

**DEVELOPMENT AND TRAINING ON
GEOGRAPHICAL INFORMATION SYSTEM (GIS)
FOR KRP'S IN GEOGRAPHY**

PAC 18.15

by

Dr.Shivanand Chinnappanavar
Programme Co-ordinator



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Preface:

The five days PAC programme titled **Development and Training on Geographical Information System (GIS) for KRP's in Geography** was conducted from 18th to 22 January 2016 by NCERT's, Regional institute of Education, Mysore.

The major objectives of this programme is to develop skills of GIS and get acquainted with open source GIS software's. The present report contains some topics and sessions which are discussed in the five days training programme and also the QGIS manual.

The training programme is attended by 11 PGT's Geography of various Navodaya Vidyalaya Samithi. In the beginning of the training programme the main objectives of training programme are briefed and also about QGIS manual. The resource persons were drawn from University of Chennai and Mysore and JSS University Mysore.

Throughout the training programme main emphasis is given on hand on experience through QGIS manual so that the participants get acquainted with GIS and develop a thematic map of their own, which can be useful in the daily classroom process of teaching and learning.

The training programme is concluded on 22nd January 2016 and the feedback and suggestion were collected from participants so that in the further training programme these concerns will be taken care.

Programme Co-ordinator

Dr. Shivanand Chinnappanavar
Assistant Professor, Geography

Programme Coordinator:

Dr. Shivananda Chinnappanavar

Team Members and Resource Persons:

Prof. Krishnamurthy, Retd. Professor, University of Mysore

Prof. Madha Suresh, Professor, Disaster Management, University of Madras

Dr. Arun Das, Assistant Professor, Dept. of Geography, University of Mysore.

Dr. Bhaskaran Assistant Professor, Dept. of Geography, University of Madras

Mr. Ravi Kumar, GIS Course Co –ordinator, JSS University, Mysore.

Mr. Sawant Sushant Anil, Assistant Professor,(Adhoc) RIE, Mysore.

Introduction to GIS

INTRODUCTION

Geographic Information Systems (GIS) are a new technology that combines the world of database management with digital maps and graphics.

A Geographic Information System can be defined as:

"A system of computer hardware, software and procedures designed to support the capture, management, analysis, modeling and display of geographically referenced data for decision making. It is a way in which to begin to represent and model the real world."

General Definition: a geographic information system is any manual or computer-based set of procedures used to store and manipulate geographically referenced data.

Specific Definition: A geographic information system is a computer-based system that provides four sets of capabilities to handle georeferenced data: 1) Input, 2) Data Management, 3) Manipulation and Analysis, 4) Output.

Why use a Geographic Information System?

Ultimately a GIS is used for decision support and decision-making concerning real-world problems. A GIS allows us to produce a model from which decision can be made concerning the real world.

ArcView is referred to as a desktop mapping and geographic information system, in that it supports the capture, management, analysis, and presentation of the data, however it is limited in its spatial analysis capabilities. By limiting the spatial analysis functions, the desktop GIS provides the user with a fast, easy to use, efficient system, with 90% of the functionality of the more advanced and costly GIS products.

For many interpretive functions what the resource person requires is a 'visual spatial analysis' using ArcView as an automated light table and the querying capabilities to analyze natural resource data. This combination automates the process of map compilation, data analysis, and map/report production.

GIS FUNCTIONS

GIS Provides four main sets of capabilities to handle geographically referenced data:

- Data Input
- Data Management
- Data Manipulation and Analysis
- Data Output

Data Input

Converts the data from an existing form into one that can be used by a GIS in a digital format. The data may be captured in either a vector format or in a raster format. This may be accomplished through manual digitizing, scanning, or from existing digital data.

Data Input Methods

1. Manual Digitizing (vector)
2. GPS (vector: point, line, area)
3. Scanning (raster)
4. Remote Sensing (raster)
5. Existing Digital Data (vector and/or raster)
6. Existing Digital Data:
7. Digital Base Maps (vector)
 - Ministry of Natural Resources, Ontario Base Maps (OBM) Scale: 1:20,000, 1:10,000, and 1:2,000.
 - Energy, Mines and Resources, National Topographic Series Scale: 1:250,000, 1:50,000.
 - USGS DLG Topographic Series: 1:24,000, 1:100,000, 1:250,000, 1:2,000,000

Graphics Formats

- SIF Standard Interchange Format
- DGN Integraph Format
- DXF AutoCAD Interchange Format
- DLG USGS Digital Line Graph

Other Data Sets

Natural Resource Data:

Ministry of Natural Resources
Ministry of Northern Development & Mines
Department of Energy, Mines and Resources

Landuse & Landcover:

U. S. Geological Survey
Environment Canada

Census-related Data:

U.S. Census Bureau; Statistics Canada
City Streets and Addresses:

- Area Master Files (Canada)
- TIGER files (USA)

Digital Elevation Data:

Digital Terrain Models (DTM, DTED)

Digital Elevation Models (DEM)

Data Management

These are the functions performed by a Geographic Information System to store and retrieve data from the database. This capability is similar to that provided by database management software. The data are entered into a pre-defined structure which may or may not be inter-related.

