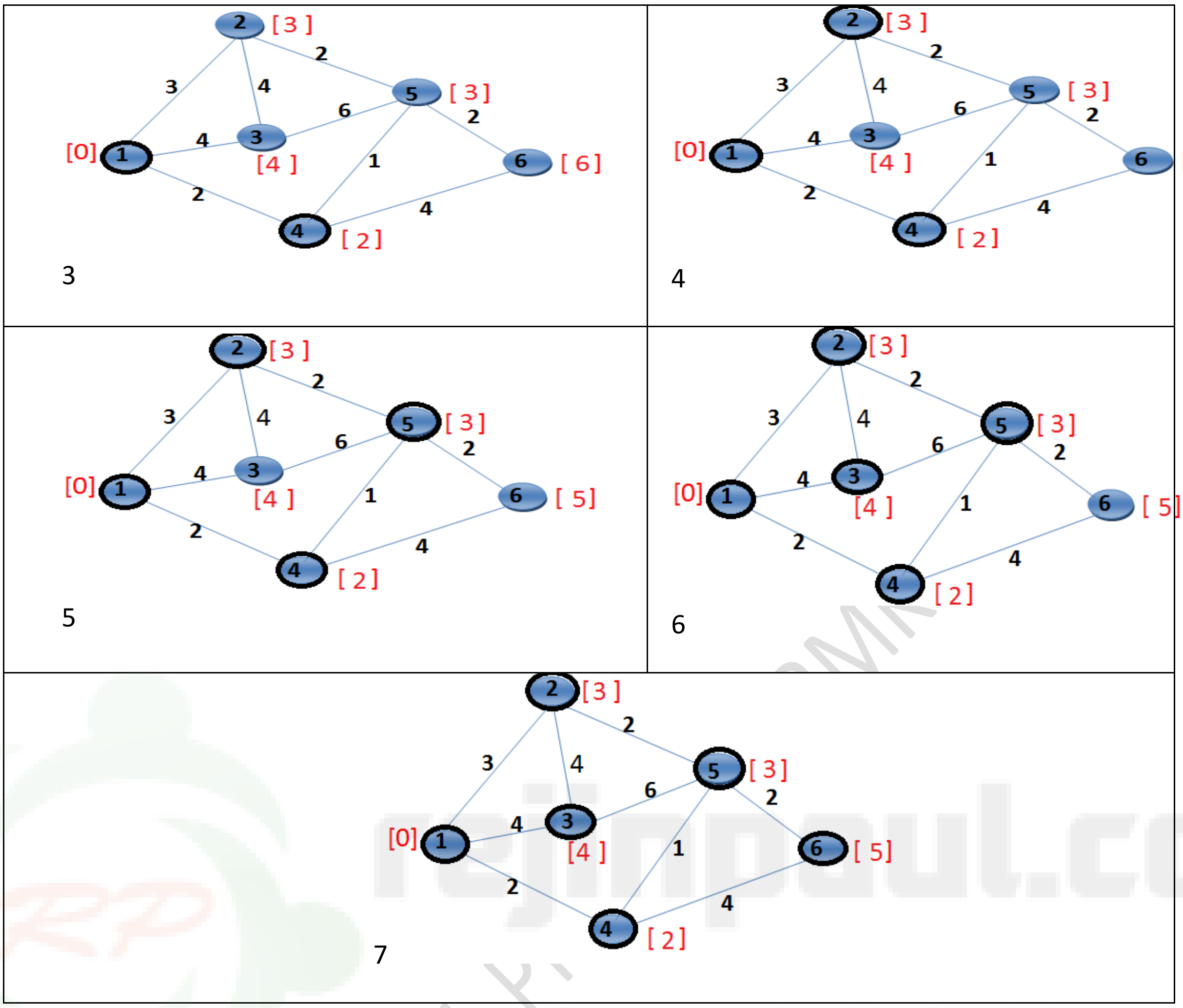
5.When all the neighbors of the current node are considered, it marks the current node as visited and is removed from the unvisited list.

6.Select a vertex from the list of unvisited nodes (which has the smallest cost) and repeat step 4.

