UNIT 1: DIGITAL IMAGE PROCESSING I

1.1 Remote Sensing Data Types

Assorted satellites with numerous sensors, each one was designed with a specific purpose. With optical sensors, the design focuses on the spectral bands to be collected. With radar imaging, the incidence angle and microwave band used plays an important role in defining which applications the sensor is best suited for. Each application itself has specific demands, for spectral resolution, spatial resolution, and temporal resolution.

The types of remote sensing data vary but each plays a significant role in the ability to analyze an area from some distance away. The first way to gather remote sensing data is through radar. Its most important uses are for air traffic control and the detection of storms or other potential disasters. In addition, Doppler radar is a common type of radar used in detecting meteorological data but is also used by law enforcement to monitor traffic and driving speeds. Other types of radar are also used to create digital models of elevation.

Another type of remote sensing data comes from lasers. These are often used in conjunction with radar altimeters on satellites to measure things like wind speeds and their direction and the direction of ocean currents. These altimeters are also useful in seafloor mapping in that they are capable of measuring bulges of water caused by gravity and the varied seafloor topography. These varied ocean heights can then be measured and analyzed to create seafloor maps.

Also common in remote sensing is LIDAR - Light Detection and Ranging. This is most famously used for weapons ranging but can also be used to measure chemicals in the atmosphere and heights of objects on the ground.

Other types of remote sensing data include stereographic pairs created from multiple air photos (often used to view features in 3-D and/or make topographic maps), radiometers and photometers which collect emitted radiation common in infra-red photos, and air photo data obtained by earth-viewing satellites such as those found in the Landsat program.

1.1.1 Multiple sources of information

Each band of information collected from a sensor contains important and unique data. We know that different wavelengths of incident energy are affected differently by each target -they are absorbed, reflected or transmitted in different proportions. The appearance of targets can easily change over time, sometimes within seconds. In many applications, using information from several different sources ensures that target identification or information extraction is as accurate as possible. The following describe ways of obtaining far more information about a target or area, than with one band from a sensor.

1.1.1.1 Multispectral

The use of multiple bands of spectral information attempts to exploit different and independent "views" of the targets so as to make their identification as confident as possible. Studies have been conducted to determine the optimum spectral bands for analyzing specific targets, such as insect damaged trees.

1.1.1.2 Multisensor

Different sensors often provide complementary information, and when integrated together, can facilitate interpretation and classification of imagery. Examples include combining high resolution panchromatic imagery with coarse resolution multispectral imagery, or merging actively and passively sensed data. A specific example is the integration of SAR imagery with multispectral imagery. SAR data adds the expression of surficial topography and relief to an otherwise flat image. The multispectral image contributes meaningful colour information about the composition or cover of the land surface. This type of image is often used in geology, where lithology or mineral composition is represented by the spectral component, and the structure is represented by the radar component.

1.1.1.3 Multitemporal

Information from multiple images taken over a period of time is referred to as multitemporal information. Multitemporal may refer to images taken days, weeks, or even years apart. Monitoring land cover change or growth in urban areas requires images from different time periods. Calibrated data, with careful controls on the quantitative aspect of the spectral or backscatter response, is required for proper monitoring activities. With uncalibrated data, a classification of the older image is compared to a classification from the recent image, and changes in the class boundaries are delineated. Another valuable multitemporal tool is the observation of vegetation phenology (how the vegetation changes throughout the growing season), which requires data at frequent intervals throughout the growing season.

"Multitemporal information" is acquired from the interpretation of images taken over the same area, but at different times. The time difference between the images is chosen so as to be able to monitor some dynamic event. Some catastrophic events (landslides, floods, fires, etc.) would need a time difference counted in days, while much slower-paced events (glacier melt, forest regrowth, etc.) would require years. This type of application also requires consistency in illumination conditions (solar angle or radar imaging geometry) to provide consistent and comparable classification results.

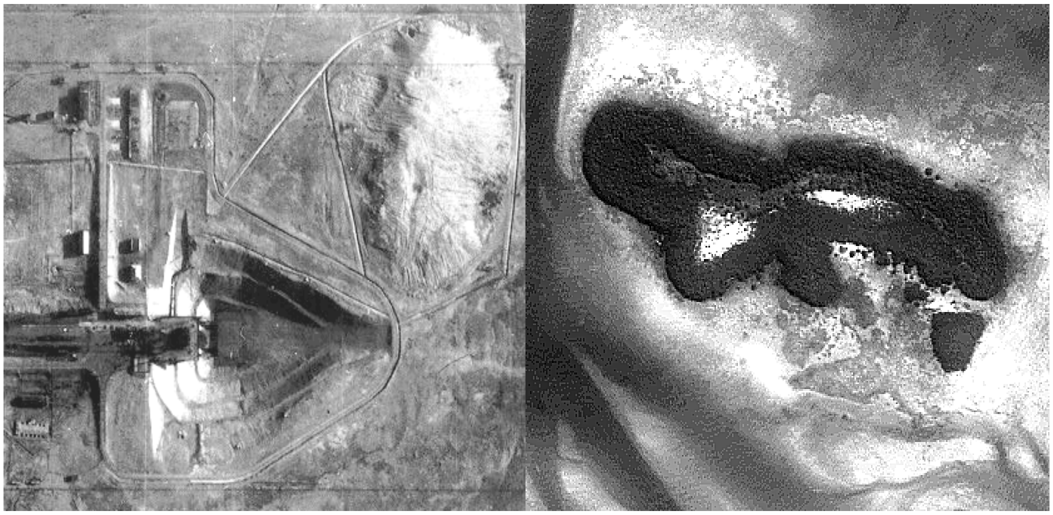
The ultimate in critical (and quantitative) multi-temporal analysis depends on calibrated data. Only by relating the brightness seen in the image to physical units, can the images be precisely compared, and thus the nature and magnitude of the observed changes be determined.

1.2 Elements of Image Interpretation

As we noted in the previous section, analysis of remote sensing imagery involves the identification of various targets in an image, and those targets may be environmental or artificial features which consist of points, lines, or areas. Targets may be defined in terms of the way they reflect or emit radiation. This radiation is measured and recorded by a sensor, and ultimately is depicted as an image product such as an air photo or a satellite image.

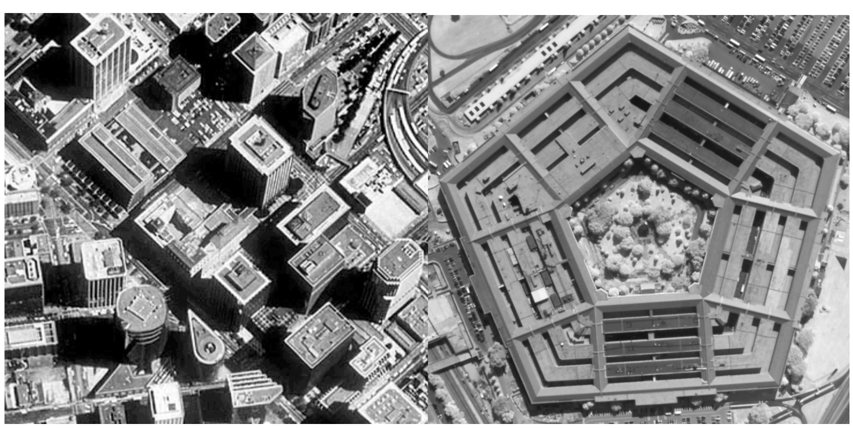
What makes interpretation of imagery more difficult than the everyday visual interpretation of our surroundings? For one, we lose our sense of depth when viewing a two-dimensional image, unless we can view it stereoscopically so as to simulate the third dimension of height. Indeed, interpretation benefits greatly in many applications when images are viewed in stereo, as visualization (and therefore, recognition) of targets is enhanced dramatically. Viewing objects from directly above also provides a very different perspective than what we are familiar with. Combining an unfamiliar perspective with a very different scale and lack of recognizable detail can make even the most familiar object unrecognizable in an image. Finally, we are used to seeing only the visible wavelengths, and the imaging of wavelengths outside of this window is more difficult for us to comprehend.

Recognizing targets is the key to interpretation and information extraction. Observing the differences between targets and their backgrounds involves comparing different targets based on any, or all, of the visual elements of tone, shape, size, pattern, texture, shadow, and association. Visual interpretation using these elements is often a part of our daily lives, whether we are conscious of it or not. Examining satellite images on the weather report, or following high speed chases by views from a helicopter are all familiar examples of visual image interpretation. Identifying targets in remotely sensed images based on these visual elements allows us to further interpret and analyze. The nature of each of these interpretation elements is described below, along with an image example of each.



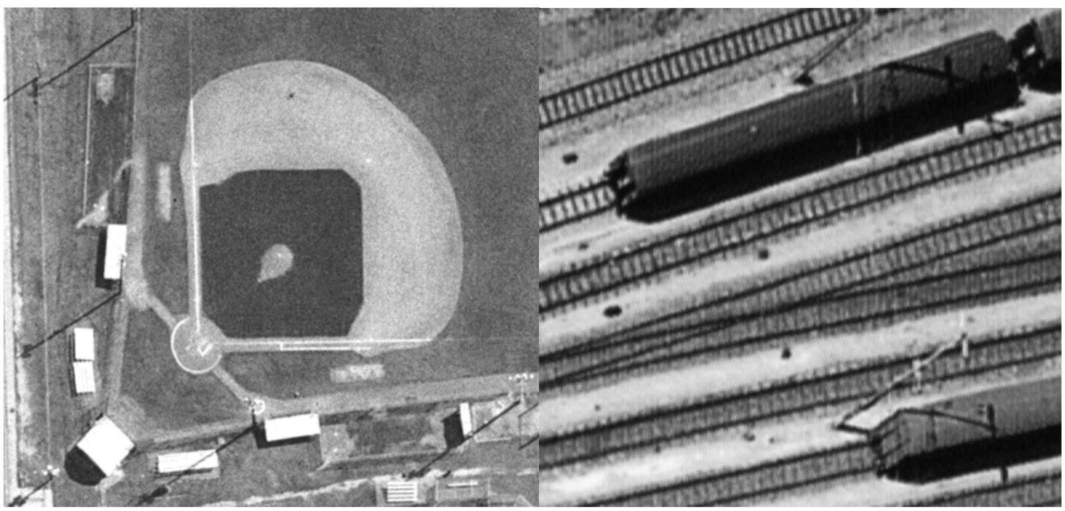
1.2.1 Tone

It refers to the relative brightness or colour of objects in an image. Generally, tone is the fundamental element for distinguishing between different targets or features. Tone can be defined as each distinguishable variation from white to black. Color may be defined as each distinguishable variation on an image produced by a multitude of combinations of hue, value and chroma. Many factors influence the tone or color of objects or features recorded on photographic emulsions. But, if there is not sufficient contrast between an object and its background to permit at least detection, there can be no identification. While a human eye may only be able to distinguish between ten and twenty shades of grey; interpreters can distinguish many more colors. Some authors state that interpreters can distinguish at least 100 times more variations of color on color photography than shades of gray on black and white photography.



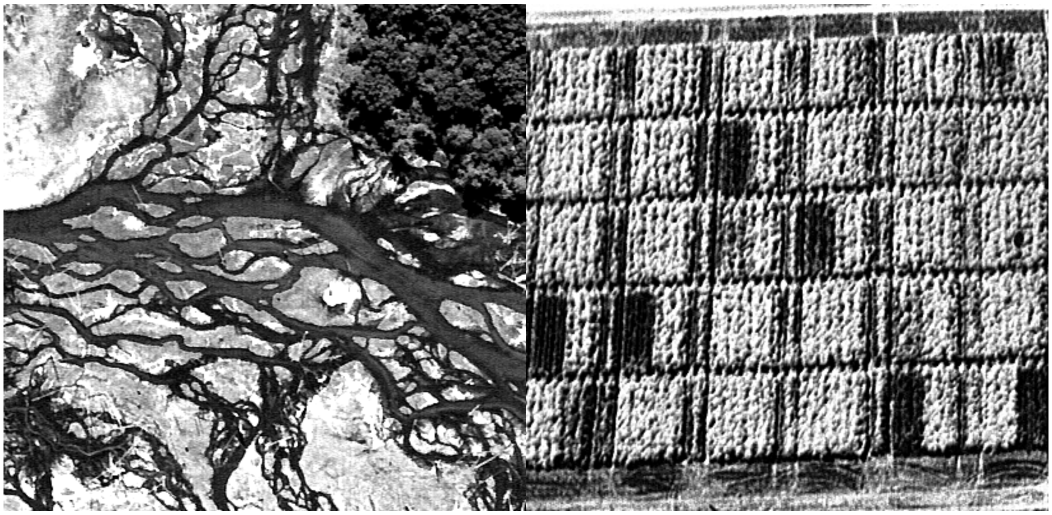
1.2.2 Shape & Height

Shape refers to the general form, structure, or outline of individual objects. Shape can be a very distinctive clue for interpretation. Straight edge shapes typically represent urban or agricultural (field) targets, while natural features, such as forest edges, are generally more irregular in shape, except where man has created a road or clear cuts. Farm or crop land irrigated by rotating sprinkler systems would appear as circular shapes. Height can add significant information in many types of interpretation tasks; particularly those that deal with the analysis of man-made features. How tall a tree is can tell something about board feet. How deep an excavation is can tell something about the amount of material that was removed.



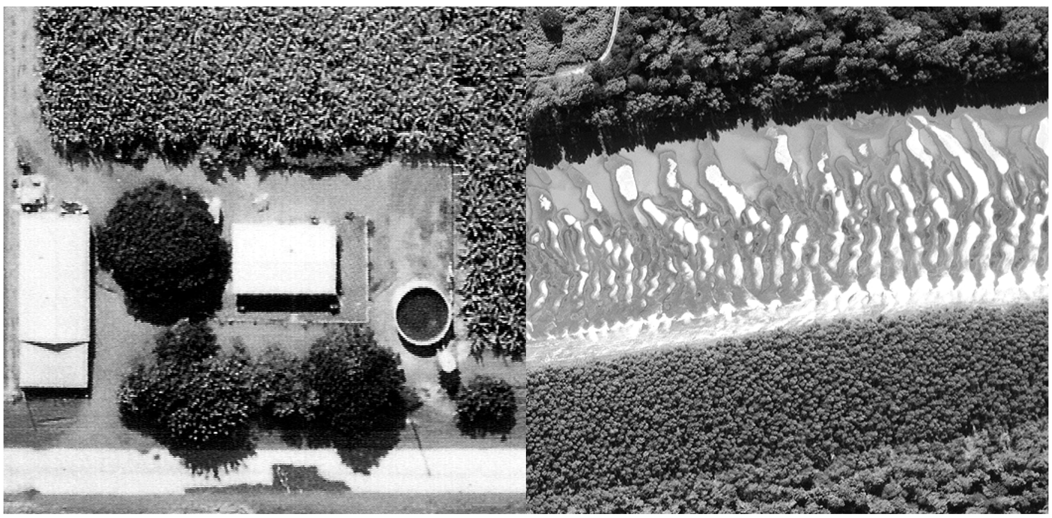
1.2.3 Size

***Size** of objects in an image is a function of scale. It is important to assess the size of a target relative to other objects in a scene, as well as the absolute size, to aid in the interpretation of that target. A quick approximation of target size can direct interpretation to an appropriate result more quickly. For example, if an interpreter had to distinguish zones of land use, and had identified an area with a number of buildings in it, large buildings such as factories or warehouses would suggest commercial property, whereas small buildings would indicate residential use.*



1.2.4 Pattern

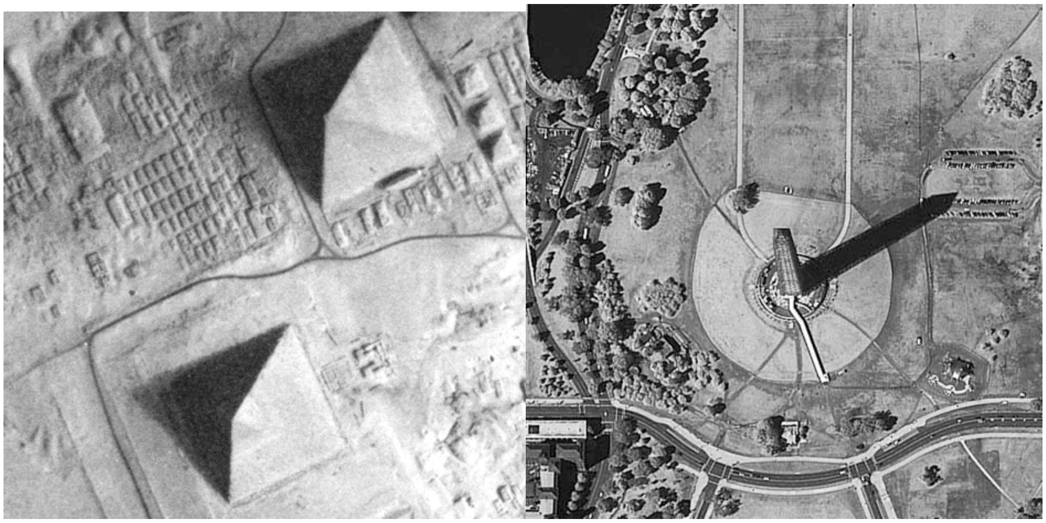
Pattern *refers to the spatial arrangement of visibly discernible objects. Typically an orderly repetition of similar tones and textures will produce a distinctive and ultimately recognizable pattern. Orchards with evenly spaced trees, and urban streets with regularly spaced houses are good examples of pattern.*



1.2.5 Texture

Texture *refers to the arrangement and frequency of tonal variation in particular areas of an image. Rough textures would consist of a mottled tone where the grey levels change abruptly in a small area, whereas smooth textures would have very little tonal variation.*

Smooth textures are most often the result of uniform, even surfaces, such as fields, asphalt, or grasslands. A target with a rough surface and irregular structure, such as a forest canopy, results in a rough textured appearance. Texture is one of the most important elements for distinguishing features in radar imagery.