Nature and Representation of Geographic Data

The three main components to geographic data are:

- Geographic Position
- Attribute or nature of the data
- Spatial Relations between the data

The geographic component may be represented in terms of a coordinate system such as Latitude, Longitude, and Elevation. The Attribute component may be the feature being represented and any quantitative or qualitative characteristics. The spatial relationship between the data is a reflection of location.

Data Models

There are two basic approaches in representing the spatial component of geographic information and these are the Raster Data Model and the Vector Data Model.

Raster Data Model: In the raster model the representation of points, lines, and areas uses a unit cell such that a line is produced by a series of cells or 'pixels'; a point is represented by one cell, and an area is represented by a two dimensional array of cells.

Vector Data Model: In the vector model the representation of points, lines and areas uses Cartesian Coordinates and have a mathematical definition.

Data Quality

Accuracy: Positional Accuracy is the expected deviation in the geographic location of an object from its true ground position. Information may be derived from hardcopy files

which have an estimated position on a map, or from coordinate data on file. When the data is digitized, the scale at which an object is represented on a map will also influence the positional accuracy.

Base maps also have a accuracy which is limited to the scale being represented. Ontario Base Maps (OBM) at 1:20,000 scale have a stated accuracy limit of +/- 10 metres; National Topographic Series Base maps at 1:250,000 have an accuracy limit of +/- 50 metres. When these maps are digitized, the georeferencing and digital conversion process may cause a shift from true location of 50 to 200 metres.

Resolution: Digital base maps are designed to be accurate within the scale at which they were digitized. When zooming or magnifying a map area using a GIS or CAD system, it is important to remember that the representation of information at a scale that is larger than the original will have the inherent inaccuracy of the base map. For an NTS 1:250,000, the maximum scale which retains the original accuracy of the map is 1:50,000, which represents the scale at which they were digitized. As well, it should also be noted that the representation of a point or symbol on a map might be several 100 metres depending on the symbol size and the scale of the map.

Data Manipulation and Analysis

Data manipulation and analysis functions may vary from one GIS to another but can be broadly sub-divided into *spatial vs. non-spatial analysis*. Spatial analysis requires knowledge of the geographic relationships between the data (points, lines, and polygons) contained in the GIS; non-spatial analysis represents a query of the database similar to those functions in database management software. Generally, a GIS with advanced spatial analysis capabilities requires more processing time and more memory storage capacity than those without.

GIS analysis functions can be sub-divided into the following categories:

1) Maintenance and Analysis of Spatial Data; this includes:

- Format Transformations ie. DXF to ArcView
- Geometric Transformations ie. map registration
- Transformations between map projections

2) Maintenance and Analysis of Non-Spatial Data; this includes:

- Attribute Editing Functions
- Attribute Query Functions

3) Integrated Analysis of Spatial and Attribute Data; this includes:

- Overlay Operations
- Neighbourhood Operations
- Connectivity Functions
- Retrieval, Classification, Measurement

4) Output Formatting; this includes:

- Map Annotation
- Text Labels
- Texture patterns and Line Styles
- Graphic Symbols

Data Output

The GIS has to output the data in the form of maps, tables, and text either as softcopy (on-screen or electronic file) or as hardcopy (paper or film). In considering a GIS it is important to assess the quality, accuracy, and ease of use for the output. Generally, vector-based systems can produce higher quality map output than raster-based systems.

Data Output Devices:

- Pen Plotters
- Printers
- Ink Jet Plotters
- Electrostatic Plotters
- Thermal Plotters
- Optical Film Writers

Some colour inkjet printers can be configured to emulate a pen plotter. The resulting output is a high quality plot in a shorter period of time compared with a normal pen plotter. For the GPS/desktop-GIS course an HP Deskjet 500C is used with HP plotter emulation software.

GIS PROJECT PLANNING

A definition of the goals and objectives for a Geographic Information System is required at the start, which is based on clear and realistic business objectives. When the purpose of the GIS has been established, a structured approach towards the design and implementation of a GIS can be considered.

The establishment of a Geographic Information System within an organization can be considered to occur in four phases:

- 1) **Conception:** the process that leads to the initiation of a GIS project. The political, administrative and monetary commitments are obtained and the general system philosophy and scope are determined.
- 2) **Design:** the general philosophy during the first phase is translated into a definition of the system, within the scope and monetary constraints identified in the conception phase. This will involve:
 - analyzing the functions of the organization
 - the inter-relationship of the various functions
 - identifying the information requirements for each function
 - deciding on priorities
 - development of a general technical design.
- 3) **Implementation:** the process of constructing the design created in the second phase. This would involve developing a technology transfer strategy, including organizational change, training plans, roles and responsibilities of organizational units.
- 4) **Operation and Maintenance:** making the system available to users and satisfying the objectives identified during conception. It includes day-to-day technical management, enhancements, and performance evaluation.