7.At the end there will be no possibilities to improve it further and then the algorithm ends

Example:





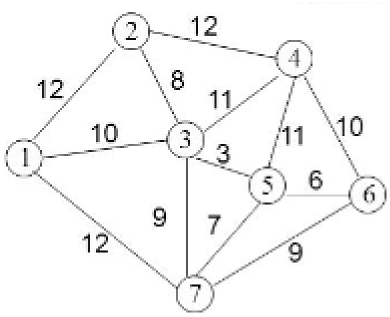
Traveling Salesman Problem:

The traveling salesman problem is a routing problem, which stipulates that the salesman must visit each of the select stops only once, and the salesman may start from any stop but must return to the original stop. The objective is to determine which route, or tour, the salesman can take to minimize the total impedance value. A common solution to the travelling salesman problem uses a heuristic method.

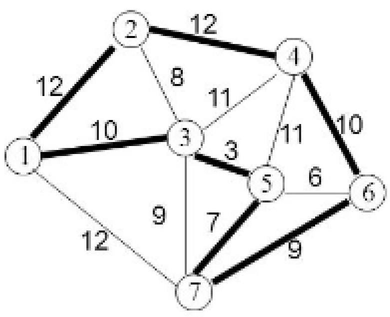
Algorithm:

Let us consider a graph G = (V, E), where V is a set of cities and E is a set of weighted edges. An edge e(u, v) represents that vertices u and v are connected. Distance between vertex u and v is d(u, v), which should be non-negative.

1. Select the source node.
2. Mark the current node as selected and compute the distance to all its adjacent nodes.
3. Choose the adjacent node with minimum distance.
4. Repeat the steps 2 and 3 till all the nodes as marked as selected.



Source node=1



The Hamilton path

Vehicle Routing Problem:

The vehicle routing problem is an extension of the traveling salesman problem. Given a fleet of vehicles and customers, the main objective of the vehicle routing problem is to schedule vehicle routes and visits to customers in such a way that the total travel time is minimized. Additional constraints such as time windows, vehicle capacity, and dynamic conditions (e.g., traffic congestion) may also exist. Because vehicle routing involves complex modeling applications, it requires the integration of GIS and special routing software in operations research and management science.

Closest Facility:

Closest facility is a network analysis that finds the closest facility among candidate facilities to any location on a network. The analysis first computes the shortest paths from the select location to all candidate facilities, and then chooses the closest facility among the candidates. A couple of options may be applied to the closest facility problem. First, rather than getting a single facility, the user may ask for a number of closest facilities. Second, the user may specify a search radius in distance or travel time, thus limiting the candidate facilities.

Allocation:

Allocation is the study of the spatial distribution of resources through a network. Resources in allocation studies often refer to public facilities, such as fire stations, schools, hospitals, and even open spaces (in case of earthquakes). Because the distribution of the resources defines the extent of the service area, the main objective of spatial allocation analysis is to measure the efficiency of these resources.

DIGITAL ELEVATION MODEL:

DEMs are a primary data source for terrain mapping and analysis. A traditional method for producing DEMs is to use a stereoplotter and stereo pairs of aerial photographs (i.e., pairs of aerial photographs of the same area taken from slightly different positions to produce the 3-D effect). The stereoplotter creates a 3-D model, allowing the operator to compile elevation data. Although this method can produce highly accurate DEM data, it requires experienced operators and is time-consuming. Another traditional method is to interpolate a DEM from the contour lines of a topographic map.

Several new techniques for DEM generation have been developed in recent years. The main techniques are using optical sensors, interferometric synthetic aperture radar (InSAR), and light detection and ranging (LiDAR).

Optical Sensors:

To make DEMs, two or more optical satellite images of the same area taken from different directions are needed. These stereo images should be taken within a short time interval so that their spectral signatures do not differ significantly. Two optical sensors that readily meet the requirement are Terra ASTER and SPOT 5. ASTER provides a nadir view and a backward view within a minute, and the HRS (High Resolution Sensor) carried on SPOT 5 provides a forward view and a backward view along its orbit. ASTER DEMs have a spatial resolution of 30 meters. Airbus Defence and Space distributes SPOT 5 DEMs with a spatial resolution of 20 meters. DEMs can also be generated from very high resolution satellite images such as World-View images as long as stereo pairs are available

InSAR:

InSAR uses two or more SAR images to generate elevations of the reflective surface, which may be vegetation, man-made features, or bare ground. SRTM (Shuttle Radar Topography Mission) DEMs, for example, are derived from SAR data collected by two radar antennas placed on the Space Shuttle in 2000. SRTM DEMs cover over 80 percent of the landmass of the Earth between 60° N and 56° S.