1.2.6 Shadow

Shadow *is also helpful in interpretation as it may provide an idea of the profile and relative height of a target or targets which may make identification easier. However, shadows can also reduce or eliminate interpretation in their area of influence, since targets within shadows are much less (or not at all) discernible from their surroundings. Shadow is also useful for enhancing or identifying topography and landforms, particularly in radar imagery.*

1.2.7 Association, Resolution and Site

Associations *of some objects are so commonly associated with one another that identification of one tends to indicate or confirm the existence of another. Smoke stacks, step buildings, cooling ponds, transformer yards, coal piles, railroad tracks = coal fired power plant. Arid terrain, basin bottom location, highly reflective surface, sparse vegetation = playa. Association is one of the most helpful clues in identifying man made installations. Aluminum manufacture requires large amounts of electrical energy. Absence of a power supply may rule out this industry. Cement plants have rotary kilns. Schools at different levels typically have characteristic playing fields, parking lots, and clusters of buildings in urban areas. Large farm silos typically indicate the presence of livestock.*

Resolution *is defined as the ability of the entire photographic system, including lens, exposure, processing, and other factors, to render a sharply defined image. An object or feature must be resolved to be detected and/or identified. Resolution is one of the most difficult concepts to address in image analysis. Resolution can be described for systems in terms of modulation transfer (or point spread) functions; or it can be discussed for camera lenses in terms of being able to resolve so many line pairs per millimeter. There are resolution targets that help to determine this when testing camera lenses for metric quality. Photo interpreters often talk about resolution in terms of ground resolved distance, the smallest normal contrast object that can be detected and identified on a photo.*

Site *shows us objects are arranged with respect to one another; or with respect to various terrain features, can be an aid in interpretation. Aspect, topography, geology, soil, vegetation and cultural features on the landscape are distinctive factors that the interpreter should use when examining a site. The relative importance of each of these factors will vary with local conditions, but all are important. Just as some vegetation grows in swamps others grow on sandy ridges. Agricultural crops may like certain conditions. Man made features may also be found on rivers (e.g. power plant) or on a hill top (observatory or radar facility).*

1.3 Image rectification and corrections

Digital image processing may involve numerous procedures including formatting and correcting of the data, digital enhancement to facilitate better visual interpretation, or even automated classification of targets and features entirely by computer. In order to process remote sensing imagery digitally, the data must be recorded and available in a digital form suitable for storage on a computer tape or disk. Obviously, the other requirement for digital image processing is a computer system, sometimes referred to as an image analysis system, with the appropriate hardware and software to process the data. Several commercially available software systems have been developed specifically for remote sensing image processing and analysis.

For discussion purposes, most of the common image processing functions available in image analysis systems can be categorized into the following four categories:

1 *Preprocessing*

2 *Image Enhancement*

3 *Image Transformation*

4 *Image Classification and Analysis*

1.3.1 Colour Composites

While displaying the different bands of a multispectral data set, images obtained in different bands are displayed in image planes (other than their own) the color composite is regarded as False Color Composite (FCC). High spectral resolution is important when producing color components. For a true color composite an image data used in red, green and blue spectral region must be assigned bits of red, green and blue image processor frame buffer memory. A color infrared composite 'standard false color composite' is displayed by placing the infrared, red, green in the red, green and blue frame buffer memory. In this healthy vegetation shows up in shades of red because vegetation absorbs most of green and red energy but reflects approximately half of *incident Infrared energy. Urban areas reflect equal portions of NIR, R & G, and therefore they appear as steel grey.*

1.3.2 Image Rectification

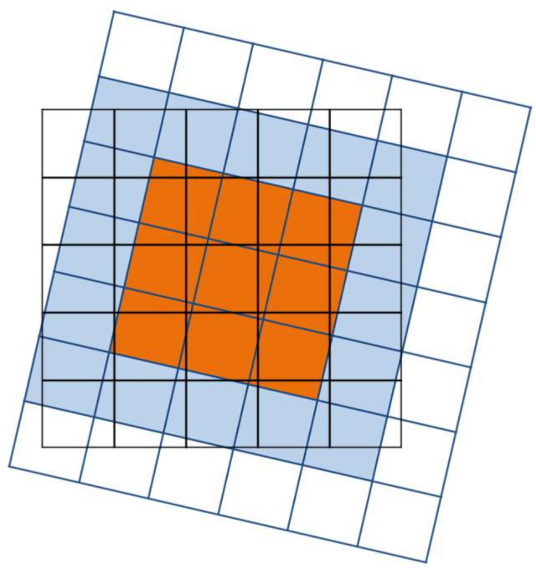
Geometric distortions manifest themselves as errors in the position of a pixel relative to other pixels in the scene and with respect to their absolute position within some defined map projection. If left uncorrected, these geometric distortions render any data extracted from the image useless. This is particularly so if the information is to be compared to other data sets, be it from another image or a GIS data set. Distortions occur for many reasons.

For instance distortions occur due to changes in platform attitude (roll, pitch and yaw), altitude, earth rotation, earth curvature, panoramic distortion and detector delay. Most of these distortions can be modelled mathematically and are removed before you buy an image. Changes in attitude however can be difficult to account for mathematically and so a procedure called image rectification is performed. Satellite systems are however geometrically quite stable and geometric rectification is a simple procedure based on a mapping transformation relating real ground coordinates, say in easting and northing, to image line and pixel coordinates.

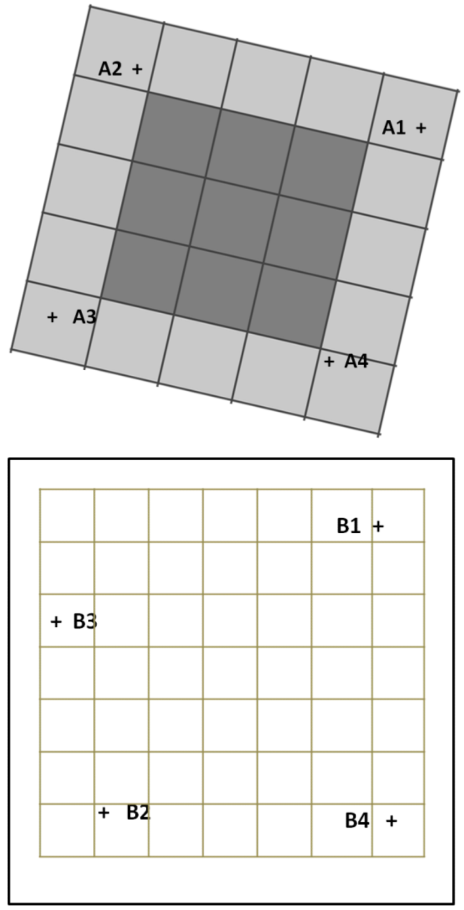
Rectification is a process of geometrically correcting an image so that it can be represented on a planar surface, conform to other images or conform to a map. That is, it is the process by which geometry of an image is made planimetric. It is necessary when accurate area, distance and direction measurements are required to be made from the imagery. It is achieved by transforming the data from one grid system into another grid system using a geometric transformation.

Rectification is not necessary if there is no distortion in the image. For example, if an image file is produced by scanning or digitizing a paper map that is in the desired projection system, then that image is already planar and does not require rectification unless there is some skew or rotation of the image. Scanning and digitizing produce images that are planar, but do not contain any map coordinate information. These *images need only to be geo-referenced, which is a much simpler process than rectification. In many cases, the image header can simply be updated with new map coordinate information. This involves redefining the map coordinate of the upper left corner of the image and the cell size (the area represented by each pixel).*

Ground Control Points (GCP) are the specific pixels in the input image for which the output map coordinates are known. By using more points than necessary to solve the transformation equations a least squares solution may be found that minimises the sum of the squares of the errors. Care should be exercised when selecting ground control points as their number, quality and distribution affect the result of the rectification.



The geometric registration process involves identifying the image coordinates (i.e. row, column) of several clearly discernible points, called ground control points (or GCPs), in the distorted image (A - A1 to A4), and matching them to their true positions in ground coordinates (e.g. latitude, longitude).



In order to actually geometrically correct the original distorted image, a procedure called resampling is used to determine the digital values to place in the new pixel locations of the corrected output image. The resampling process calculates the new pixel values from the original digital pixel values in the uncorrected image. There are three common methods for resampling: nearest neighbour, bilinear interpolation, and cubic convolution.

Nearest Neighbor: *Each output cell value in the nearest neighbor method is the unmodified value from the closest input cell. Less computation is involved than in the other methods, leading to a speed advantage for large input rasters. Preservation of the original cell values can also be an advantage if the resampled raster will be used in later quantitative analysis, such as automatic classification. However, nearest neighbor resampling can cause feature edges to be offset by distances up to half of the input cell* *size. If the raster is resampled to a different cell size, a blocky appearance can result from the duplication (smaller output cell size) or dropping (larger cell size) of input cell values.*

Bilinear Interpolation: *An output cell value in the bilinear interpolation method is the weighted average of the four closest input cell values, with weighting factors determined by the linear distance between output and input cells. This method produces a smoother appearance than the nearest neighbor approach, but it can diminish the contrast and sharpness of feature edges. It works best when you are resampling to a smaller output cell size.*

Cubic Convolution: *The cubic convolution method calculates an output cell value from a 4 x 4 block of surrounding input cells. The output value is a distance- weighted average, but the weight values vary as a nonlinear function of distance. This method produces sharper, less blurry images than bilinear interpolation, but it is the most computationally intensive resampling method. It is the preferred method when resampling to a larger output cell size.*

Nearest neighbor resampling is the only method that is appropriate for categorical rasters, such as class rasters produced by the Automatic Classification process. Cell values in these rasters are merely arbitrary labels without numerical significance, so mathematical combinations of adjacent cell values have no meaning.

1.4 Image Classification

The overall objective of image classification is to automatically categorize all pixels in an image into land cover classes or themes. Normally, multispectral data are used to perform the classification, and the spectral pattern present within the data for each pixel is used as numerical basis for categorization. That is, different feature types manifest different combination of DNs based on their inherent spectral reflectance and emittance properties.

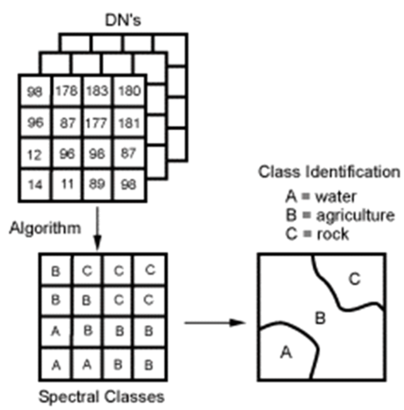
The term classifier refers loosely to a computer program that implements a specific procedure for image classification. Over the years scientists have devised many *classification strategies. From these alternatives the analyst must select the classifier that will best accomplish a specific task.*

The traditional methods of classification mainly follow two approaches: unsupervised and supervised. The unsupervised approach attempts spectral grouping that may have an unclear meaning from the user's point of view. Having established these, the analyst then tries to associate an information class with each group. The unsupervised approach is often referred to as clustering and results in statistics that are for spectral, statistical clusters. In the supervised approach to classification, the image analyst supervises the pixel categorization process by specifying to the computer algorithm; numerical descriptors of the various land cover types present in the scene. To do this, representative sample sites of known cover types, called training areas or training sites, are used to compile a numerical interpretation key that describes the spectral attributes for each feature type of interest. Each pixel in the data set is then compared numerically to each category in the interpretation key and labeled with the name of the category it looks most like. In the supervised approach the user defines useful information categories and then examines their spectral separability whereas in the unsupervised approach he first determines spectrally separable classes and then defines their informational utility.

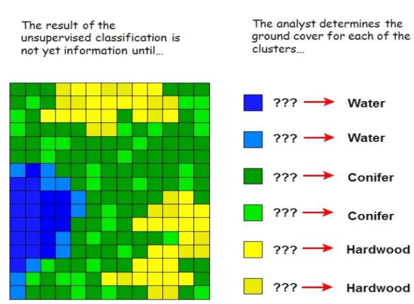
It has been found that in areas of complex terrain, the unsupervised approach is preferable to the supervised one. In such conditions if the supervised approach is used, the user will have difficulty in selecting training sites because of the variability of spectral response within each class. Consequently, a prior ground data collection can be very time consuming. Also, the supervised approach is subjective in the sense that the analyst tries to classify information categories, which are often composed of several spectral classes whereas spectrally distinguishable classes will be revealed by the unsupervised approach, and hence ground data collection requirements may be reduced. Additionally, the unsupervised approach has the potential advantage of revealing discriminable classes unknown from previous work. However, when definition of representative training areas is possible and statistical information classes show a close correspondence, the results of supervised classification will be superior to unsupervised classification.

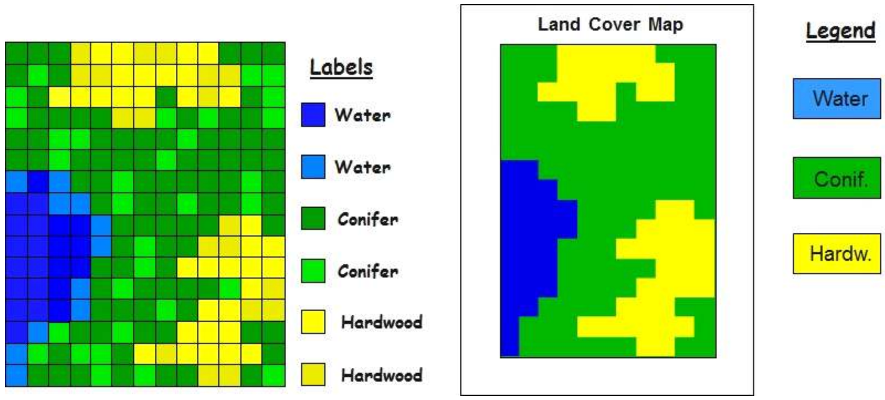
1.4.1 Unsupervised classification

Unsupervised classifiers do not utilize training data as the basis for classification. Rather, this family of classifiers involves algorithms that examine the unknown pixels in an image and aggregate them into a number of classes based on the natural groupings or clusters present in the image values. It performs very well in cases where the values within a given cover type are close together in the measurement space, data in different classes are comparatively well separated.



The classes that result from unsupervised classification are spectral classes because they are based solely on the natural groupings in the image values, the identity of the spectral classes will not be initially known. The analyst must compare the classified data with some form of reference data (such as larger scale imagery or maps) to determine the identity and informational value of the spectral classes. In the supervised approach we define useful information categories and then examine their spectral separability; in the unsupervised approach we determine spectrally separable classes and then define their informational utility.





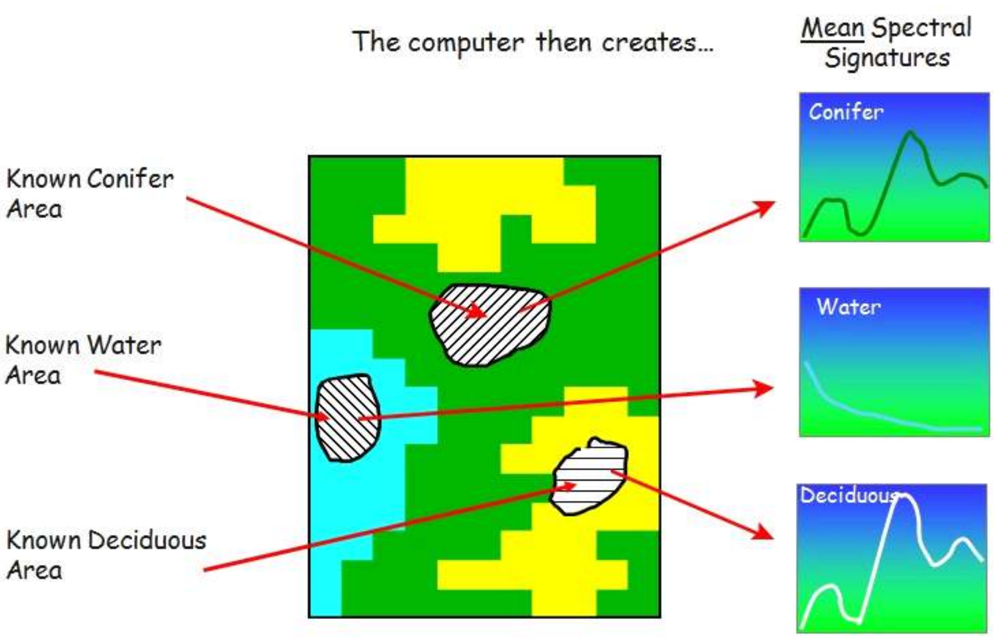
There are numerous clustering algorithms that can be used to determine the natural spectral groupings present in data set. One common form of clustering, called the "K-means" approach also called as ISODATA (Interaction Self-Organizing Data Analysis Technique) accepts from the analyst the number of clusters to be located in the data. The algorithm then arbitrarily "seeds", or locates, that number of cluster centers in the multidimensional measurement space. Each pixel in the image is then assigned to the cluster whose arbitrary mean vector is closest. After all pixels have been classified in this manner, revised mean vectors for each of the clusters are computed. The revised means are then used as the basis of reclassification of the image data. The procedure continues until there is no significant change in the location of class mean vectors between successive iterations of the algorithm. Once this point is reached, the analyst determines the land cover identity of each spectral class. Because the K-means approach is iterative, it is computationally intensive. Therefore, it is often applied only to image sub-areas rather than to full scenes.

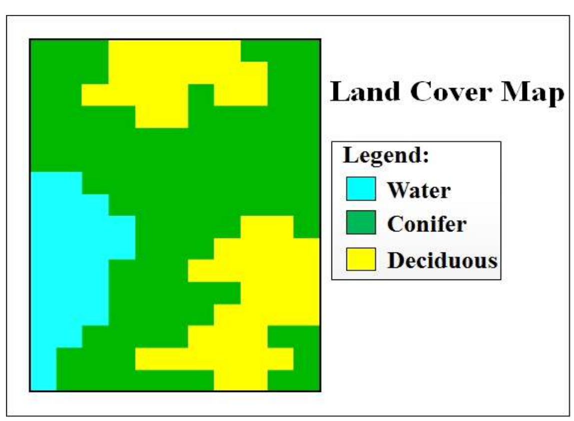
1.4.2 Supervised classification

Supervised classification can be defined normally as the process of samples of known identity to classify pixels of unknown identity. Samples of known identity are those pixels located within training areas. Pixels located within these areas term the training samples used to guide the classification algorithm to assigning specific spectral values to appropriate informational class.

1.4.2.1 Training data

Training fields are areas of known identity delineated on the digital image, usually by specifying the corner points of a rectangular or polygonal area using line and column numbers within the coordinate system of the digital image. The analyst must, of course, know the correct class for each area. Usually the analyst begins by assembling maps and aerial photographs of the area to be classified. Specific training areas are identified for each informational category following the guidelines outlined below. The objective is to identify a set of pixels that accurately represents spectral variation present within each information region.





1.4.3 Ground Truthing

Ground truthing is the process of sending technicians to gather data in the field that either complements or disputes airborne remote sensing data collected by aerial photography, satellite sidescan radar, or infrared images. The team of ground truthing scientists will be collecting detailed calibrations, measurements, observations, and samples of predetermined sites. From this data, scientists are able to identify land use or cover of the location and compare it to what is shown on the image. They then verify and update existing data and maps.

In remote sensing, ground truth is just a jargon term for at-surface or near-surface observations made to confirm their identification/classification by interpretation of aerial or satellite imagery. The term in its simplest meaning refers to "what is actually on the ground that needs to be correlated with the corresponding features in the visualized scene.