A planning-prototyping (pilot project) approach to desktop GIS implementation is the most optimal in that it allows the organization to assess the value of a system, using a readily available data set before committing to a final system architecture. This allows the organization to determine their functional requirements and achieve a level of productivity that would otherwise require more time.

Accustomization to Computer

1 Introduction

GIS has moved into the mainstream to become a core enterprise technology. As a result, GIS is treated as a corporate resource that needs computing platforms and capabilities to support multi-terabyte-sized data storage. The overwhelming trend has a voracious appetite for more computing power in the enterprise - power to speed application processing, power to respond to more users, and power to access and transfer more information.

First, rapid software and hardware innovation continues to increase system performance and reduce computing's relative cost. Software innovation includes the implementation of multi-tier, distributed software components that enable scaling GIS and other information technology (IT) applications across multiple processors, computer clusters and data storage clusters. Hardware innovation includes advanced processors, memory systems, input/output connectivity and data storage systems. In particular, workstation and server manufacturers have been quick to adopt the latest processors from Intel, including Intel's 32-bit Pentium III Xeon processors. They're also using 64-bit processor technology, including the fast 64-bit RISC processors produced by Silicon Graphics, Sun Microsystems, IBM and Hewlett-Packard, and the forthcoming Intel 64-bit Itanium processor.

Second, while computer performance is going up, the relative cost of computing power continues to get less expensive. Users can buy computers and more powerful computer system configurations for end users and the enterprise. The increased market demand continues to drive the relative cost down to affordable levels for tremendous computing capacity.

Third, the Internet continues to become more integrated into businesses. This increases demand for enterprise- and workgroup-level servers, for workstations used to develop distributed applications and digital content, and for desktops/notebooks that support end users. The enterprise-level server configurations are providing powerful solutions for thin-client 'server farms' that support high-volume file and print sharing, database applications, and messaging requirements to support Internet and intranet applications.

In short, today's hardware companies offer more options than ever for graphics-intensive applications such as GIS.

2.2 Components of a computer : A computer has four essential components namely Input unit, memory unit, Central Processing unit and Output unit.

Input unit accepts the data and program to process the data.

Memory unit stores in it the data and program accepted by the input unit.

Processing unit retrieves the program and data from the memory unit and processes that to achieve the desired results. The processing unit then stores these results in the memory unit.

Output unit prints the stored results.

2.2.1 Software is a collection of programs written to perform a specific application. An application may have many functions to be performed and the purpose is solved by having the combined result. All the necessary programs are integrated (Packed) for that purpose. This package of programs is then called a software.

What types of software exist? There are two types of software; one which enables the users to write programs easily, in a way this type of software provide an environment for the easy use of computers. These are called *system software*. Examples are DOS (Disk Operating System), UNIX operating system, other operating systems, compilers editors, loaders etc.. Second type of software is known as *application software*. These software are designed and developed to perform certain user required tasks. Some examples are, GIS and Image Processing software e.g. ARC/INFO, ERDAS, PAMAP, EASI/PACE and other software like WordStar, LOTUS etc..

2.2.2 Hardware of a computer refers to the physical tangible components . When a computer does a job, each of these hardware components does a part of job. A computer system consists of a processing unit, and a memory unit connected to a number of peripheral devices. A peripheral device is external to a computer's processing and memory unit. Examples are printers, plotters, keyboards, mouse, plotter pen, display terminal etc. All the four logical units of computer system viz. input, output, processing, and memory units are composed of corresponding hardware devices which are termed as input devices, output devices, central processor and storage devices respectively.

2.2.3 Input/Output unit : As we had seen earlier that the input unit accepts the data in machine readable form . It then transforms the data to the appropriate internal code and stores in then computer memory. The processed data stored in the memory is sent to an output unit when commanded by a program . The output unit transforms the internal representation of the data into a form which can be read by people. The input and output units of a computer are normally abbreviated as I/O units

The most commonly used input devices are punched card readers, magnetic floppy disk readers etc. note that the input devices are not data entry devices. Some examples of the data entry devices are keyboards, digitisers, plotter pens, scanners etc.

Principal devices to output information from a computer are printers, drum printers, chain printers, serial printers, various other devices such as printer plotters, plotters and laser printers.

2.2.4 Central Processing unit : A central processing unit in a computer interprets instructions in a program and carries them out.

Processors are designed to interpret a specified number of instruction codes. Each instruction code is a string of binary digits. All processors have input/output instructions, arithmetic instructions, branch instructions, and instructions to manipulate characters. The number and type of instructions differ from processor to processor.

The hardware of the CPU is a large scale semiconductor integrated circuit chip. This chip contains

- * An instruction register and decoder
- * An Arithmetic Logic unit (ALU)
- * A number of registers to store and manipulate data
- * Control and timing circuits

An integrated circuit (IC) is fabricated on a chip of doped silicon using processes of oxidation, coating with photo resist chemical, etching, diffusion, metal vaporisation, gold bonding of leads and finally capsulation. Integrated circuits are classified as small scale IC (VLSI), medium scale IC (MSI), large scale IC (LSI) and very large scale IC (VLSI) based on the number of transistors on the chip. The respective number of transistors are 20, 100, 1000, and 10000.