LiDAR:

The basic components of a LiDAR system include a laser scanner mounted in an aircraft, GPS, and an Inertial Measurement Unit (IMU). The laser scanner has a pulse generator, which emits rapid laser pulses (0.8 — 1.6 μm wavelength) over an area of interest, and a receiver, which gets scattered and reflected pulses from targets. Using the time lapse of the pulse, the distance (range) between the scanner and the target can be calculated. At the same time, the location and orientation of the aircraft are measured by the GPS and IMU, respectively. The target location in a three dimensional space can therefore be determined by using the information obtained by the LiDAR system. A major application of LiDAR technology is the creation of high resolution DEMs, with a spatial resolution of 0.5 to 2 meters.

Application of Digital Elevation Model:

- DEMs have many applications in remote sensing and mapping, such as topographic mapping (contours), thematic mapping, orthoimage generation and image analysis, map revision, and so on.
- DEMs are important in providing valuable geological information that can be used as a guide in defining the geology of a given area. Geological structures and rock unit boundaries showing a strong correlation with relief can be mapped with detailed topographic analysis.
- DEMs are used to extract information relevant to ground water studies such as potential areas or groundwater recharge or contamination.

3D DATA COLLECTION AND UTILIZATION:

3D GIS brings enhanced depth into data collection and analysis by incorporating a z-value into mapping. Most commonly, that means including elevation data, but users have many options for adding layers of information. For instance, a map might include a dimension based on the concentrations of certain chemicals and minerals or which parcels of land are best suited for development. Working with three dimensions, GIS professionals can often apply their findings to address real-world issues with greater accuracy. While 3D models are more difficult to create and maintain than 2D ones, there are many 3D GIS applications where this technology is greatly beneficial.

These four examples demonstrate how an investment in 3D GIS modeling can generate added value:

City Planning:

Cities have a way of growing to encompass previously under- or undeveloped areas in a process often called urbanization or urban sprawl. There are many reasons behind urban sprawl, including a desire to build improved infrastructure, affordable land or tax rates, or overcrowding inside the city. Urban sprawl can have a major impact on people who decide to leave the city as well as those who remain. For example, as residents move farther away from the city center, infrastructure such as roads or public transportation systems must accommodate their commutes, and traffic can lead to higher rates of air pollution. To minimize the negative impacts of urban sprawl and increased development, it's important for city planners to carefully determine the best way to grow urban areas.

3D GIS software can help city planners visualize what their proposed changes will look like and predict the outcomes for current residents and future generations. The wide range of integrated information allowed architects, planning engineers and others to collaborate effectively. As the district develops further, the 3D model will help future planners with energy and environmental modeling and guide public participation initiatives.

Building Information Modeling:

Building information modeling (BIM) is a technology that generates digital representations of facilities and relevant processes. BIM has given facilities managers the ability to closely review structures, beginning with the construction planning phase. Used in conjunction with 3D GIS data, BIM can help create robust building management plans and allow for more detailed analysis. For example, before breaking ground on a construction project, stakeholders can review findings from GIS and BIM to draw conclusions about environmental impact, sustainability, disaster readiness and how to optimize the use of assets and space. BIM and 3D GIS can also come together to support the preservation and restoration of historical buildings.

Coastal Modeling and Analysis:

A nation's coastline is a crucial gateway for imports and exports, and about 40 percent of the world's population lives within 60 miles of a coast. But these areas also pose numerous challenges for development. Its critical for planners to understand the factors that affect construction and maintenance for shipping ports, fisheries, mineral mining operations and wilderness preservation areas. Responsible coastal development must be informed by underwater topography, local vegetation and predictions for the long-term environmental impact. Resource planning systems that draw on GIS can provide insights into the economic, environmental and cultural results of activities along the coast. The right data makes all the difference in sustainably performing operations like construction or excavation.

Wind Farm Assessment:

Planning a wind farm requires a detailed analysis of an environment and the potential effects of the structures. By using 3D GIS modeling, planners and other stakeholders can get a better idea of the impact from wind farm development on wildlife and people. For example, when assessing possible wind farm locations in two dimensions, a bird's migratory path might make a location seem inaccessible. However, reviewing that same space using 3D GIS data, may reveal that the elevation of birds' flight paths and the height of the wind farm are compatible.

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