There are three main reasons to conduct ground truth activities:

To obtain relevant data and information helpful as inputs and reference in the analysis of a remotely sensed scene;

To verify that what has been identified and classified using remote sensing data is actually correct (accuracy assessment);

To provide control measurements, from targets of known identities, that are useful in calibrating sensors used on the observing platforms.

Ground truthing is a way of looking at an entire mountain range, costal plane, forest, inland sea, coral reef, dessert, grassland, river, or marsh and understand many of the realities involved. With our present technology, we canmeasure an entire watershed and understand its capacities and impact on a region and mankind's positive or negative influence.

1.4.3.1 Collecting Ground Information

The spectral signature within a pixel of an image consists of an average of reflectances of all materials within that pixel. So, for a spatial resolution of 5x5 pixels, the spectral response for a stand of vegetation will consist of a combination of spectra of all vegetation types, soil, ground litter, etc.

Take representative spectrometer readings above the canopies for as many categories or classes of vegetation as possible within time or access constraints. Features like wet and dry soils and rock outcroppings may require additional location-specific GPS data. Examples of categories of vegetation in India include grasslands, marshland, mangroves, stands of pine, and mixed vegetation, both evergreen and deciduous; Categories of soil might be wet soil and dry soil, along with soil which is contaminated and are significantly visible on satellite imagery.

Site conditions and project goals likely will dictate sampling methodology – either take many readings in a single location (narrow, deep sampling) or obtain few readings at many locations (broad, shallow sampling). If surface or subsurface contaminants are important, collect appropriate spectral data. Sampling along transects from contaminated areas to background (clean) areas across a plume may prove useful.

Collect actual leaf / soil / litter samples for later reflectance analysis in the lab. If the entire canopy consisted of leaves, presumably, its spectra would resemble the leaf spectra. In reality, the canopy is made up of different materials accounted for accordingly in its spectra.

Ground-truthing data to collect at each site include:

- *Field notes regarding site and light conditions*
- *Spectra-radiometer readings : Calibration targets (dark and light); and Vegetation*

- *Vegetation sample – leaf or leaf cluster*
- *Ground Control Points collected using a GPS*
- *Photograph of the site and write down the picture number as reference in the field note.*

1.5 Summary

This unit begins with the digital image processing techniques. Although the pre-processing is similar for all kinds of satellite imageries, the difference in the band combinations and resolutions asks for different interpretation techniques. The various keys of image visual interpretation are also described here. The rectification of a satellite data to make it compatible with other existing databases and also for accurate assessment of ground conditions is elaborated herewith. Later in the unit we also learn about the digital image processing techniques, namely supervised and unsupervised classification. Classification alone is incomplete without proper ground verification. Thus ground verification methods along with the various aspects of the ground data that has to be collected is mentioned here.

1.6 Glossary

Interpretation-*the act of interpreting; an explanation of the meaning of another's artistic or creative work; an elucidation*

Bits- *The smallest unit of information within a computer. A bit can have one of two values, 1 and 0, that can represent on and off, yes and no, or true and false.*

Calibration- *an explanation of the meaning of another's artistic or creative work; an elucidation*

Convolution- *a rolled up or coiled condition*

Interpolation- *The estimation of surface values at unsampled points based on known surface* ***Kernel-*** *the central or most important part of anything; essence; gist; core*

Model- *An abstraction of reality used to represent objects, processes, or events Values of surrounding points. Interpolation can be used to estimate elevation, rainfall, temperature, chemical dispersion, or other spatially-based phenomena. Interpolation is commonly a raster operation, but it can also be done in a vector environment using a TIN surface model. There are several well-known interpolation techniques, including spline and kriging.*

1.7 References

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5. *http://www.rese.ch/pdf/atcor3_manual.pdf*
6. *http://www.wamis.org/agm/pubs/agm8/Paper-5.pdf*
7. *http://educationally.narod.ru/gis3112photoalbum.html*
8. *http://www.smithsonianconference.org/climate/wpcontent/uploads/2009/09/ImageInterpretation.pdf*
9. *http://userpages.umbc.edu/~tbenja1/umbc7/santabar/vol1/lec2/2-3.html*
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13. http://rst.gsfc.nasa.gov/Sect13/Sect13_1.html

1.8 Suggested Readings

1. Jensen, John R. Remote Sensing Of The Environment (2nd Ed.). Published by Dorling Kindersley India (2006) ISBN NO 10: 0131889508 ISBN 13: 9780131889507

2. Lillesand, Thomas M., Ralph W. Kiefer, and Jonathan W. Chipman. 2004. Remote Sensing and Image Interpretation, 5th ed., Published by John Wiley and Sons, Toronto. ISBN NO: 0471152277

1.9 Terminal Questions

1. What are the 2 types of remote sensing? Explain.

2. What are the 7 image interpretation keys. Explain any 2 keys.

3. What type of area is shown here? Which key/keys did you use interpret this?
4. Give 2 reasons for image rectification.
5. What is image to image registration and why is it done?
6. What are the two types of classification methods? Explain in 2 sentences each type.
7. What is the significance of ground truthing?

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UNIT 2: DATA: SPATIAL AND NON-SPATIAL II

2.1 Different formats of Non-spatial Data, Tables, charts

2.1.1 Data Warehouse

2.1.2 Metadata

2.2 Conversion of GPS data

2.3 Database Editing, Errors and Finalisation

2.3.1 Database Errors

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2.3.1.4 One table to hold all information

2.3.1.5 Using Keys

2.3.1.6 Not using SQL facilities to protect data integrity

2.3.1.7 Corrupt Table / Index Header

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2.3.1.9 Digitization Errors

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2.8 Terminal Questions

2.1 Different formats of Non-spatial Data, Tables, charts

"The most scarce resources is no longer information itself, but the capability of processing information in the information era."(Herbert A. Simon, 1966)

The first thing is to get information that you want from vast information ocean. The information era creates new opportunities as well as challenges for information retrieval. The amount of information is growing rapidly, as well as new users inexperienced among which many users encounter the information starvation (Sergey B., Lawrence P., 1998). Search method or search engine can be the bridge of communication between information ocean and user request. However search engine nowadays cannot meet people's request in the geographic domain for the complexity of spatial entities. As the geographic data comes into more valuable application, more and more people want to integrate the spatial data, attribute data, even temporal data in order to support spatial decision or to explore geographic pattern.

Socio-economic data and ground based observation related to natural resources form non-spatial elements of the database which act as collateral data to spatial data (maps). Spatial and non-spatial data together form meaningful information, which can be used for various applications. Following parameters constitute the non-spatial database:

- *Social (Demography)*
- *Economic (Occupation)*
- *Amenities (Health, Education, Communication, General, Landuse, Dependency etc.)*
- *Meteorology (Rainfall, Temperature, Wind speed etc.)*
- *Resources attributes (Soil depth, Number of wells etc.)*
- *Hazard specific data (Flood, Earthquakes etc.)*

While generating thematic and non-spatial databases paper maps and tables and such outputs are not flexible for many applications particularly for querying. Updation, layering for integrated analysis and other processes though not impossible, is difficult and time consuming and also integrated analysis need to be executed under the guidance of an experts. In this context, computerization of the data has distinct advantages which are enumerated below:

Handling of large volume of data, with appropriate data structure

Computerization of data opens a new horizon which facilitate data storage, retrieval, display, updation, query and analysis of spatial data in conjunction with non-spatial data. The spatial data available in the form of maps for a specific region can be mosaiced together on the computer format which would offer contiguity of spatial data.

Digital form of spatial data can have active link which allow integration of both elements (spatial and non-spatial). New information can be derived from primary database using specialised software such as Geographic Information System (GIS) and such information are valuable in the integrated analysis.

Digital form of data facilitates easy and effective information flow and data updation. The aim of this is to make the computer understand semantic meaning contained in the question. Following substeps are needed.

Categorization of user request: *Questions and problems should be categorized into several types for simplicity. Respective answers and solutions are matched by means of regular expressions or text categorization.*

Spatialization of geographic information: *Spatialization will map geographic information into spatial extent or coordinates (in latitude/longitude or other unified coordinates system). However resolving the definition of certain geographical terms is still an active research area. GIS data portal and nodes in the geographic data infrastructure can be accessed by means of metadata or directory. Many geographic information service sites can provide spatial data services from raw data, static maps, vector maps to bundle of datasets; other sites may further provide spatial operation* *services from simple query to complex buffer, route analysis which conform to OGC web service specification.*

2.1.1 Data Warehouse

Data Warehouse is a central managed and integrated database containing data from the operational sources in an organization. It may gather manual inputs from users determining criteria and parameters for grouping or classifying records.

A fundamental concept of a data warehouse is the distinction between data and information. Data is composed of observable and recordable facts that are often found in operational or transactional systems. In a data warehouse environment, data only comes to have value to end-users when it is organized and presented as information. Information is an integrated collection of facts and is used as the basis for decision making.

Database contains structured data for query analysis and can be accessed by users. The data warehouse can be created or updated at any time, with minimum disruption to operational systems. A source for the data warehouse is a data extract from operational databases. The data is validated, cleansed, transformed and finally aggregated and it becomes ready to be loaded into the data warehouse.

The data warehouse as mentioned earlier serves the rapid access to information deducible from the raw data demanded by the end-user. Slicing and dicing select subsets of the multidimensional database belonging to one or more constants in one or a few dimensions.

Pivoting determines the measures in different cross-tabular layouts.

Roll-up results in generalization of one or more dimensions, by aggregating the corresponding measures.

Drill-down produces a detailed view of the selected dimension(s).

2.1.2 Metadata

Metadata is st ructured information that describes, explains, locates, or otherwise makes it easier to retrieve, use, or manage an information resource. Metadata is often called data about data or information about information. In the library environment, metadata is commonly used for any formal scheme of resource description, applying to any type of object, digital or non-digital. Traditional library cataloging is a form of metadata.

There are three main types of metadata:

***Descriptive** metadata describes a resource for purposes such as discovery and identification. It can include elements such as title, abstract, author, and keywords.*

Structural metadata indicates how compound objects are put together for example, how pages are ordered to form chapters.

***Administrative** metadata provides information to help manage a resource, such as when and how it was created, file type and other technical information, and who can access it.*

There are several subsets of administrative data; two that sometimes are listed as separate metadata types are:

− Rights management metadata, which deals with intellectual property rights, and

− Preservation metadata, which contains information needed to archive and preserve a resource.

2.2 Conversion of GPS data

Geodetic-quality GPS units are usually able to output data directly into a GIS-friendly format like shapefiles, either with built-in software or with add-on packages like Trimble's Terrasync or ESRI's ArcPad. But what if you have a consumer-grade GPS unit without the ability to run this software (or you don't feel like coughing up hundreds of dollars to buy a copy)? This post and the next one will cover some options for downloading data directly from a GPS and converting it to the GIS-friendly shapefile format. Most GPS devices come with downloading software.

After downloading and installing the software program, hook up your GPS unit to the your computer, turn it on, and run the program. The software should determine that you have a GPS connected; if it doesn't, go to the GPS menu, and make sure the right port is selected. Once the GPS is recognized by the program, you can go to the Waypoint, Track or Route menu to Upload data from your GPS.

The data table lists off all the combined track points that have been uploaded, with a track identifier and position for every one (altitude as well if it's a 3D fix). You can modify, or even delete, individual track points in the data table.

Shapefiles come in three basic varieties, point, line and area/polygon, with each type only able to hold data of a particular type. In other words, if you have a point shapefile, you can't put lines or areas into it. While that holds true for saving data in DNRGarmin in shapefile format, you do have a choice of what format you save data in. Suppose you have a track that describes the perimeter of a particular area you're interested in. If you download that track data, software gives you the option of saving the data in any of the three shapefile types:

Point – Every point in the track is saved as a single point vertex in the shapefile

Line – The track is saved as a line shapefile, with every track point as a vertex

Polygon (area) – The track points are treated as vertices describing an polygon, with the first and last points in the track automatically connected together to complete the polygon perimeter.

If you download a set of individual waypoints that describe a line or an area, you can also save those as a line or polygon shapefile as well. After downloading the individual waypoints, just select “Track” or “Route” from the radio buttons near the top, and the software will let you save those points in line or polygon shapefile format.

2.3 Database Editing, Errors and Finalisation

Database editing is as essential as database generation. There is nothing worse than a database which is created in a disorganized and complex manner. Database errors are simple problems of designing that we tend to overlook in order to “get our job done”. The most vital part of having a decision support system in GIS is the organization and designing of the databae. Some common data errors are discussed below related to databases and digitization techniques.

2.3.1 Database Errors

2.3.1.1 Poor design/planning

A good database is built with forethought, and with proper care and attention given to the needs of the data that will inhabit it; it cannot be tossed together in some sort of reverse implosion.

Since the database is the cornerstone of pretty much every business project, if you don't take the time to map out the needs of the project and how the database is going to meet them, then the chances are that the whole project will veer off course and lose direction. Furthermore, if you don't take the time at the start to get the database design right, then you'll find that any substantial changes in the database structures that you need to make further down the line could have a huge impact on the whole *project, and greatly increase the likelihood of the project timeline slipping.*

Far too often, a proper planning phase is ignored in favor of just "getting it done". The project heads off in a certain direction and when problems inevitably arise – due to the lack of proper designing and planning – there is "no time" to go back and fix them properly, using proper techniques

2.3.1.2 Poor naming standards

Names, while a personal choice, are the first and most important line of documentation for your application. I will not get into all of the details of how best to name things here– it is a large and messy topic. The names you choose are not just to enable you to identify the purpose of an object, but to allow all future programmers, users, and so on to quickly and easily understand how a component part of your database was intended to be used, and what data it stores. No future user of your design should need to wade through a 500 page document to determine the meaning of some wacky name.

2.3.1.3 Lack of documentation

Not only will a well-designed data model adhere to a solid naming standard, it will also contain definitions on its tables, columns, relationships, and even default and check constraints, so that it is clear to everyone how they are intended to be used.

Where this documentation is stored is largely a matter of corporate standards and/or convenience to the developer and end users. It could be stored in the database itself, using extended properties. Alternatively, it might be in maintained in the data modeling tools. It could even be in a separate data store, such as Excel or another relational database. My company maintains a metadata repository database, which we developed *in order to present this data to end users in a searchable, linkable format. Format and usability is important, but the primary battle is to have the information available and up to date.*

2.3.1.4 One table to hold all information

Relational databases are based on the fundamental idea that every object represents one and only one thing. There should never be any doubt as to what a piece of data refers to. By tracing through the relationships, from column name, to table name, to primary key, it should be easy to examine the relationships and know exactly what a piece of data means.

2.3.1.5 Using Keys

A key is a set of columns that can be used to identify or access a particular row or rows. The key is identified in the description of a table, index, or referential constraint. The same column can be part of more than one key.

A unique key is a key that is constrained so that no two of its values are equal. The columns of a unique key cannot contain NULL values. For example, an employee number column can be defined as a unique key, because each value in the column identifies only one employee. No two employees can have the same employee number.

The primary key is one of the unique keys defined on a table, but is selected to be the key of first importance. There can be only one primary key on a table.

A primary index is automatically created for the primary key. The primary index is used by the database manager for efficient access to table rows, and allows the database manager to enforce the uniqueness of the primary key.

2.3.1.6 Not using SQL facilities to protect data integrity

SQL often referred to as Structured Query Language, is a database computer language designed for managing data in relational database management systems (RDBMS), and originally based upon relational algebra and calculus. Its scope includes data insert, query, update and delete, schema creation and modification, and data access control.

2.3.1.7 Corrupt Table / Index Header

This is caused by one of the internal tables becoming corrupted or damaged. These errors are generally associated with the files which index the table, but can also occur with the data files (DBF or DBT) themselves. The index tables only store pointers to the data in the data files and a corrupt index does not mean that data has been lost. This type of error can be caused by improperly shutting down the computer with the software open, hardware issues with memory or the hard disk, issues with the electrical power supply to the building, or heavy. The full text of the error message will identify the table along with the name of the file that is getting the error message. If column headings are changed by opening the database with some other software, then also this error can come up.

2.3.1.8 Map registration or Georeferencing

Registration of the map, or georeferencing is performed after the acquisition of the satellite imagery of at the beginning of the digitization session. This is done so that map units are converted into geographic units and measurements are possible. For this process known control points or GCPs or GPS location readings are required. These control points should generally be well spaced for example near the corners of the map. Depending on the software used, minimum of four points are required.

An error limit needs to be specified. This is the maximum error that is acceptable to register your paper map. The default error limit is 0.004 *inches (or its equivalent units). Once we enter a minimum of 4 pairs of map and paper control points, the software calculates the Root Mean Square (RMS) error and compares the value with the one you specified in the Error Limit edit box. If the calculated error is less than the specified error limit, then the georeferencing coordinates entered are much accurate and one can proceed with the georeferencing. Else the process has to be worked on again.*

RMS error

The Root Mean Square (RMS) error represents the difference between the original control points and the new control point locations calculated by the transformation process. The transformation scale indicates how much the map being digitised will be scaled to match the real-world coordinates.

The RMS error is given in both page units and in map units. To maintain highly accurate geographic data, the RMS error should be kept under 0.004 inches (or its equivalent measurement in the coordinate system being used). For less accurate data, the value can be as high as 0.008 inches or its equivalent measure.

Common causes of high RMS error are - incorrectly digitised control points, careless placement of control points on the map sheet, and digitising from a wrinkled map. For more accurate results when digitising a control point, check that the cursor remains centered on the control point.

2.3.1.9 Digitization Errors

Process of digitization involves creation of vector layers using digitizing tools. It is a method of converting raster data into vector data. This vector data can be stored as point feature, like settlements, wells; line feature are drawn for roads and railway lines, sometimes rivers too; Polygon features *are created to demarcate agricultural or forest patches, water bodies like dams,*

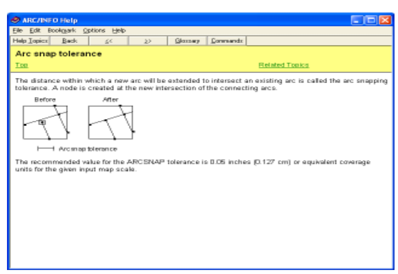
In this process a satellite image covering area of interest or raster map containing desired features is used as background and features are traced over it with the help of digitizing tools available in the GIS software. Separate vector layers are created for different features for example- roads, rivers, railways, water bodies, land use, wells, etc.

Before starting off with digitization, snapping tolerance has to be set namely, vertex snapping, edge snapping and end snapping.