2.2.5 Memory unit : A memory unit is required in a computer to store programs and data processed by programs. When we talk about the actual hardware of memory, we must first discuss the smallest components of which a memory is made up of. This smallest component is called a memory cell. The technology allows the memory cell to store only one of the two symbols. In other words, the technology is such that it allows the memory cell to be only in one of the two stable states at a time. The reason is that the actual physical devices used to build a memory cell are only two state devices. Some examples of two state devices are electric switches which can be either ON or OFF, a magnetic field which is either N(north) or S(south). Thus a memory cell stores information in the form of string of bits 0 and 1. The memory cells are organised as a set of addressable words, each word storing a sequence of bits.

2.3 STORAGE DEVICES

2.3.1 Magnetic Hard Disk

Magnetic disks are smooth metal plates coated on both sides with a thin film of magnetic material. A set of such magnetic plates are fixed to a spindle one below the other to make a disk pack. The disk pack is mounted on a disk drive. The disk drive consists of a motor

to rotate the disk pack about its axis at a speed of about 3600 revolutions per minute. The drive also has a set of magnetic heads mounted on arms. The arm assembly is capable of moving in and out in a radial direction. Information is recorded on the surface of a disk as it rotates about its axis. Thus it is on the circular tracks on each surface (Fig.2.4a). A set of concentric tracks are recorded on each surface. A set of corresponding tracks all surfaces of a disk pack is called a cylinder. In a disk pack with 6 plates there are 12 surfaces. Out of the 12 surfaces, the topmost surface and the bottom most surface are not used for recording. Thus there are 10 surfaces on which information is recorded. Each track on the disk is divided into sectors. Read and write operations on a disk start at sector boundaries. Typically 512 bytes are stored in a sector. There are 50 sectors per track per track and 400 tracks per surface.

Capacity of the Hard Disk: The total number of bytes a hard disk can store is:

(no. of surface x no. of tracks per surface x no. of sectors per track x no. of bytes per sector) = $10 \times 400 \times 50 \times 512 = 102400000 = 102.4 \text{ m}$

i.e. the capacity of a hard disk is 102.4 million bytes.

Your hard disk plays a significant role in the following important aspects of your computer system:

- **Performance:** The hard disk plays a very important role in overall system performance, probably more than most people recognize. The speed at which the PC boots up and programs load is directly related to hard disk speed. The hard disk's performance is also critical when multitasking is being used or when processing large amounts of data such as graphics work, editing sound and video, or working with databases.
- **Storage Capacity:** This is kind of obvious, but a bigger hard disk lets you store more programs and data.
- **Software Support:** Newer software needs more space and faster hard disks to load them efficiently. It's easy to remember when 100 MB was a lot of disk space but now a PC with that much can't even hold a full installation of many operating systems.
- **Reliability:** There is perhaps nothing quite so frustrating as a hard disk problem that can cause unreliable operation or even data loss. A good quality hard disk, combined with smart maintenance and backup habits, can help ensure that this doesn't become a problem.

2.3.2 Floppy Disks:

A soft magnetic disk. It is called *floppy* because it flops if you wave it (at least, the 5¼-inch variety does). Unlike most hard disks, floppy disks (often called *floppies* or *diskettes*) are portable, because you can remove them from a disk drive. Disk drives for floppy disks are called *floppy drives*. Floppy disks are slower to access than hard disks and have less storage capacity, but they are much less expensive. And most importantly, they are portable.

Floppies come in two basic sizes (Fig.2.4 b):

- **5¼-inch:** The common size for PCs made before 1987. This type of floppy is generally capable of storing between 100K and 1.2MB (megabytes) of data. The most common sizes are 360K and 1.2MB.
- **3½-inch:** *Floppy* is something of a misnomer for these disks, as they are encased in a rigid envelope. Despite their small size, microfloppies have a larger storage capacity than their cousins -- from 400K to 1.4MB of data. The most common size for PC 1.44MB (high-density). Macintoshes support disks of 400K, 800K, and 1.2MB.

Floppy Disk Densities

<i>5¼-inches</i>			
	<i>Single</i>	<i>Double</i>	<i>High</i>
PC	360K	720K	1.2MB
Mac	NA	NA	NA
<i>3½-inch</i>			
	<i>Single</i>	<i>Double</i>	<i>High</i>
PC	NA	720K	1.44MB
Mac	400K	800K	1.2MB

2.3.3 Magnetic Tape:

Magnetic tape memories are similar to the commonly used audio tape recorders. A magnetic tape drive consists of a spool on which a magnetic tape is wound. The tape is transported across a set of magnetic heads and is taken up on another spool. The nine heads record information on nine parallel tracks, parallel to the edge of the tape. Out of the nine tracks, eight tracks are used to record a parity bit for each type. The width of the tape is 0.5 inch. The recording density is bits per inch (bpi) along its length. If 1600 bpi is the recording density, the total number of bits stored will be $1600 \times 9 = 14400$ bits. The data recorded on a tape is accessed only sequentially.