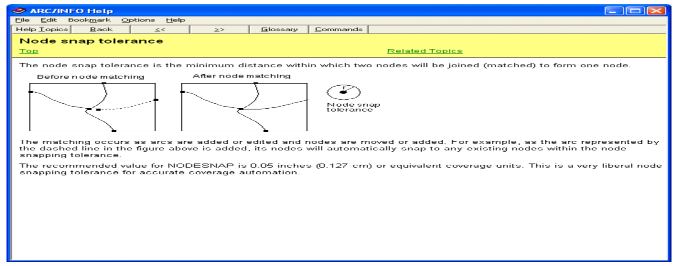
Tolerance

Setting the tolerance is an important part of digitization and database building. Snap tolerance, Grain tolerance , seed tolerance, weed tolerance and fuzzy are most commonly used.

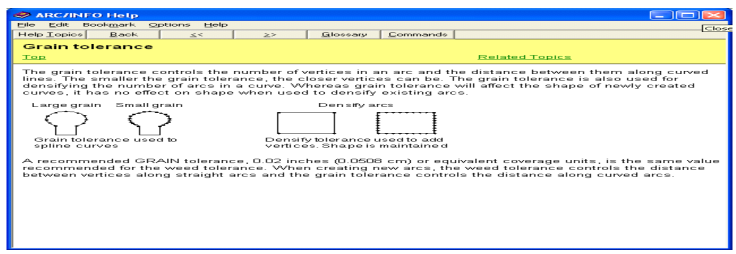
The distance within which a new arc will be extended to intersect an existing arc is called the arc snapping tolerance. A node or a vertex is created at the new intersection of the connecting arcs.



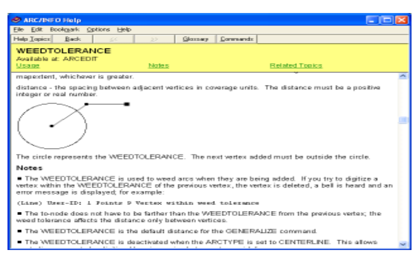
The node snap tolerance is the minimum distance within which two nodes will be joined (matched) to form one node.



The grain tolerance controls the number of vertices in an arc and the distance between them along curved lines. The smaller the grain tolerance, the closer vertices can be. The grain tolerance is also used for densifying the number of arcs in a curve. Whereas grain tolerance will affect the shape of newly created curves, it has no effect on shape when used to densify existing arcs.

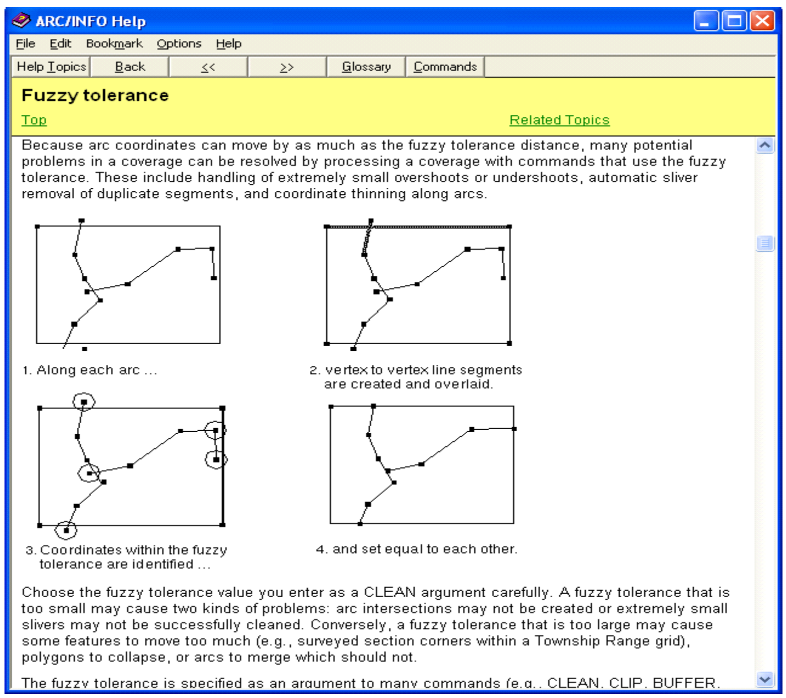


Weed tolerance specifies the minimum distance between adjacent vertices on an added arc. The distance must be a positive integer or real number.



The circle represents the weed tolerance. The next vertex added must be outside the circle. If you try to digitize a vertex within the weed tolerance *of the previous vertex, the vertex is deleted, a bell is heard and an error message is displayed*

Coverage resolution is influenced by the fuzzy tolerance, which represents the minimum distance separating all arc coordinates (nodes and vertices) in a coverage. By definition, it also defines the distance a coordinate can move during certain operations. The fuzzy tolerance is an extremely small distance used to resolve inexact intersection locations due to limited arithmetic precision of computers. Fuzzy tolerance values typically range from 1/10,000 to 1/1,000,000 times the width of the coverage extent



Digitization requires a lot of patience. The tool and task may seem simple, but there are a lot of precision involved in generating a smooth map with minimum errors, specially while calculating the area within an enclosed boundary or the length of the road, etc. The most common error while digitization are dangles created in a line file and slivers created in a polygon file.

Dangles

Dangles are topological errors where an arc or a line does not end at the point where it should. These are created due to improper digitization. Dangles are of two types - overshoots and undershoots.

Overshoots

When an arc or a line does not end at its termination point on another arc and goes beyond it is called as overshoot.

Undershoots

When an arc or a line finishes before connecting to another arc on desired location it is called as undershoot.

Spurious Polygons

Spurious polygons or slivers are often created during overlay of two or more polygon layers. Slivers are small polygons which results due to overlay operations of polygons whose edges do not match.

Avoiding/removing Dangles and spurious polygons

Dangles can be avoided it proper snapping tolerance is defines before starting digitization. Even then if dangles are created then these can be removed during 'cleaning' of vector layers- at that time also desired tolerance should be set and cleaning is done which automatically removes dangles.

Spurious polygons can be removed during cleaning operation by setting proper tolerance values.

2.4 Summary

This unit elaborates the various types of non-spatial data, that are available and how they can be arranged such that they can be used with spatially rectified data. Some important aspects of data, like data warehouse and metadata have also been discussed. We also learn about collecting GPS data its conversion and use with other databases.

Database creation form various analogue datasets are not independent of errors. The most common and critical database errors have been discussed here.

2.5 Glossary

- ***Geographic Domain***- *A reference system that uses latitude and longitude to define the locations of points on the surface of a sphere or spheroid. A geographic coordinate system definition includes a datum, prime meridian, and angular unit.*

- ***Georeferencing***- *Aligning geographic data to a known coordinate system so it can be viewed, queried, and analyzed with other geographic data. Georeferencing may involve shifting, rotating, scaling, skewing, and in some cases warping, rubber sheeting, or orthorectifying the data.*

- ***Mosaic***- *A raster dataset composed of two or more merged raster datasets—for example, one image created by merging several individual images or photographs of adjacent areas.*

- ***Shapefiles***- *A vector data storage format for storing the location, shape, and attributes of geographic features. A shapefile is stored in a set of related files and contains one feature class.*

- ***Spurious***- *not genuine, authentic, or true; not from the claimed, pretended, or proper source; counterfeit.*

2.6 References

1. *http://www.maharashtra.gov.in/english/gis/gis-ch4-datag.php*

2. *http://www.isprs.org/proceedings/XXXVI/2-W25/source/RESEARCH%20ON%20PROBLEMBASED%20SPATIAL%20AND%20NONSPATIAL%20INFORMATION%20SEARCH%20METHODS.pdf*

3. *http://etl-tools.info/en/bi/datawarehouse_concepts.htm*

4. *http://oirap.rutgers.edu/dwbasics.pdf*
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12. *http://publib.boulder.ibm.com/infocenter/db2luw/v8/index.jsp?topic=/com.ibm.db2.udb.doc/admin/c0004799.htm*
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2.7 Suggested Readings

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2. *Clarke, Keith C. 2002. Getting Started with Geographic Information Systems, 4th ed., Prentice Hall Series in Geographic Information Science, Prentice-Hall Inc., Upper Saddle River, New Jersey. ISBN NO: 0130460273*

3. *Clarke, Keith C., Parks, Bradley O., and Michael P. Crane (eds.). 2001. Geographic Information Systems and Environmental Modeling. Published by Prentice-Hall Inc., Upper Saddle River, New Jersey. ISBN NO 10: 0130408174 ISBN 13: 9780130408174*

2.8 Terminal Questions

1 *What is data warehouse and metadata?*

2 *Name 5 database errors.*

3 *Name and briefly explain any 3 types of tolerances.*

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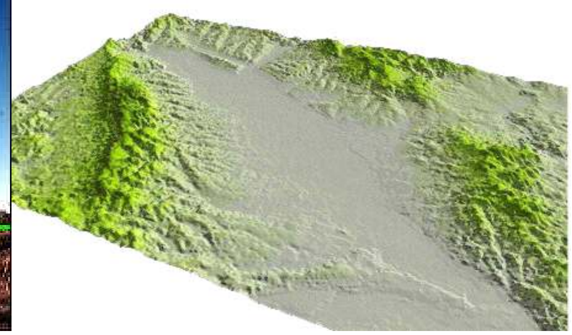
UNIT 3: DIGITAL ELEVATION MODEL

3.1 What is a DEM?

Digital Terrain Model or DTM is a digital representation of a topographic surface interpolated from the surveyed contours. It will not include surface features such as buildings and trees. This extra information is often referred to as 'clutter' and can be found typically in a laser scanned Digital Elevation Model (DEM). Digital Elevation Models are data files that contain the elevation of the terrain over a specified area, usually at a fixed grid interval over the "Bare Earth". For practical purpose this "Bare Earth" DEM is generally synonymous with a Digital Terrain Model (DTM).



Quality DEM products are measured by how accurate the elevation is at each pixel and how accurately the morphology is presented. Several factors are important for quality of DEM-derived products:

- *Terrain roughness*
- *Sampling density (elevation data collection method)*
- *Grid resolution or pixel size*
- *Interpolation algorithm*
- *Vertical resolution*
- *Terrain analysis algorithm*

Common uses of DEMs include:

- *DEM's may be used in the generation of three-dimensional graphics displaying terrain slope, apsect (direction of slope), and terrain profiles between selected points.*
- *Extracting terrain parameters*
- *Modeling water flow or mass movement (for example, landslides)*
- *Creation of relief maps*
- *Rendering of 3D visualizations*
- *Creation of physical models (including raised-relief maps)*
- *Rectification of aerial photography or satellite imagery*
- *Reduction (terrain correction) of gravity measurements (gravimetry, physical geodesy)*
- *Terrain analyses in geomorphology and physical geography*

Break Line

Breaklines define and control surface behavior in terms of smoothness and continuity. As their name implies, breaklines are linear features. They have a significant effect in terms of describing surface behavior when incorporated in a surface model such as a TIN. Breaklines can describe and enforce a change in the behavior of the surface. Two types of breaklines are included in this layer: hard and soft.

Hard breaklines *define interruptions in surface smoothness and are typically used to define streams, ridges, shorelines, building footprints, dams, and other locations of abrupt surface change.*

Soft breaklines *are used to ensure that known "Z" (elevation) values along a linear feature (such as a roadway) are maintained in a TIN. Soft breaklines can also be used to ensure that linear features and polygon edges are maintained in the TIN surface model* *by enforcing the breakline as TIN edges. Soft breaklines, however, do not define interruptions in surface smoothness.*

- *Mass Points*

Mass Points are irregularly distributed sample points, each with an x/y location and a z-value, which are used as the basic elements to build a TIN. Each mass point has important, yet equal, significance in terms defining the TIN surface. Ideally, the location of each mass point is intelligently chosen to capture important variations in the surface's morphology.

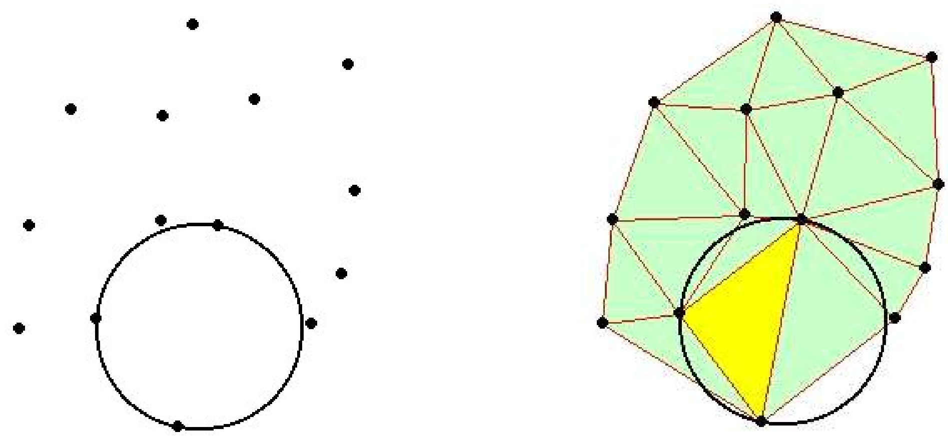
- *TIN*

A triangulated irregular network (TIN) is a digital data structure used in a geographic information system (GIS) for the representation of a surface. A TIN is a vector based representation of the physical land surface or sea bottom, made up of irregularly distributed nodes and lines with three dimensional coordinates (x,y, and z) that are arranged in a network of non-overlapping triangles. TINs are often derived from the elevation data of a rasterized digital elevation model (DEM). An advantage of using a TIN over a raster DEM in mapping and analysis is that the points of a TIN are distributed variably based on an algorithm that determines which points are most necessary to an accurate representation of the terrain. Data input is therefore flexible and fewer points need to be stored than in a raster DEM, with regularly distributed points. A TIN may be less suited than a raster DEM for certain kinds of GIS applications, such as analysis of a surface's slope and aspect.

A TIN comprises a triangular network of vertices, known as mass points, with associated coordinates in three dimensions connected by edges to form a triangular tessellation. Three-dimensional visualizations are readily created by rendering of the triangular facets. In regions where there is little variation in surface height, the points may be widely spaced whereas in areas of more intense variation in height the point density is increased.

- *The Delaunay Triangulation*

Delaunay triangulation is a proximal method that satisfies the requirement that a circle drawn through the three nodes of a triangle will contain no other node



Delaunay triangulation has several advantages over other triangulation methods:

The triangles are as equi-angular as possible, thus reducing potential numerical precision problems created by long skinny triangles, ensuring that any point on the surface is as close as possible to a node. The triangulation is independent of the order the points are processed

3.2 Sources to create a DEM

The availability of digital elevation models (DEMs) is critical for performing geometric and radiometric corrections for terrain on remotely sensed imagery, and allows the generation of contour lines and terrain models, thus providing another source of information for analysis.

Present mapping programs are rarely implemented with only planimetric considerations. The demand for digital elevation models is growing with increasing use of GIS and with increasing evidence of improvement in information extracted using elevation data (for example, in discriminating wetlands, flood mapping, and forest management). The incorporation of elevation and terrain data is crucial to many applications, particularly if radar data is being used, to compensate for foreshortening and layover effects and *slope induced radiometric effects. Elevation data is used in the production of popular topographic maps.*

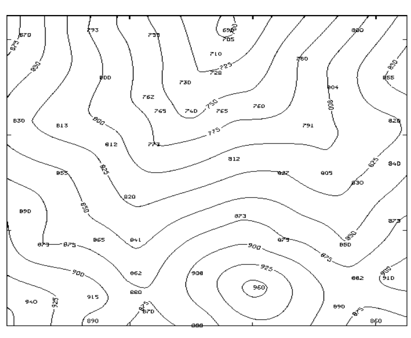
Elevation data, integrated with imagery is also used for generating perspective views, useful for tourism, route planning, to optimize views for developments, to lessen visibility of forest clear cuts from major transportation routes, and even golf course planning and development. Elevation models are integrated into the programming of cruise missiles, to guide them over the terrain.

Resource management, telecommunications planning, and military mapping are some of the applications associated with DEMs.

3.2.1 Contours and Interpolation

Contour lines are isolines showing equal elevation. This is the most common way of numerically showing elevation, and is familiar from topographic maps. During the mapping process, contours can be determined by several different methods, both on the ground and from the air. Surveyors use sophisticated equipment such as total stations (electronic versions of the old surveyor's transit) to map out contours onsite.

A primitive way to map contours on the ground, but one that easily illustrates the same process undertaken by electronic instruments, is through the use of a line level. A string of a specific length (oftentimes eight meters) is attached between two poles of equal height, which is leveled by the spirit bubble at the center. Instruments like Dumpy level and theodolites were extensively used before the bloom of the digital techniques.



Interpolation is the process of drawing contour lines by inferring their plan position and trend from spot levels or from other contours, assuming the intervening ground to have uniform slope. Mathematical computation for the location of each line would be time-consuming and would increase with the number of lines or contour intervals.

With the advent of digital softwares and technology, the contours were created by digitization on maps into digital contour layers.

Elevation data has traditionally been generated from the interpolation of contour information.

3.2.2 Baseline Thematic Mapping

There is a growing demand for digital databases of topographic and thematic information to facilitate data integration and efficient updating of other spatially oriented data. Topographic maps consist of elevation contours and planimetric detail of varied scale, and serve as general base information for civilian and military use.