2.3.3 CD-ROMs

In recent years, optical (as opposed to magnetic) disks have become available. They have much higher recording densities than conventional magnetic disks. Optical disks were originally developed for recording television programs, but they can be put to more esthetic use as computer storage devices. Due to their potentially enormous capacity, optical disks have been the subject of a great deal of research and have gone through an incredibly rapid evolution. Most commercial software now comes on CD-ROMs (Fig.2.4 c).

All CDs are 120 mm across and 1.2 mm thick, with a 15-mm hole in the middle. A CD is prepared by using a high-power infrared laser to burn 0.8-micron diameter holes in a coated glass master disk. -From this master, a mold is made, with bumps where the laser holes were. Into this mold, molten polycarbonate resin is injected to form a CD with the same pattern of holes as the glass master. Then a very thin layer of reflective aluminum

is deposited on the polycarbonate, topped by a protective lacquer and finally a label. The depressions in the polycarbonate substrate are called pits; the unburned areas between the pits are called lands. When played back, a low-power laser diode shines infrared light with a wavelength of 0.78 micron on the pits and lands as they stream by. The laser is on the polycarbonate side, so the pits stick out toward the laser as bumps in the otherwise flat surface. Because the pits have a height of one-quarter the wavelength of the laser light, light reflecting off a pit is half a wavelength out of phase with light reflecting off the surrounding surface. As a result, the two parts interfere destructively and return less light to the player's photodetector than light bouncing off a land. This is how the player tells a pit from a land. Although it might seem simplest to use a pit to record a 0 and a land to record a 1, it is more reliable to use a pit/land or land/pit transition for a 1 and its absence as a 0, so this scheme is used. The pits and lands are written in a single continuous spiral starting near the hole and working out a distance of 32 mm toward the edge. The spiral makes 22,188 revolutions around the disk (about 6000 per mm). The spiral is illustrated in Fig.2.1

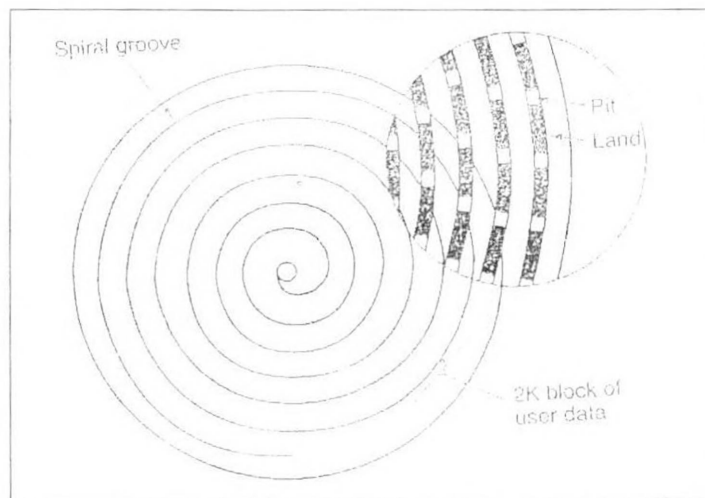


Figure 2.1 Recording structure of a Compact Disc or CD-ROM

2.3.4.1 CD-Recordables:

Physically, CD-Rs start with 120-mm polycarbonate blanks that are like CD-ROMs, except that they contain a 0.6-mm wide groove to guide the laser for writing. The groove has a sinusoidal excursion of 0.3 mm at a frequency of exactly 22.05 kHz to provide continuous feedback so the rotation speed can be accurately monitored and adjusted if need be. CD-Rs look like regular CD-ROMs except that they are gold colored on top instead of silver colored. The gold color comes from the use of real gold instead of aluminum for the reflective layer. Unlike silver CDs, which have physical depressions on them, on CD-Rs the differing reflectivity of pits and lands has to be simulated. This is done by adding a layer of dye between the polycarbonate and the reflective gold layer, as shown in Fig. 2.2. Two kinds of dye are used: cyanine, which is green, and phthalocyanine, which is a yellowish orange.

In its initial state, the dye layer is transparent and lets the laser light pass through and reflect off the gold layer. To write, the CD-R laser is turned up to high power (8-16 mW). When the beam hits a spot of dye, it heats up, breaking a chemical bond. This change to the molecular structure creates a dark spot. When read back (at 0.5 mW), the photodetector sees a difference between the dark spots where the dye has been hit and transparent areas where it is intact. This difference is interpreted as the difference

between pits and lands, even when read back on a regular CD-ROM reader or even on an audio CD player

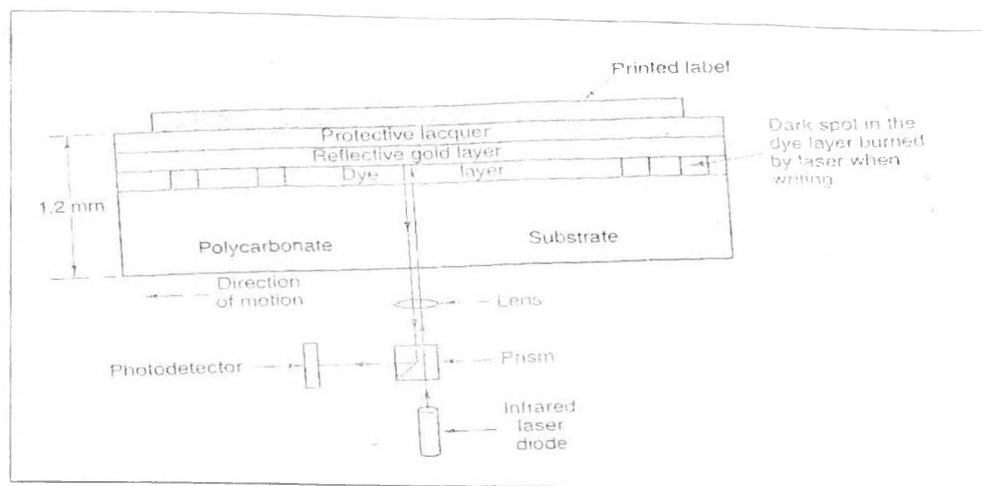


Fig.2.2 Cross section of a CD-R disk and laser.

2.3.4.2 CD-Rewritables

CD-RW drives use lasers with three different powers. At high power, the laser melts the alloy, converting it from the high-reflectivity crystalline state to the low-reflectivity amorphous state to represent a pit. At medium power, the alloy melts and reforms in its natural crystalline state to become a land again. At low power, the state of the material is sensed (for reading), but no phase transition occurs.

The reason CD-RW has not replaced CD-R is that the CD-RW blanks are much more expensive than the CD-R blanks. Also, for applications consisting of backing up hard disks, the fact that once written, a CD-R cannot be accidentally erased is a big plus.

2.3.5 DVD

The basic CD/CD-ROM format has been around since 1980. The technology has improved since then, so higher-capacity optical disks are now economically feasible and there is great demand for them. **DVD**, originally an acronym for **Digital Video Disk**, but now officially **Digital Versatile Disk** (Fig 2.3 & 2.4 d). DVDs use the same general design as CDs, with 120-mm injection-molded polycarbonate disks containing pits and lands that are illuminated by a laser diode and read by a photodetector. -What is new is the use of

1. Smaller pits (0.4 microns versus 0.8 microns for CDs).
2. A tighter spiral (0.74 microns between tracks versus 1.6 microns for CDs).
3. A red laser (at 0.65 microns versus 0.78 microns for CDs).

Together, these improvements raise the capacity sevenfold, to 4.7 GB. A 1x DVD drive operates at 1.4 MB/sec (versus 150 KB/sec for CDs). Unfortunately, the switch to the red lasers used in supermarkets means that DVD players will require a second laser or fancy conversion optics to be able to read existing CDs and CDROMs, something not all of them may provide. Also, reading CD-Rs and CDRWs on a DVD drive may not be possible. So four formats have been defined:

1. Single-sided, single-layer (4.7 GB).
2. Single-sided, dual-layer (8.5 GB).
3. Double-sided, single-layer (9.4 GB).
4. Double-sided, dual-layer (17 GB).

The dual layering technology has a reflective layer at the bottom, topped with a semireflective layer. Depending on where the laser is focused, it bounces off one layer or the other. The lower layer needs slightly larger pits and lands to be read reliably, so its capacity is slightly smaller than the upper layer's.

Double-sided disks are made by taking two 0.6-mm single-sided disks and gluing them together back to back. To make the thicknesses of all versions the same, a single-sided disk consists of a 0.6-mm disk bonded to a blank substrate (or perhaps in the future, one consisting of 133 minutes of advertising, in the hope that people will, be curious as to what is down there). The structure of the double-sided, dual-layer disk is illustrated in Fig. 2.3.

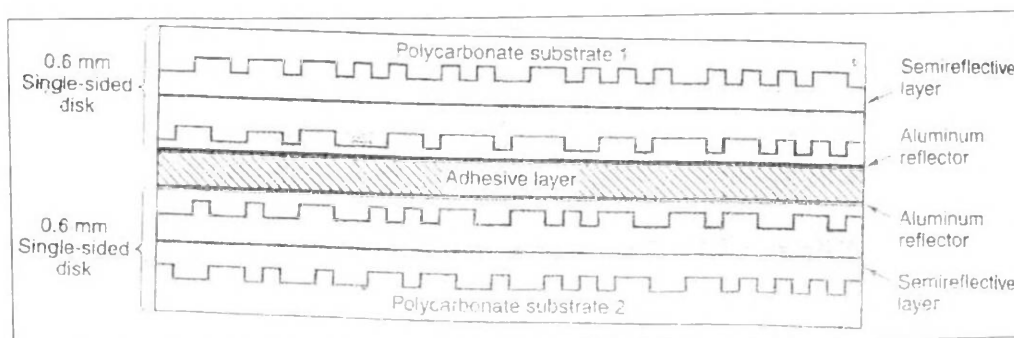


Fig.2.3 A double sided, dual layer DVD disk

2.3.5 DAT

Digital Audio Tape (Fig.2.4 e) was developed in the 1980's as a successor to the analog cassette tape. Sometimes called "4mm," the tape is actually 3.81mm wide. Information is recorded using the "helical scan" recording technique which is the same method used in