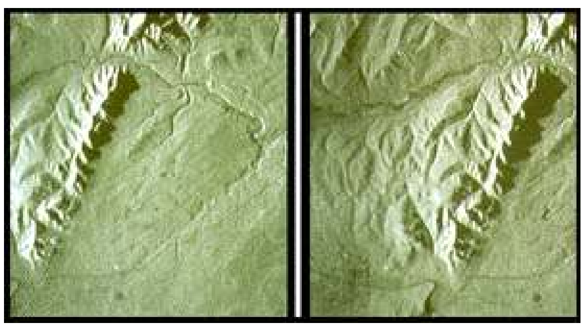
Baseline thematic mapping (BTM) is a digital integration of satellite imagery, land use, land cover, and topographic data to produce an "image map" with contour lines and vector planimetry information. This new concept of thematic mapping was developed to take advantage of improvements in digital processing and integration of spatial information, increased compatibility of multisource data sets, the wide use of geographic information systems to synthesize information and execute analyses customized for the user, and increased ability to present the data in cartographic form. The data for baseline thematic maps are compiled from topographic, land cover, and infrastructure databases. Appropriate thematic information is superimposed on a base map, providing specific information for specific end users, such as resource managers. Various combinations of thematic information may be displayed to optimize the map information for application specific purposes, whether for land use allocation, *utility site selection and route planning, watershed management, or natural resource management and operations.*

3.2.3 DEM from remote sensing data

Generating DEMs from remotely sensed data can be cost effective and efficient. A variety of sensors and methodologies to generate such models are available and proven for mapping applications. Two primary methods if generating elevation data are

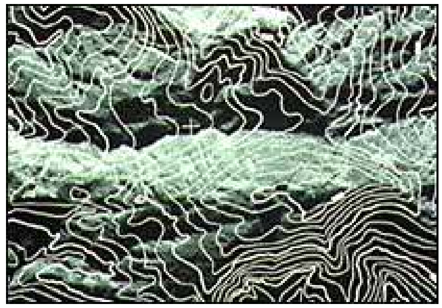
1. Stereogrammetry techniques using airphotos (photogrammetry), VIR imagery, or radar data (radargrammetry), and

2. Radar interferometry



3.2.3.1 Stereogrammetry

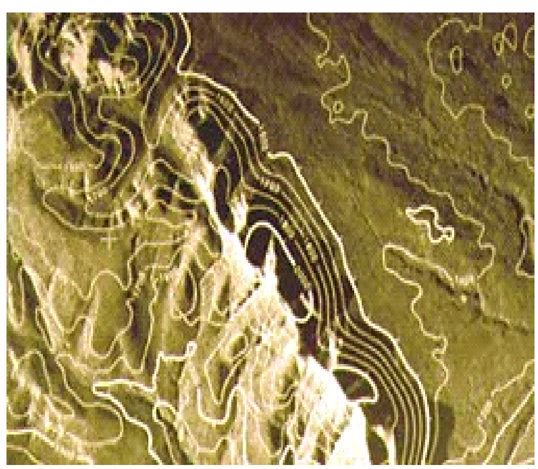
Stereogrammetry involves the extraction of elevation information from stereo overlapping images, typically airphotos, SPOT imagery, or radar. To give an example, stereo pairs of airborne SAR data are used to find point elevations, using the concept of parallax. Contours (lines of equal elevation) can be traced along the images by operators constantly viewing the images in stereo. The basic data requirement for both stereogrammetric and interferometric techniques is that the target site has been imaged two times, with the sensor imaging positions separated to give two different viewing angles.

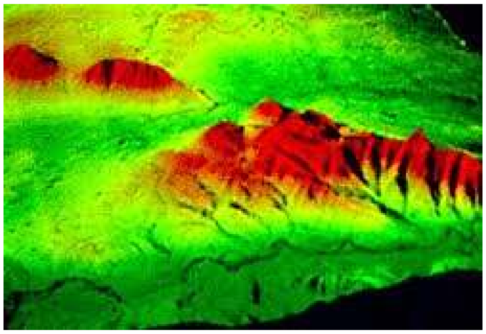


3.2.3.2 Radar Interferometry

The potential of radar interferometric techniques to measure terrain height, and to detect and measure minute changes in elevation and horizontal base, is becoming quickly recognized.

Interferometry involves the gathering of precise elevation data using successive passes (or dual antenna reception) of spaceborne or airborne SAR. Subsequent images from nearly the same track are acquired and instead of examining the amplitude images, the phase information of the returned signals is compared. A computation of phase integration, and geometric rectification are performed to determine altitude values. High accuracies have been achieved in demonstrations using both airborne (in the order of a few centimeters) and spaceborne data (in the order of 10m).





Primary applications of interferometry include high quality DEM generation, monitoring of surface deformations (measurement of land subsidence due to natural processes, gas removal, or groundwater extraction; volcanic inflation prior to eruption; relative earth movements caused by earthquakes), and hazard assessment and monitoring of natural landscape features and fabricated structures, such as dams. This type of data would be useful for insurance companies who could better measure damage due to natural disasters, and for hydrology-specialty companies and researchers interested in routine monitoring of ice jams for bridge safety, and changes in mass balance of glaciers or volcano growth prior to an eruption.

From elevation models, contour lines can be generated for topographic maps, slope and aspect models can be created for integration into (land cover) thematic classification datasets or used as a sole data source, or the model itself can be used to orthorectify remote sensing imagery and generate perspective views.

3.2.3.3 USGS – SRTM

The Shuttle Radar Topography Mission (SRTM) was flown aboard the space shuttle Endeavour on February 11 - 22, 2000. SRTM data are intended for scientific use with a Geographic Information System (GIS) or other special application software. The radars used during the SRTM mission were actually developed and flown on two Endeavour missions in

1994. The Spaceborne Imaging Radar-C (SIR-C) and the X-Band Synthetic Aperture Radar (X-SAR) hardware were used on board the space shuttle to gather data about Earth's environment. A key SRTM technology was radar interferometry, which compared two radar images or signals taken at slightly different angles. Differences between the two signals allowed for the calculation of surface elevation.

The elevation models are arranged into tiles, each covering one degree of latitude and one degree of longitude, named according to their south western corners. It follows that "n45e006" stretches from 45°N 6°E to 46°N 7°E . The resolution of the cells of the source data is one arc second, but 1" (approx. 30 meter) data have only been released over United States territory; for the rest of the world, only three-arc-second (approx. 90-meter) data are available.

3.2.3.4 ASTER DEM

ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) is a Japanese sensor which is one of five remote sensory devices on board the Terra satellite launched into Earth orbit by NASA in 1999. The instrument has been collecting surficial data since February 2000.

ASTER provides high-resolution images of the Earth in 15 different bands of the electromagnetic spectrum, ranging from visible to thermal infrared light. The resolution of images ranges between 15 to 90 meters. ASTER data are used to create detailed maps of surface temperature of land, emissivity, reflectance, and elevation.

On 29 June 2009, the Global Digital Elevation Model (GDEM) was released to the public. A joint operation between NASA and Japan's Ministry of Economy, Trade and Industry (METI), the Global Digital Elevation Model is the most complete mapping of the earth ever made, *covering 99% of its surface. The previous most comprehensive map, NASA's Shuttle Radar Topography Mission, covered approximately 80% of the Earth's surface, with a global resolution of 90 meters, and a resolution of 30 meters over the USA. The GDEM covers the planet from 83 degrees North to 83 degrees South (surpassing SRTM's coverage of 56 °S to 60 °N), becoming the first earth mapping system that provides comprehensive coverage of the Polar Regions. It was created by compiling 1.3 million VNIR images taken by ASTER using single-pass stereoscopic correlation techniques, with terrain elevation measurements taken globally at 30 meter (98 ft) intervals.*

3.2.3.5 LIDAR

Light Detection and Ranging (LIDAR) techniques use similar principles to those of Radio Detection and Ranging (RADAR) with the exception that it utilizes a laser beam instead of radio waves. Airborne systems typically collect topographic elevation measurements of the surface in the form of positional X, Y, Z coordinates at pre-defined intervals.

The data produced from a LIDAR sensor in its most common form, is often represented by a series of spatial coordinates in an American Standard Code for Information Interchange file (ASCII). The data in the file is recorded in a tabular format where each line has coordinate information separated by a common delimiter. The data can include other attribute information for each point as well. There are additional ways to represent LIDAR data such as LAS format, which is an alternative to the generic ASCII file format used by many companies.

Softwares can interpolate elevations from the LIDAR data in LAS format directly to generate a continuous raster digital surface model. Single LAS file or several adjacent LAS vector files could be used together to generate a seamless surface. This is an important feature with LIDAR data because *most often the data will be split into tiles to prevent the datasets from becoming too large in file size.*

3.3 Terrain mapping : Slope, Aspect, Viewshade, Relief

3.3.1 Slope

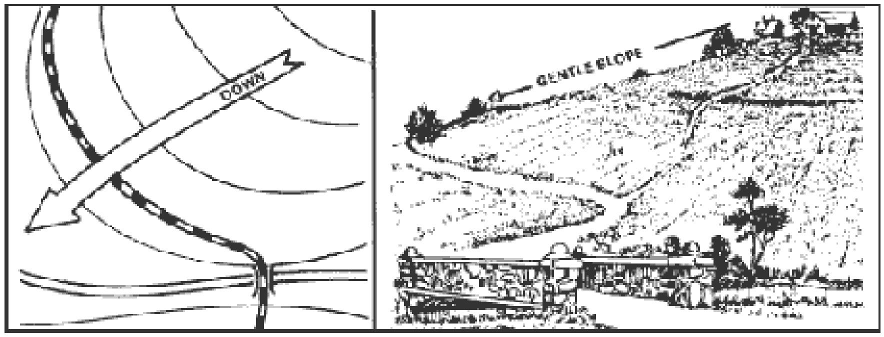
Slope is defined by a plane tangent to a topographic surface, as modelled by the DEM at a point. Slope is classified as a vector; as such it has a quantity (gradient) and a direction (aspect). Slope gradient is defined as the maximum rate of change in altitude as the compass direction of this maximum rate of change.

3.3.2 Types of slopes

Depending on the military mission, soldiers may need to determine not only the height of a hill, but the degree of the hill's slope as well. The rate of rise or fall of a terrain feature is known as its slope. The speed at which equipment or personnel can move is affected by the slope of the ground or terrain feature. This slope can be determined from the map by studying the contour lines—the closer the contour lines, the steeper the slope; the farther apart the contour lines, the gentler the slope. Four types of slopes that concern the military are as follows:

3.3.2.1 Gentle

Contour lines showing a uniform, gentle slope will be evenly spaced and wide apart. Considering relief only, a uniform, gentle slope allows the defender to use grazing fire. The attacking force has to climb a slight incline.



Uniform, gentle slope

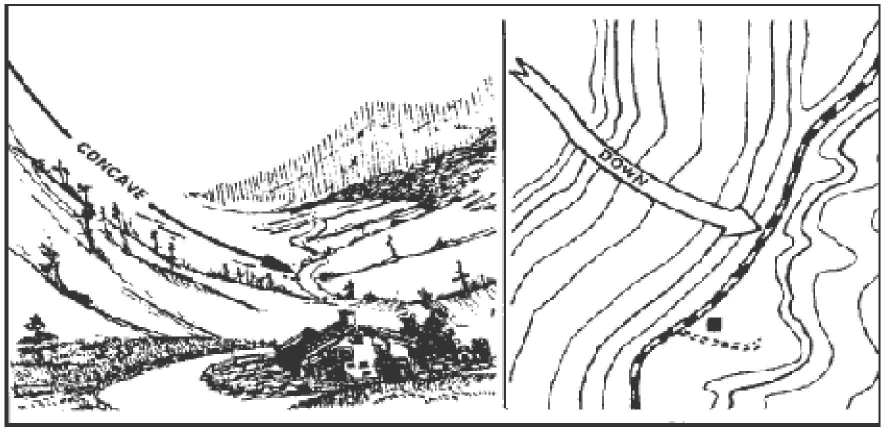
3.3.2.2 Steep

Contour lines showing a uniform, steep slope on a map will be evenly spaced, but close together. Remember, the closer the contour lines, the steeper the slope. Considering relief only, a uniform, steep slope allows the defender to use grazing fire, and the attacking force has to negotiate a steep incline.

Uniform, steep slope

3.3.2.3 Concave

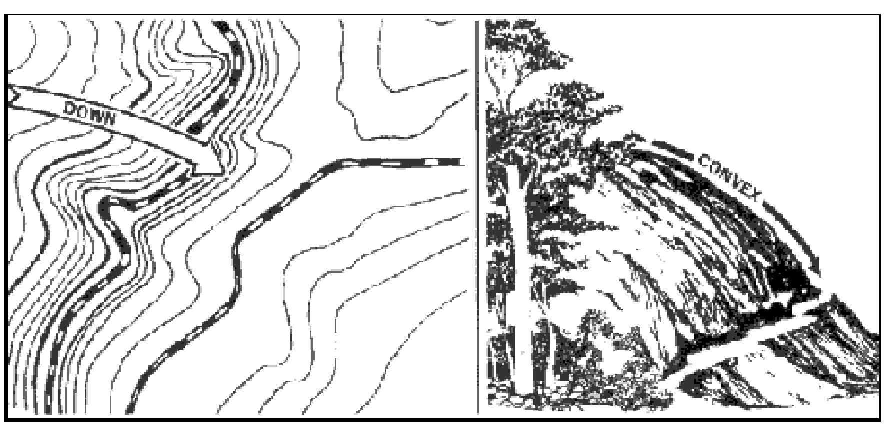
Contour lines showing a concave slope on a map will be closely spaced at the top of the terrain feature and widely spaced at the bottom. Considering relief only, the defender at the top of the slope can observe the entire slope *and the terrain at the bottom, but he cannot use grazing fire. The attacker would have no cover from the defender's observation of fire, and his climb would become more difficult as he got farther up the slope.*



Concave slope

3.3.2.4 Convex

Contour lines showing a convex slope on a map will be widely spaced at the top and closely spaced at the bottom. Considering relief only, the defender at the top of the convex slope can obtain a small distance of grazing fire, but he cannot observe most of the slope or the terrain at the bottom. The attacker will have concealment on most of the slope and an easier climb as he nears the top.

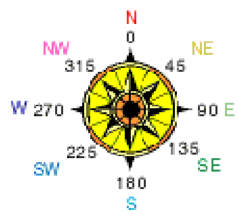


Convex slope

3.3.3 Aspect

Aspect identifies the steepest downslope direction from each cell to its neighbors. It can be thought of as slope direction or the compass direction a hill faces.

Aspect is measured clockwise in degrees from 0 (due north) to 360 (again due north), coming full circle.



The value of each cell in an aspect dataset indicates the direction the cell's slope faces. Flat areas having no downslope direction are given a value of -1.

3.3.4 Viewshade

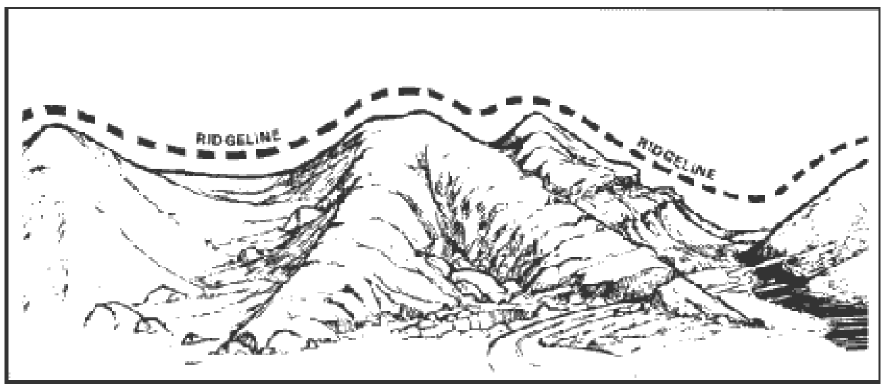
Viewshed identifies the cells in an input raster that can be seen from one or more observation points or lines. Each cell in the output raster receives a value that indicates how many observer points can be seen from each location. If you have only one observer point, each cell that can see that observer point is given a value of one. All cells that cannot see the observer point are given a value of zero. The observer points feature class can contain points or lines. The nodes and vertices of lines will be used as observation points.

3.3.5 Relief

Relief is the representation (as depicted by the mapmaker) of the shapes of hills, valleys, streams, or terrain features on the earth's surface. It usually refers to the terrain of the place. For example, plain, plateau, mountain, hill etc. are forms of relief. In a topographic map relief is generally shown by the contours. A relief *map can be created from dividing the contour patterns into different landforms. Hence it is a physical map that shows changes in elevation.*

3.3.5.1 Terrain Features

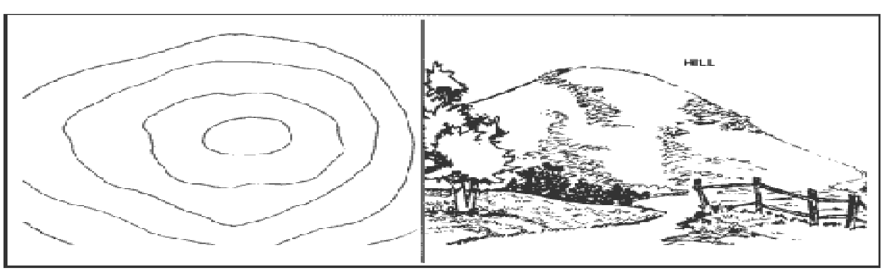
All terrain features are derived from a complex landmass known as a mountain or ridgeline. The term ridgeline is not interchangeable with the term ridge. A ridgeline is a line of high ground, usually with changes in elevation along its top and low ground on all sides from which a total of 10 natural or man-made terrain features are classified.



Ridgeline

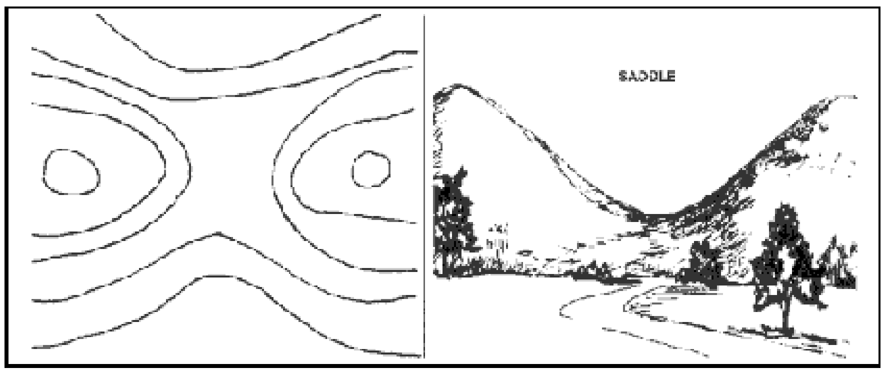
3.3.5.2 Major Terrain Features

(1) Hill. A hill is an area of high ground. From a hilltop, the ground slopes down in all directions. A hill is shown on a map by contour lines forming concentric circles. The inside of the smallest closed circle is the hilltop.



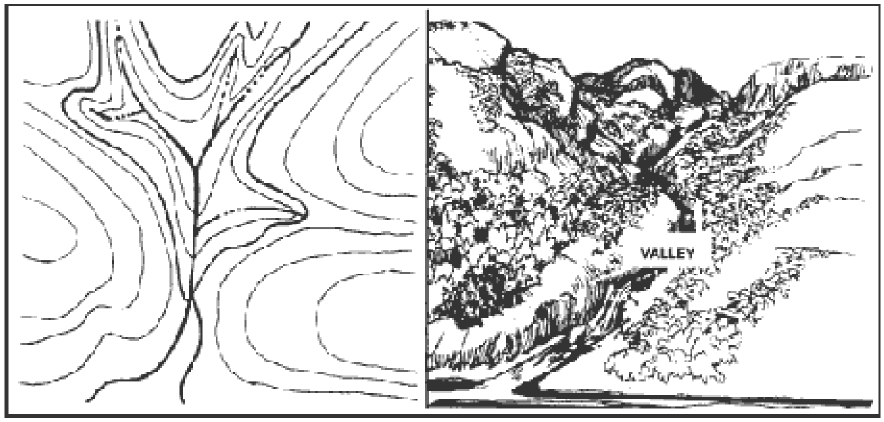
Hill

(2) Saddle. A saddle is a dip or low point between two areas of higher ground. A saddle is not necessarily the lower ground between two hilltops; it may be simply a dip or break along a level ridge crest. If you are in a saddle, there is high ground in two opposite directions and lower ground in the other two directions. A saddle is normally represented as an hourglass.