VHS, Beta, and 8mm videocassette recorders. Compared to these other formats, DAT tapes are much smaller and the information is encoded digitally. Although the 4mm format was originally designed for audio use, it has received widespread acceptance for archival (backup) of computer data.

Digital Audio Tape is a new format to store music developed in the mid-1980s by Sony and Philips. As digital music was popularized by compact discs, the need for a digital recording format for the consumer existed. The problem is because digital music contains such a high volume of data (over 5 megabytes of data per minute before error correction and supplementary information) an aggressive way of storing it is needed. Prior to DAT, the only way to record digitally was to use a video deck or a reel-to-reel, not convenient consumer products. The solution was to use a rotary-head format, where the read/write head spins diagonally across the tape (also called a helical scan). This is the way that VCRs are able to store their large amounts of data. Thus the proper name is "R-DAT", where "R" for rotary distinguishes it from "S-DAT", a stationary design that did not make it out of the laboratories. Studio reel-to-reel decks are able to use stationary heads because they can have wider tape and faster tape speeds, but for the desired small medium of DAT the rotary-head compromise was made. This means more moving parts and potentials for problems, but the results are stunning. Most decks appear to be a cross between a typical analog cassette deck and a compact disc player. In addition to the music, one can record subcode information such as the number of the track (so one can jump between songs in a certain order) or absolute time (counted from the beginning of the tape). The tape speed is much faster than a regular deck (one can rewind 30 minutes of music in 10-25 seconds), though not quite as fast as a compact disc player. Decks have analog inputs and outputs like on a regular tape player; they also have digital i/o. This allows one to make a copy onto another DAT deck directly (without having the music converted to analog and then reconverted to digital). This will make perfect copies since all that is transferred is numbers (no music that can be distorted). The procedure is very easy since there are no levels to set or other factors: everything is preserved as on the original. Making "clones" like this can thus preserve the quality of the original recording through a theoretically infinite number of copies, though some respected producers dispute this. As the deck is similar in technology to a video deck, so too is the tape similar to a video tape. The tape shell is about half the size of an analog cassette and is protected by a hinged door like a videotape. Upon playing, the door is opened and the tape pulled out and wrapped around the spinning head. A tape can be as long as 90 or 120 minutes, and since there is only one "side" to the tape that is uninterrupted time! Even if recordable CDs become available for consumers, it will be a while before they can approach times longer than an hour. DAT defines the following recording modes with the following performance specifications... 2 channel 48KHz Sample rate, 16-bit linear encoding, 120 min max. Frequency Response 2-22KHz (± 0.5 dB) SN = 93 dB DR = 93 dB 2 channel 44.1KHz Sample rate, 16-bit linear encoding, 120 min max Frequency Response 2-22KHz (± 0.5 dB) SN = 93 dB DR = 93 dB 2 channel 32KHz Sample Rate, 12-bit non-linear encoding, 240 min max Frequency Response 2-14.5KHz (± 0.5 dB) SN = 92 dB DR = 92 dB DAT also defines a 4 channel 32KHz mode.

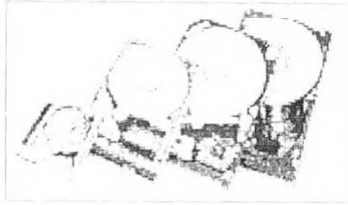


Fig.2.4 (a) HARD DISK

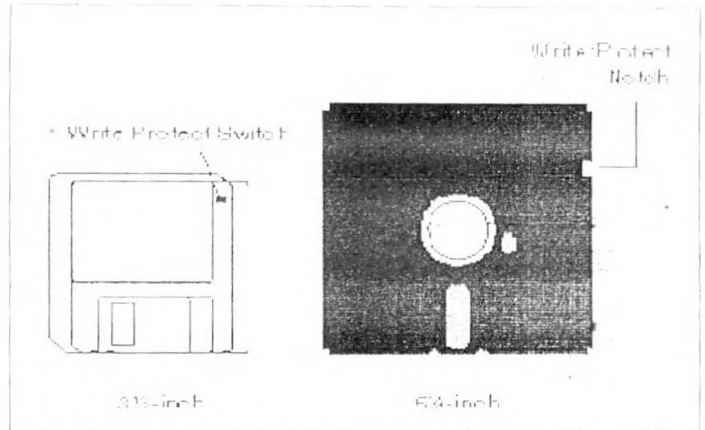


Fig.2.4 (c) CD-ROM



Fig.2.4 (d) DVD



Fig.2.4 (e) DAT

Fig.2.4 (b) Floppy Disk

2.4 Design Philosophy of GIS:

Attracted by glitter and promises of industry's marketing strategy, inexperienced users and even experienced users do mistakes in choosing a proper hardware and software. There are different phases involved in implementing a GIS and we will be concentrating mainly on Hardware and Software part.