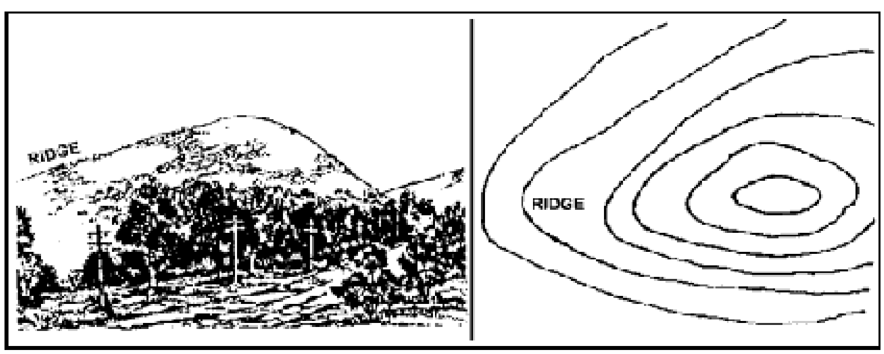
Saddle

(3) Valley. A valley is a stretched-out groove in the land, usually formed by streams or rivers. A valley begins with high ground on three sides, and usually has a course of running water through it. If standing in a valley, three directions offer high ground, while the fourth direction offers low ground. Depending on its size and where a person is standing, it may not be obvious that there is high ground in the third direction, but water flows from higher to lower ground. Contour lines forming a valley are either U-shaped or V-shaped. To determine the direction water is flowing, look at the contour lines. The closed end of the contour line (U or V) always points upstream or toward high ground.



Valley

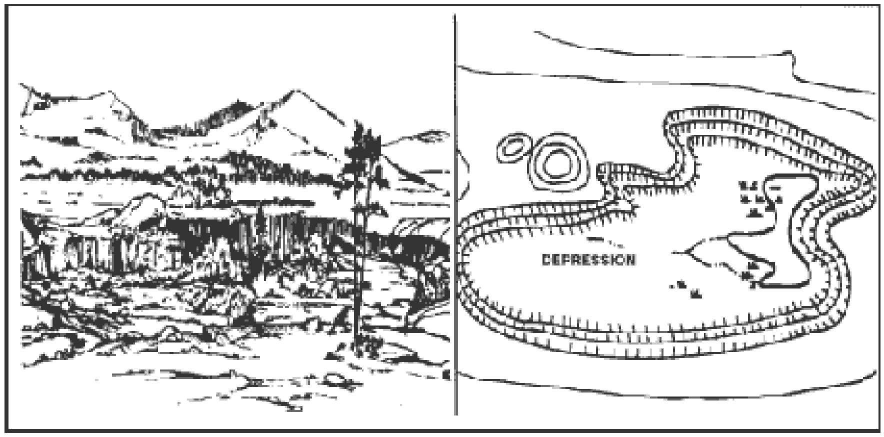
(4) Ridge. A ridge is a sloping line of high ground. If you are standing on the centerline of a ridge, you will normally have low ground in three directions and high ground in one direction with varying degrees of slope. If you cross a ridge at right angles, you will climb steeply to the crest and then descend steeply to the base. When you move along the path of the ridge, depending on the geographic location, there may be either an almost unnoticeable slope or a very obvious incline. Contour lines forming a ridge tend to be U-shaped or V-shaped. The closed end of the contour line points away from high ground.



Ridge

(5) Depression. A depression is a low point in the ground or a sinkhole. It could be described as an area of low ground surrounded by higher ground in all directions, or simply a hole in the ground. Usually only

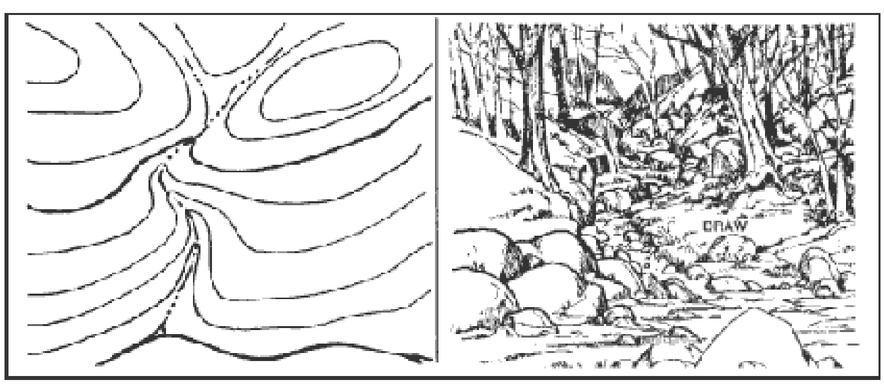
depressions that are equal to or greater than the contour interval will be shown. On maps, depressions are represented by closed contour lines that have tick marks pointing toward low ground.



Depression

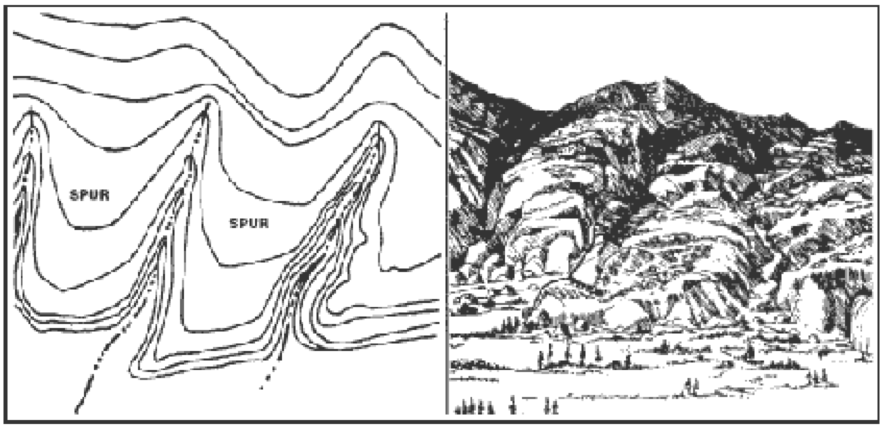
3.3.5.3 Minor Terrain Features

(1) Draw. A draw is a less developed stream course than a valley. In a draw, there is essentially no level ground and, therefore, little or no maneuver room within its confines. If you are standing in a draw, the ground slopes upward in three directions and downward in the other direction. A draw could be considered as the initial formation of a valley. The contour lines depicting a draw are U-shaped or V-shaped, pointing toward high ground.



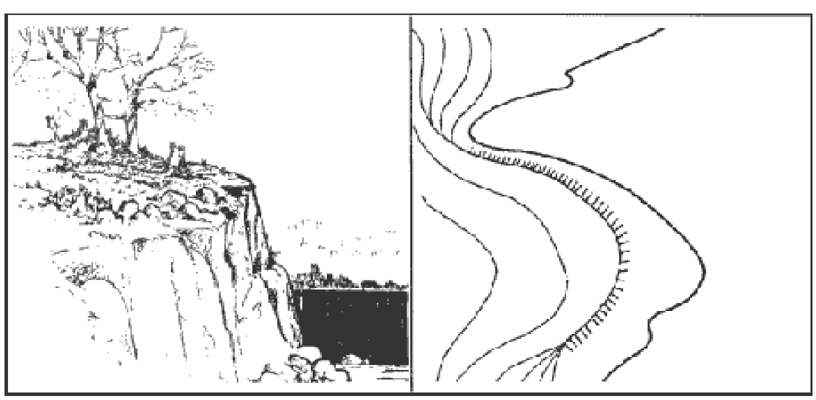
Draw

(2) Spur. A spur is a short, continuous sloping line of higher ground, normally jutting out from the side of a ridge. A spur is often formed by two rough parallel streams, which cut draws down the side of a ridge. The ground sloped down in three directions and up in one direction. Contour lines on a map depict a spur with the U or V pointing away from high ground.

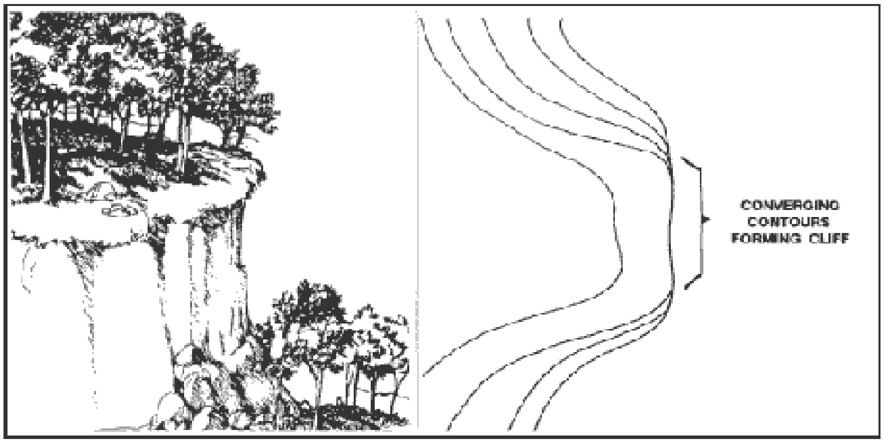


Spur

(3) Cliff. A cliff is a vertical or near vertical feature; it is an abrupt change of the land. When a slope is so steep that the contour lines converge into one "carrying" contour of contours, this last contour line has tick marks pointing toward low ground. Cliffs are also shown by contour lines very close together and, in some instances, touching each other.



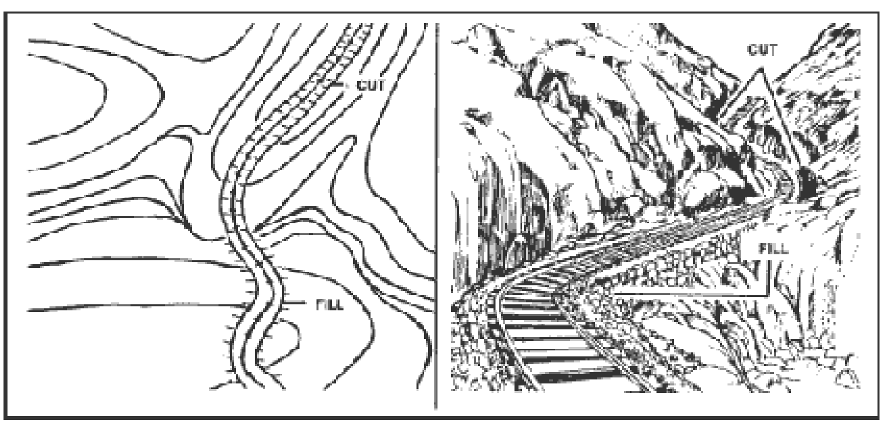
Cliff



Cliff

c. Supplementary Terrain Features.

(1) Cut. A cut is a man-made feature resulting from cutting through raised ground, usually to form a level bed for a road or railroad track. Cuts are shown on a map when they are at least 10 feet high, and they are drawn with a contour line along the cut line. This contour line extends the length of the cut and has tick marks that extend from the cut line to the roadbed, if the map scale permits this level of detail.



Cut and fill

(2) Fill. A fill is a man-made feature resulting from filling a low area, usually to form a level bed for a road or railroad track. Fills are shown on a map when they are at least 10 feet high, and they are drawn with a contour line along the fill line. This contour line extends the length of the filled area and has tick marks that point toward lower ground. If the map scale permits, the length of the fill tick marks are drawn to scale and extend from the base line of the fill symbol

3.3.5.4 Methods of depicting relief

Mapmakers use several methods to depict relief of the terrain.

a. Layer Tinting. Layer tinting is a method of showing relief by color. A different color is used for each band of elevation. Each shade of color, or band, represents a definite elevation range. A legend is printed on the map margin to indicate the elevation range represented by each color. However, this method does not allow the map user to determine the exact elevation of a specific point—only the range.

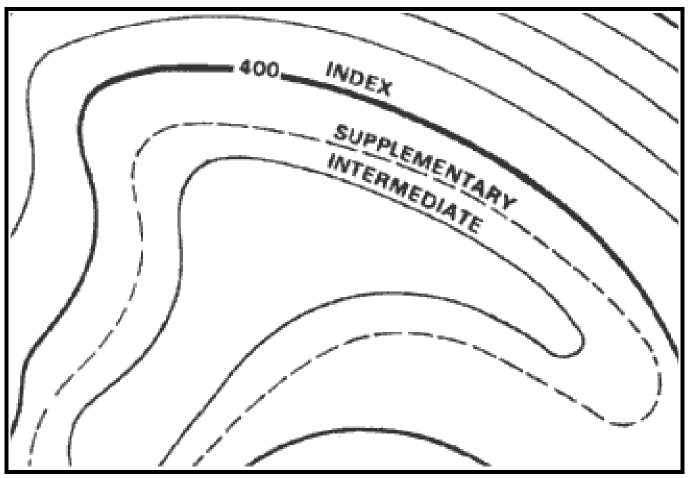
b. Form Lines. Form lines are not measured from any datum plane. Form lines have no standard elevation and give only a general idea of relief. Form lines are represented on a map as dashed lines and are never labeled with representative elevations.

c. Shaded Relief. Relief shading indicates relief by a shadow effect achieved by tone and color that results in the darkening of one side of terrain features, such as hills and ridges. The darker the shading, the steeper the slope. Shaded relief is sometimes used in conjunction with contour lines to emphasize these features.

d. Hachures. Hachures are short, broken lines used to show relief. Hachures are sometimes used with contour lines. They do not represent exact elevations, but are mainly used to show large, rocky outcrop areas.

Hachures are used extensively on small-scale maps to show mountain ranges, plateaus, and mountain peaks.

e. Contour Lines. Contour lines are the most common method of showing relief and elevation on a standard topographic map. A contour line represents an imaginary line on the ground, above or below sea level. All points on the contour line are at the same elevation. The elevation represented by contour lines is the vertical distance above or below sea level. The three types of contour lines used on a standard topographic map are as follows:



Contour lines

(1) Index. Starting at zero elevation or mean sea level, every fifth contour line is a heavier line. These are known as index contour lines. Normally, each index contour line is numbered at some point. This number is the elevation of that line.

(2) Intermediate. The contour lines falling between the index contour lines are called intermediate contour lines. These lines are finer and do not have their elevations given. There are normally four intermediate contour lines between index contour lines.

(3) Supplementary. These contour lines resemble dashes. They show changes in elevation of at least one-half the contour interval. These lines are normally found where there is very little change in elevation, such as on fairly level terrain.

3.4 Summary

This unit introduces another form of digital data, the digital elevation model or the DEM. The basic concepts of the construction of a digital elevation model have also been elaborated here. The various types of elevation data in digital format is also described here. The various sources of elevation information cater to the various types of elevation data varying is scale. The derivation for information, like slope, aspect, etc, is also included here.

3.5 Glossary

Digital*- Any data in computer readable format usually stored on magnetic tape, CD, disk or hard drive.*

Elevation- *Vertical distance of a point above or below a reference surface or datum.*

Isolines- *A line connecting points of equal value on a map. Isolines fall into two classes: those in which the values actually exist at points, such as temperature or elevation values, and those in which the values are ratios that exist over areas, such as population per square kilometer or crop yield per acre. The first type of isoline is specifically called an isometric line or isarithm; the second type is called an isopleth.*

LIDAR- *Acronym for light detection and ranging. A remote-sensing technique that uses lasers to measure distances to reflective surfaces.*

Terrain- *An area of land having a particular characteristic, such as sandy terrain or mountainous terrain.*

3.6 References

1. *http://www.satimagingcorp.com/svc/dem.html*
2. *http://rockyweb.cr.usgs.gov/elevation/dpi_dem.html*
3. *http://www.radio-soft.co.uk/mapdata.html*
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13. *http://www.map-reading.com/ch10-5.php*
14. *http://www.map-reading.com/chap10.php*

3.7 Suggested Readings

1. *Burrough, Peter A. and Rachael A. McDonnell. 1998. Principles of Geographical Information Systems. Published by Oxford University Press, Toronto. ISBN13: 9780198233657 ISBN10: 0198233655*

2. *Longley, P.A., M.F. Goodchild, D.J. Manguire, D.W. Rhind, Geographical Information System*
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3. *O'Sullivan, David and David J. Unwin. 2003. Geographic Information Analysis Published by John Wiley & Sons, Inc, Hoboken, New Jersey ISBN NO 10: 0471211761 ISBN 13: 9780471211761*

3.8 Terminal Questions

1. *What is a DEM? What does it show or represent? Name 3 uses of DEM.*

2. *What are the different terrain types that are mapped from a DEM? Give 1 line description of each.*

3. *What is a TIN? Give 3 differences between a TIN and a DEM.*

***

UNIT 4: AESTHETICS OF MAP COMPOSITION

4.1 Introduction

"A picture is worth a thousand words" Emperor of the Xia Dynasty in China about 4,000 years ago.

A map is a graphic representation or scale model of spatial concepts. It is a means for conveying geographic information. Maps are a universal medium for communication, easily understood and appreciated by most people, regardless of language or culture. Incorporated in a map is the understanding that it is a "snapshot" of an idea, a single picture, a selection of concepts from a constantly changing database of geographic information. Maps are one means by which scientists distribute their ideas and pass them on to future generations.

A map can display only a few selected features, which are portrayed usually in highly symbolic styles according to some kind of classification scheme. In these ways, all maps are estimations, generalizations, and interpretations of true geographic conditions.

All maps are made according to certain basic assumptions, for example sea-level datum, which are not always true or verifiable. Lastly, a map is the product of human endeavor, and as such may be subject to unwitting errors, misrepresentation or bias. In spite of these limitations, maps have proven to be remarkably adaptable and useful through several millennia of human civilization.

4.1.1 Cartography

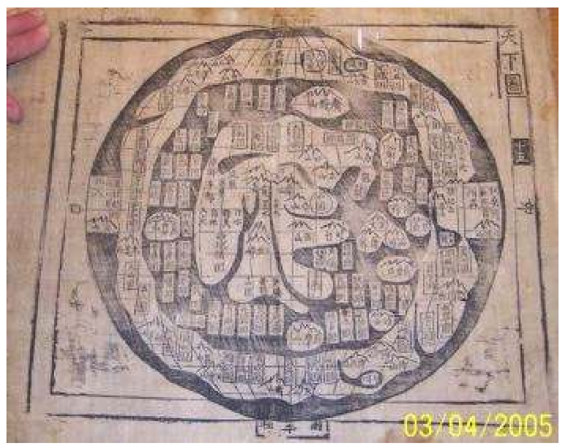
Cartography is the art and science of making maps. The purpose of the map along with the placement of all the components, like heading, scale, index, legend, labels, the colours and symbol which represent each component, contribute in making the map useful. This very subject of preserving the aesthetics of a map is cartography.

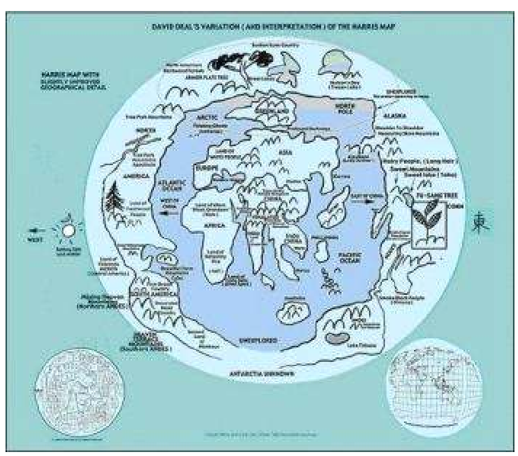
4.1.2 Brief History of Cartography

4.1.2.1 Early Maps

The oldest known maps are preserved on Babylonian clay tablets from about 2300 B.C. Cartography was considerably advanced in ancient Greece. The concept of a spherical Earth was well known among Greek philosophers by the time of Aristotle (ca. 350 B.C.) and has been accepted by all geographers since.

Greek and Roman cartography reached a culmination with Claudius Ptolemaeus (Ptolemy, about A.D. 85-165). His "world map" depicted the Old World from about 60°N to 30°S latitudes.

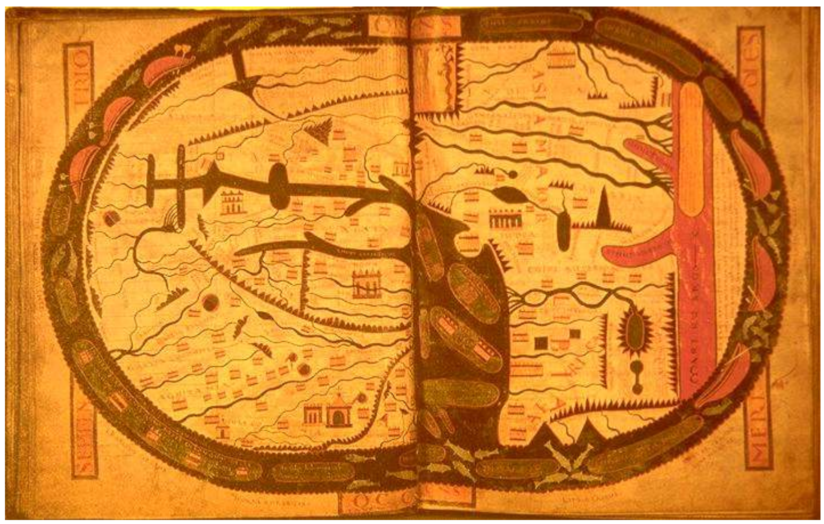




The first image is one of the ancient Chinese maps from Dr. Hendon Harris Jr.'s collection, published in his book in 1973. The second drawing is the interpretation of the first map.

4.1.2.2 Medieval Maps

During the Medieval period, European maps were dominated by religious views. The T-O map was common. In this map format, Jerusalem was depicted at the center and east was oriented toward the map top.



4.1.2.3 Renaissance Maps

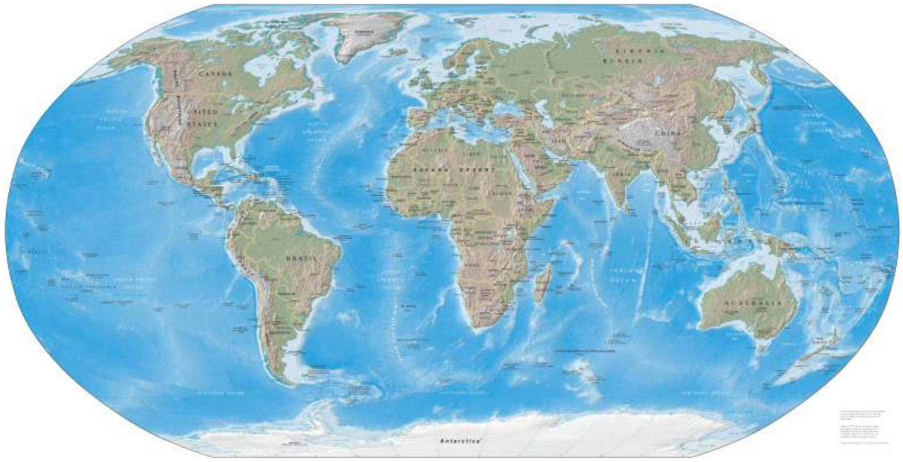
The invention of printing made maps much more widely available beginning in the 15th century. Maps were at first printed using carved wooden blocks (see above). Among the most important map makers of this period was Sebastian Münster in Basel (now Switzerland). His Geographia, published in 1540, became the new global standard for maps of the world.

Printing with engraved copper plates appeared in the 16th century and continued to be the standard until photographic techniques were developed. During the Age of Exploration in the 15th and 16th centuries map makers responded with navigation charts, which depicted coast lines, *islands, rivers, harbors, and features of sailing interest. Compass lines and other navigation aids were included, new map projections were devised, and globes were constructed. Such maps and globes were held in great value for economic, military, and diplomatic purposes, and so were often treated as national or commercial secrets--classified or proprietary maps.*

4.1.2.4 Modern Maps

The first true world map is generally credited to Martin Waldseemüller in 1507. This map utilized an expanded Ptolemaic projection and was the first map to use the name America for the New World.

Maps became increasingly accurate and factual during the 17th, 18th and 19th centuries with the application of scientific methods. Nonetheless, much of the world was poorly known until the widespread use of aerial photography following World War I. Modern cartography is based on a combination of ground observations and remote sensing. Geographic information systems (GIS) emerged in the 1970-80s period. GIS represents a major shift in the cartography paradigm. In traditional (paper) *cartography, the map was both the database and the display of geographic information. For GIS, the database, analysis, and display are physically and conceptually separate aspects of handling geographic data.*



4.2 Purpose of the Map

4.2.1 Topographic Maps

The subject of every map is a place. Topographic maps are designed especially to support a general exploration and discussion of the essential physical and cultural components of a place and it pertinent surroundings and their relationships with each other.

Data are chosen to represent these concepts; and the data are transformed into graphics portrayal in planimetric scale, and with a graphic hierarchy that makes it intuitively easy for the reader to discover the key concepts and relationships that you intend to emphasize. The art of selecting, transforming, and portraying information on a map involves the delicate balance of anticipating and answering reasonable questions related to your subject, while not overwhelming your reader's attention with needless detail, or forcing the reader to work in order to figure out what your map is intended to communicate.

4.2.1.1 Title and Labels

Include a Title that indicates the purpose for the map. This is a matter of being concise. Don't make me guess what you are trying to communicate with this map.

Put your name, your institutional context, source of primary data and date A map user expects a map to be biased, depending on the circumstances of its creation.

Include a caption that explains the critical concepts and relationships you are trying to illustrate. Without an explanation of the purpose of the map, the user may waste their time trying to figure out what the map's intention is.

The caption should convey an idea of what specific concepts are being explored by the map, and how a specific dataset has been used to portray an estimate the pattern that these concepts create on the ground. A good caption will reflect on the fitness of the data as an exact reflection of the ideal concepts. One way to make this simpler is to simply be clear that the map is a portrayal of a specific collection of observations made on a certain class of real world objects, using a particular method.

Label Key Elements on the Map. Certainly, any feature that you mention in your caption should be clearly portrayed and labeled on your map.

4.2.1.2 Scale, Projection and North

Cite Projection Method and Case All maps have a scale that should have planimetric scale properties - that is a scale that is constant in all directions and portions of the map and the north-south and east west axes should be at right angles to each other. These properties assure that *shapes and relative sizes of objects and distances will be represented correctly. Understanding this requires knowledge of the projection method used to transform the data for portrayal on the map. Therefore your choice of map projection method and case should be stated near to the north arrow and scale bar.*

Put a graphical scale bar on the map. Most maps these days are intended to be viewed on computer screens or projected against a wall. In these cases, a scale expressed as a fraction, eg. One Inch to One Mile or 1:63,000, is almost guaranteed to be wrong. In all cases a map should include a graphic scale bar. Only include fractional scales if you never to share your map in any other way than paper print.

4.2.1.3 Incorporate a Graphical Hierarchy

The key concepts as discussed in your text should be given emphasis with a bright color and bold line-weights and labels. Key relationships may be portrayed with diagramatic graphics. At a lesser level of emphasis you should provide a framework of reference for named places and circulation. There may be a hierarchy of emphasis among reference elements, such as line-weights and colors to portray different grades of roads. When color portrayal is an option, the color white should be reserved for non-map areas, such as margins, and the background of legend and text boxes. Other aspects of graphic hierarchy are discussed in the sections on topographic and thematic mapping.

4.2.1.4 Legend

A Concise Legend, if necessary the map legend should be reserved for making key distinctions that are important for understanding the points you are making in your caption. Not every symbol used on the map needs to be in the legend. When the symbology on the map is self-explanatory, or if the distinctions being symbolized objects is not an aspect of the key *concepts being described, then the map symbols should speak for themselves. When legends are included, the headings and descriptions should always be in plain english, avoiding cryptic file names and attribute codes. More tips on legends are discussed in the section on thematic maps, below.*

4.2.2 Thematic Maps

Beyond an understanding of the current context of a place, many documents will include maps that portray data that helps to support some assertion that one may want to make about a place as it relates to other places (in terms of land use or demographics or some other theme.) These are known as thematic maps. Thematic maps symbolize features according to the value of their attributes. These attributes may be qualitative, or quantitative. In the case of quantitative maps, we make a distinction between attributes that represent raw quantities versus measures of intensity.

4.2.2.1 Elements that Every Thematic Map Should Have

All of the requirements for maps, of portraying a contextual framework, listed above, apply also to thematic maps. There are additional considerations that also apply when we are trying to portray other sorts of measurements and observations on out maps.

Contextual Framework Portraying data without some frame of reference results needless difficulty for your audience to understand the relationship of the data or phenomena with the key places in and around the area of interest.

Concise, evocative legend your thematic data should be re-categorized if necessary so that your readers are not challenged to keep track of more than 5 different classes. Use plain terms in legend headings and labels. If you accept the software defaults for your legend labels and headings, *people who understand maps will also understand that you simply don't care about communicating.*

Try not to hide important information in arbitrarily broad categories The categories portrayed in the legend, whether qualitative or quantitative, should highlight distinctions that are useful.

Discuss the Aerial Precision of Mapping Units Whether the data are quantitative or qualitative, thematic data have a particular granularity. For example Census Data may be aggregated at a Block level or Tract. Land Use Data may only register distinctions for patches of ground larger than a stated Minimum Mapping Unit (like 5 acres, or a 90 meter cell.)

Graphical Hierarchy the same ideas about graphical hierarchy that apply to topographic maps may also apply with thematic maps. This is especially true with regard to the foreground layer of key topographic features and a reference layers to provide context. You may decide to drop some of the labels used in your reference layer -- particularly when your map document includes separate maps for presenting the contextual framework. Typically, the thematic layer will be the background layer of the map but you may also use transparency and an aerial photo at large scale, or shaded relief at smaller (broader) scales. When mixing background layers with transparency you should be careful that whatever background layers you use -- particularly aerial photos and or shaded relief, to not make the key distinctions in your thematic layer more difficult to read.

4.2.3 Quantitative Thematic Maps

Maps that portray quantitative measurements or summary statistics use tricks of graphics that cause the audience to visually weigh and compare aspects of places. Making effective quantitative maps and interpreting them requires an understanding the two major types of quantitative data: Intensive Statistics, *versus Raw Counts; and how the intuitive computer of the eye/mind interprets symbol color intensity versus symbol size. Intensive statistics (e.g. heat or concentration) versus extensive, count statistics (e.g. weights or counts).*

The cartographer should also understand two major classes of symbols for portraying quantitative properties: Proportional symbols change their visual weight according to a quantitative property. These are appropriate for extensive statistics. Choropleth maps portray data collection areas (such as counties, or census tracts) with color. Color is best used to represent intensive statistics such as percentages or densities. When using color this way, observe how the darkness and intensity (or value) of the color is evaluated by the eye as a measure of intensity or concentration.

Whenever you include a map portraying a proportion, such as Percent of housing units that are rental you should include a map that shows the density of the total -- e.g. total housing units per acre. It is often the case that areas that are near the ends of the scale in terms of proportion are ones that have very little actual activity in them.

Whenever your legend involves quantities of any type, your legend title or labels should explicitly state the units. When normalizing for density, please use an aerial unit that has an evocative scale. Can you create a picture in your mind of 10,000 people in a Square Kilometer? What about 100 People in a Hectare? (two soccer fields.) Convert your units if you have to.

Handy Conversion Factors		
You Have:	*Acres*	*Hectares*
Square Miles	*640*	*259*
Square Meters	*4,047*	*10,000*
0.001 Square Kilometers	*4.047*	*10*

4.3 Mapping proportions and Scales

From the very start of a cartographic project, you must keep an eye on the format of the final production--its final size and proportions and the media that will be used for production. If your final map will occupy a half page in a journal printed on 8x10 inch paper in black on white, you must design without color, with the frame of the map in the proportion of 4:5, and make allowances for lettering and symbols that may be illegible at small sizes. Strategies that work for one paper size may not work for another. Also, a map placed in a book, journal, or thesis will usually is captioned rather than titled and some of the other information needed for effective communication will move to this caption.

4.3.1 The issue of generalization, simplification, and abstraction

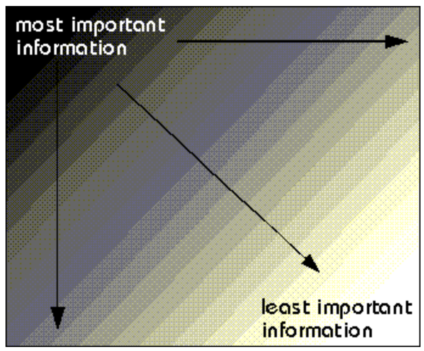
Cartography is very much a process of abstraction in which features of the real world are generalized or simplified to meet the demands of the theme and audience. Not all elements or details have a bearing on the pattern or process being studied and so some are eliminated to draw the reader's attention to those facts that are relevant. Too much detail can even hide or disguise the message of a map. The amount of detail that can be included is very much dependent on the scale at which the map will be produced, as the following examples demonstrate. A small-scale map of an area must, almost of necessity, be more generalized. Some automated systems now have the ability to provide assistance in the generalization and simplification of features.

Be aware, however, that adding just "a little" information, unless done wisely, can lead to confusion. Sometimes locator and index maps are used to help orient the reader to the location of the area of interest.

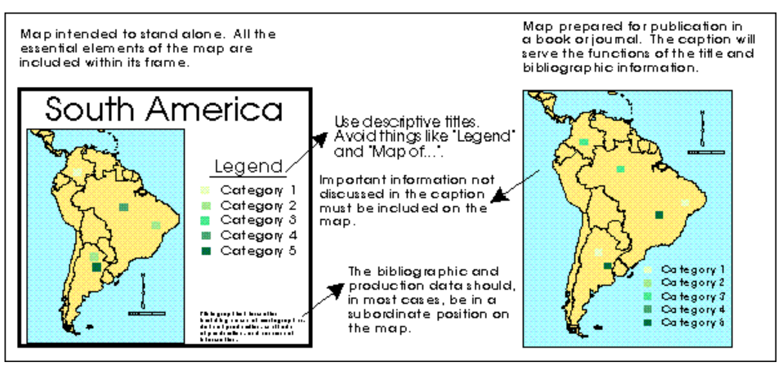
Almost all maps must include certain basic elements that provide the reader with critical information, like the title, scale, legend, body of the map, north arrow, cartographer, neatline, date of production, projection used, and information *about sources. The placement of this information and the style of its depiction will vary greatly from map to map.*

Elements are balanced within the visual hierarchy and frame of the map.

As a first approximation, the most important information should be featured near the top or to the left of the map. Less important and ancillary map elements can be positioned toward the bottom and right. In general terms, the importance of a given map element should be reflected in its position and the amount space it occupies on the map.



Once the elements are arranged to reflect their importance, attention can be given to their overall balance in the map frame. The idea here is to distribute the elements as evenly as possible within the map frame to avoid unnecessary crowding or, conversely, large blank areas. The cartographer can also align map elements within the frame to allow readers to more easily scan the page



4.3.1.1 Experiment with map layouts

Experimentation is often required to achieve an effective layout. You might begin by preparing some simple sketches of you map. Sketches such as this allow you to consider alternative layouts before you begin to compose the elements in detail.

There should be a defensible reason for each element placed on a map and for its composition

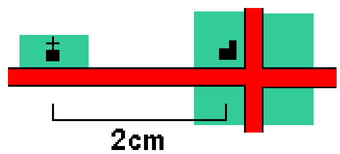
As you develop a design for a map, think carefully about every element--does it play an essential function, could it be simplified, does it require elaboration, is it of critical importance to reader comprehension, or only of background interest. Everything that appears on a map should be there for a defensible reason relating to message and audience.

4.3.1.2 Less is more

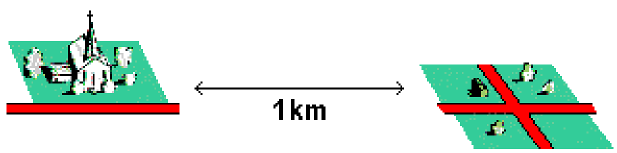
As you work, consider ways in which you can simplify your design and make it more legible. Too much detail or too complex a layout can confuse readers and work against effective communication. Do not avoid experiments, but be sure to test them carefully with your potential readers.

4.3.2 Scales

Maps are made to scale. In each case, the scale represents the ratio of a distance on the map to the actual distance on the ground. For example, if 2 cm on a map….



Represents 1 km on the ground….



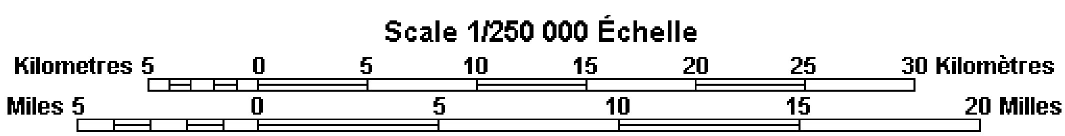
$$\frac{\text{Distance on the Map}}{\text{Distance on the Ground}} = \frac{2\text{ cm}}{1\text{ km}} = \frac{2\text{ cm}}{100\,000\text{ cm}}$$

$$= \frac{1}{50\,000}$$

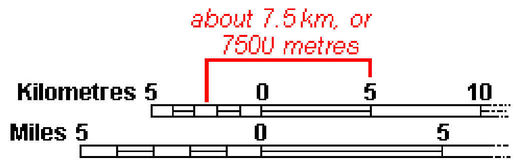
$$= \text{1/50 000 Scale}$$

The scale would be 2 cm = 1 km, or….

Use the Scale Bar found at the bottom of every National Topographic System (NTS) map to determine distances between points or along lines on the map sheet. (Note, the example below is not to scale.)



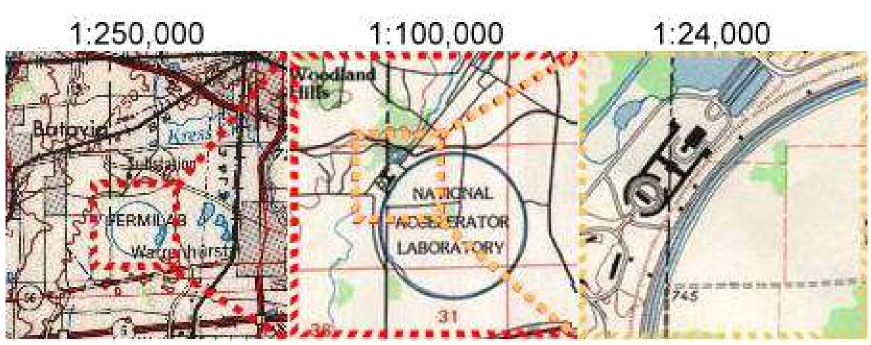
Use the secondary division on the left of the Scale Bar for measuring fractions of a kilometer. The measurement indicated is about 7.5 kilometers or 7 500 meters.



Large scale maps or Small scale maps

A large scale map shows greater detail because the scale is a larger fraction than a small scale map.
Large scale maps have a scale of 1:50,000 or greater (1:24,000, 1:10,000). Maps with scales from 1:50,000 to 1:250,000 are considered intermediate. Small scale maps are those with scales smaller than 1:250,000. A map of the world that fits on two pages of letter sized paper would be very small scale with a scale of around 1:100,00,000.

Here are 3 views of the same location on maps with different scales:



4.3.2.1 Selecting the scale for the map

On a small-scale map, such as a page-size map of Switzerland, places of religious worship occur at points, but on a large scale map, such as a map of a local neighborhood, individual buildings would likely be apparent, and thus the focus might be on the area covered by the place of worship. Similarly, a river could be considered a linear phenomenon on a small-

scale map, but on a large-scale map, the emphasis could be on the area covered by the river. So, the map scale must be adapted to:

- ***The map content:*** *Some special themes cannot have various scales, but only the most logical one. For example, population density maps cannot be larger than 1:100 000 otherwise the mapped people are not representative (commuters, day laborer, etc.).*

- ***The map purpose:*** *The map scale must be adapted to the purpose of the map and not to the first design or aesthetic idea of the author. Here you should think how wide will the earth area to be mapped be?*

- ***The map precision:*** *With what measuring and counting will the map be built? Here you should think how detailed the information you display on the map will be. With large scale maps, the information is precise because they are less generalized.*

Large scale maps are on the whole not economic, not easy to handle, and sometimes misleading. And, small scales make on the whole the map difficult to read, complicate, and sometimes are meaningless. Which scale is selected for a given map design problem will finally depend on the map purpose and physical size. The amount of geographical detail necessary to satisfy the purpose of the map will also act as a constraint in scale selection.

Generally, the scale used will be a compromise between these two controlling factors. When you represent the scale graphically on the map, the measurement dimensions and the line thickness should be adapted to the map graphics.

4.4 Labeling

The general Map Labeling Problem consists of defining positions for the labels of several graphical features (cities, roads, lakes, rivers, national parks, states, countries, etc.) of a map, such that these features can be uniquely identified.

These rules are:

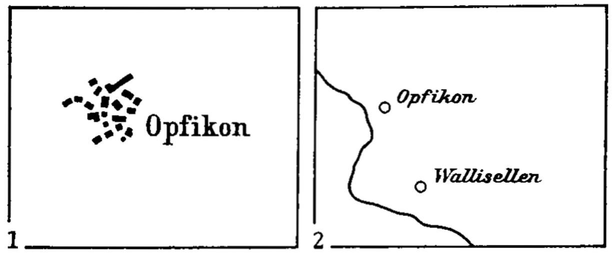
1. Readability: labels must have legible sizes;

2. Unambiguity: each label must be easily identified with exactly one graphical feature;

3. Avoidance of overlaps: labels should not overlap with other labels or other graphical features.

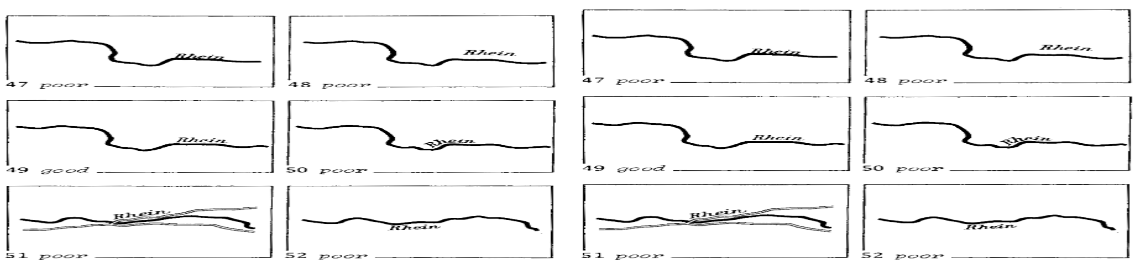
Six general requirements for a good label placement are summarized below:

- ***Readability:*** *chosen typeface, letter size and color on the one hand and positioning of the text on the other should support perception.*
- ***Definite attachment:*** *it should be clear which object belongs to a text.*
- ***Avoidance of overlaps:*** *the other map elements should not be covered by a label.*
- ***Spatial integration:*** *the label, looked on as a graphical shape without textual information, should help to clarify the spatial context of the designated object.*
- ***Site identification:*** *the chosen font should be a hint to the type of the labeled object.*
- ***Overall aesthetics:*** *the labels should not be spread over the map symetrically, but name clusters do also look disagreeable. This takes effect on generalization as well as on the placement.*

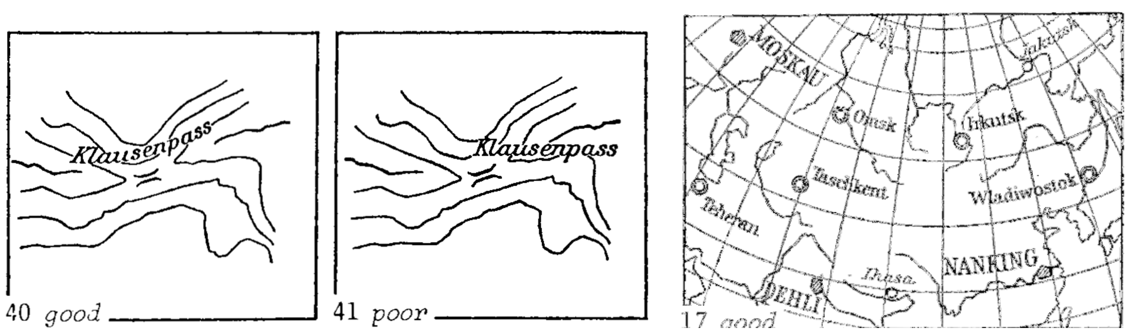


Cartographers arrange the named features in three groups, ordered by their topographical dimension: point features: cities, summits, but also area features on small scales

Linear features: rivers, streets, borders



Area features: mountains, islands, countries, lakes



Whereas the notations for point and linear features are arranged aside the object, they are written into the described object in case of area features (except for the case the area feature is sized too small to place the label inside its boundaries; then, it is treated like a point feature).

4.4.1 Label Placement

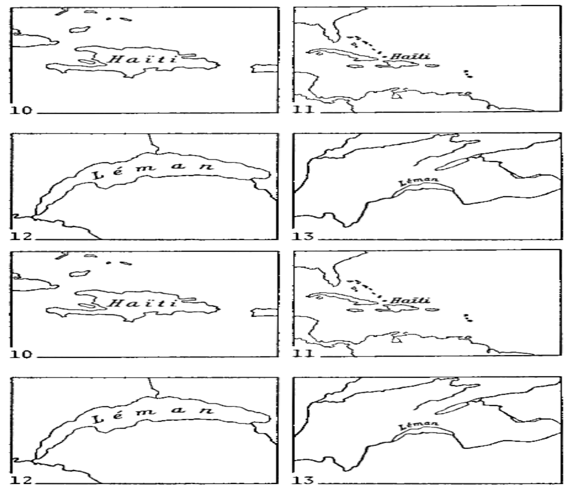
Features shown on maps and displays can be differentiated and identified in various ways: symbols, e.g. church, bridge. Labels provide the greatest flexibility to attach descriptions to point, line and area features names of administrative divisions, lakes, rivers etc. elevations of contours, spot heights, highway numbers, in cartography positioning labels is a complex and sophisticated process.

There have been few attempts to write down the rules used. It has proven difficult to emulate these rules in automated map production or GIS positioning labels on screen displays is especially difficult because of low resolution (e.g. 640 by 480 pixels), and the importance of speed.

Prof. Dr. Eduard Imhof, dean of European cartographers, has been an astute student of the esthetic-scientific characteristics of the cartographic method. In his publication of 1975. The labeling methods he described are summarized as Imhof's basic rules, mentioned below:

Names on maps should:

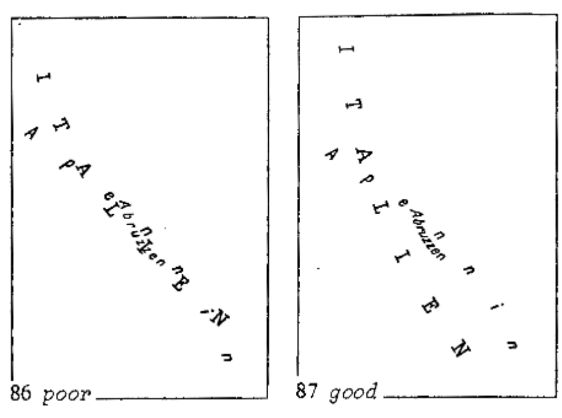
- *be legible*
- *be easily associated with the features they describe*
- *not overlap other map contents*
- *be placed so as to show the extent of the feature*
- *reflect the hierarchy of features by the use of different font sizes*
- *not be densely clustered nor evenly dispersed*

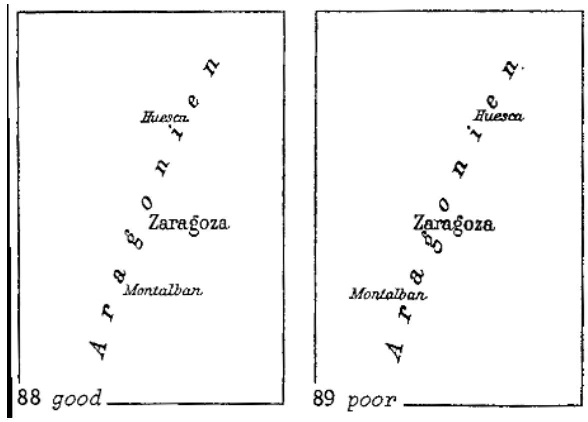


The best solution will balance conflicting objectives, e.g. need to associate name with feature vs. need to avoid overlap of contents label placement is a complex problem because of the vast number of possible positions that have to be searched and the number of conflicting objectives

two labeling problems are particularly significant in automated mapping and GIS: Over posting and polygon labeling

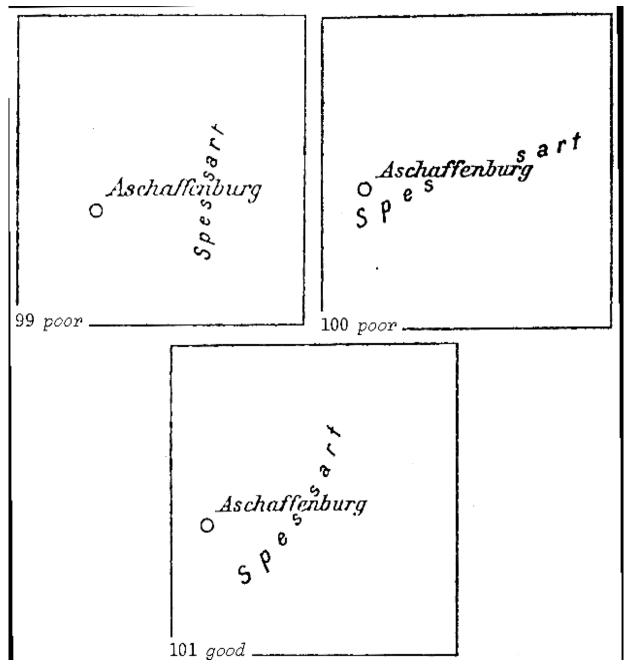
4.4.1.1 Over posting





- *when features are densely packed on a map or screen, it is difficult to keep labels separated*
- *labels may overlap (over posting)*
- *labels must be positioned to avoid over posting, but without destroying the eye's ability to associate labels with appropriate features, e.g. point features*
- *optimum position for a label is above and to the right*
- *below and to the right is less acceptable*
- *least acceptable positions are to the left*
- *label can be turned (non-horizontal) if necessary, but only by a small amount*
- *over posting is a problem because the computer must search a vast number of possible positions*
- *in practice, must limit the number of positions somehow*
- *some solutions define a fixed number of possible absolute positions, like a raster*

- *other solutions define a fixed number of positions relative to the feature diagram*

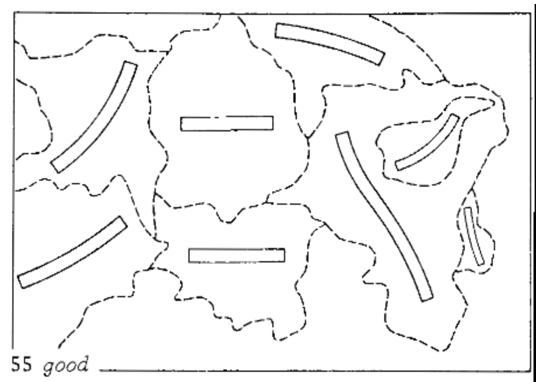


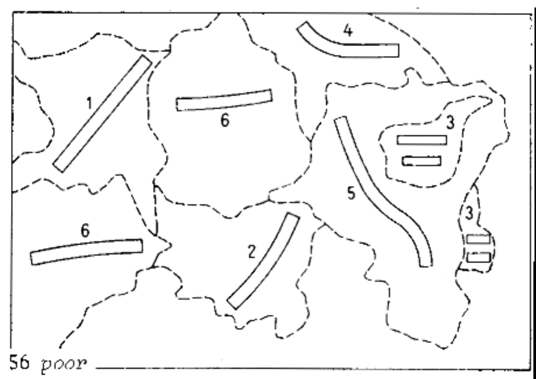
4.4.1.2 Polygon labeling

- *labeling polygons has become notorious within automated mapping as a difficult and challenging programming problem*

- *the label should be central to the feature, may be reoriented or curved to fit the feature diagram*

- *in some cases the label may be connected with the feature by an arrow diagram*





4.4.2 Simple methods

1. Label centered on the polygon centroid problems:

- *centroid may lie outside the polygon*
- *a long label may have to be multi-line to fit inside*
- *solution fails to meet Imhof's criterion of showing the extent of the feature*

2. Variable rectangle positioned inside the polygon

- *search for feasible positions for a rectangle wholly enclosed within the polygon*
- *ratio of width to height should be as high as possible*
- *solution will not curve the label to fit the feature*

- *largest enclosed rectangle may be in an inappropriate part of the polygon diagram*

3. Skeleton

- *shrink the polygon by moving its edges inward at a uniform rate*
- *the vertices trace out a network known as the skeleton diagram*
- *position the label along the central part of the skeleton*
- *best for polygons like Florida which require curved labels*
- *practical labeling methods use combinations of rules for different shapes, sizes of polygons*
- *many developers have used the term expert system to describe label placement software*
- *an expert system works with complex sets of rules in a rule base*
- *the objective of the expert system is to emulate the complex decision process of a cartographer*

4.5 Summary

In this unit we learn about the presentation of out spatial data through maps. The basic concepts of map designing and how it has evolved through time is also outline here. The key components, like title, legend, scale along with their proper placements all contribute to the readability and usefulness of a map. The scale at which the map displays the data is also elaborated here. The labeling of features and its placement on the map together enhances the usefulness of the map.

4.6 Glossary

- ***Aesthetic***- *pertaining to a sense of the beautiful*
- ***Medieval***- *of, pertaining to, characteristic of, or in the style of the Middle Ages:*
- ***Renaissance***-*The activity, spirit, or time of the great revival of art, literature, and learning in Europe beginning in the 14thcentury and extending to the 17th century, marking the transition from the medieval to the modern world.*
- ***Attribute***- *Nongraphic descriptive information about features, characteristics or elements of a database. For a database feature like census tract, attributes might include many demographic facts including total population, average income, and age. In statistical parlance, an attribute is a variable, whereas the database feature represents an observation of the variable.*
- ***Statistics***-*The science that deals with the collection, classification, analysis and interpretation of numerical facts or data and that by use of mathematical theories of probability, imposes order and regularity on aggregates of more or less disparate elements.*
- ***Layout***- *The arrangement of elements on a map, possibly including a title, legend, north arrow, scale bar, and geographic data.*

4.7 References

1 *http://academic.emporia.edu/aberjame/map/h_map/h_map.htm*

2 *http://www.theepochtimes.com/n2/content/view/24170/*

3 *http://49987376.nhd.weebly.com/world-maps-the-need-facilitated-change.html*

4 *http://www.colorado.edu/geography/gcraft/notes/cartocom/section4.html*

5 *http://www.gsd.harvard.edu/gis/manual/style/*

6 *http://maps.nrcan.gc.ca/topo101/scale_e.php*

7 *http://www.compassdude.com/map-scales.shtml*

8 *http://gitta.info/LayoutDesign/en/html/MapSizeScale_learningObject3.html*

9 *http://www.sonic.net/~dmed/MedeCart/About_Me_files/Positioning_Names_on_Maps.pdf*

10 *http://ls11-www.cs.uni-dortmund.de/people/preuss/pages/projects/dip/dip.pdf*

4.8 Suggested Readings

1 *Misra, R.P. and A. Ramesh. 1989. Fundamentals of Cartography (Revised and Enlarged). Published by Concept Publishing Company, Mohan Garden, New Delhi, India. ISBN (Paperback): ISBN NO: 9788170222224*

4.9 Terminal Questions

1 *What, in your opinion, is the use of a map?*

2 *Name 3 criteria which should be kept in mind when labeling in a map.*

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