Implementation process of a GIS can be divided broadly into Five major stages.

- **Concept** (Requirement analysis, Feasibility analysis)
- **Design** (Implementation plan, system design, DB design)
- **Development** (System acquisition, DB acqu., Organizing staff & training, Operation procedure preparation, site preparation)
- **Operation** (System installation, pilot project, data conversion, application Development, conversion to automated operations)
- **Audit** (System review, system expansion)

The philosophy of a GIS design can be drawn as following (Fig.2.5):

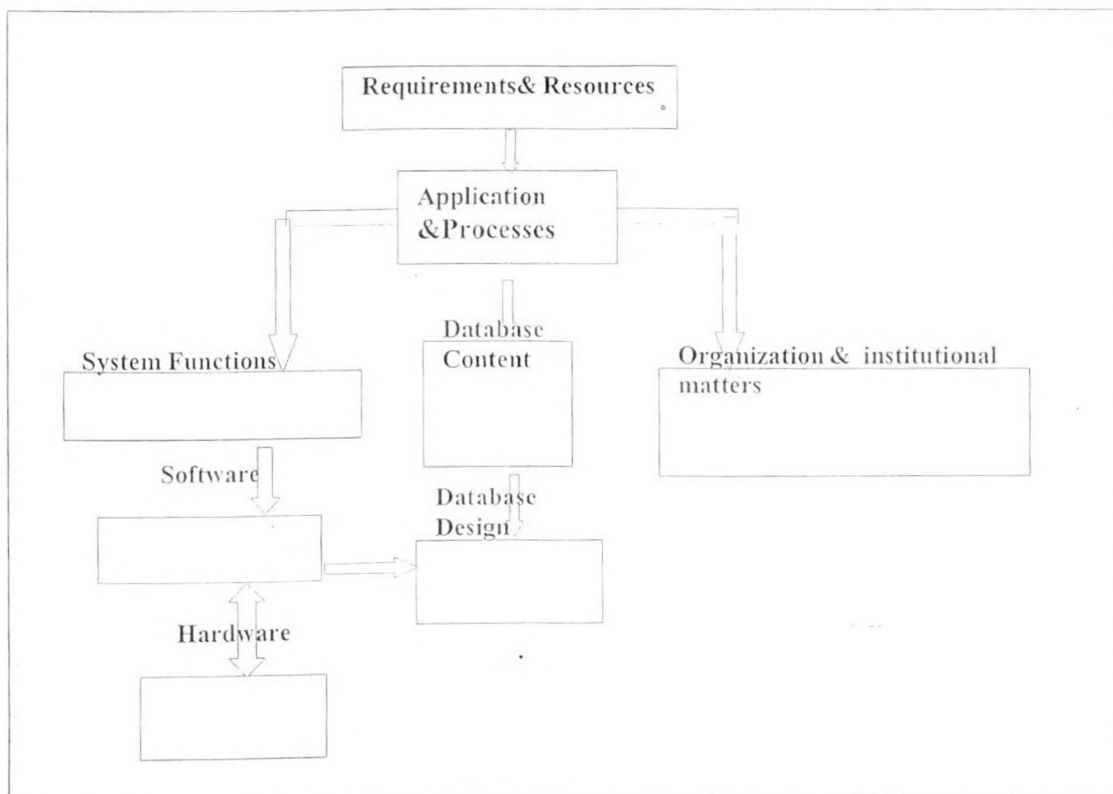


Fig.2.5 GIS Design

It is clear that *Applications drives the system design*. Hardware and Software part plays the brickstone part which can be bought at any time once the conceptual design is ready. But at the same time we cannot ignore them. Once again between software and hardware it was a general opinion that **Computer hardware should be viewed as subordinate to software**.

In some situations, processor and operating system influence, even control, the selection of GIS software. An organization that has accepted a particular vendor as its supplier sometimes limits its software choices. In other instances, the availability of existing processing resources and the need to avoid additional costs governs the choice of a hardware platform.

2.5 System Design:

GIS is implemented typically by acquiring a commercially available hardware and software system. Numerous GIS systems are available in the market place, each with individual strengths and weaknesses that should be assessed in light of the organization's requirements.

Hardware: Generally Hardware is being accessed by six factors.

- Affordability (Cost of the machine)
- Scalability (Vertical or horizontal growth)
- Reliability (System performance, Average down/recovery time)
- Connectivity (Network capability)
- Security (Protection from hackers)
- Accessibility (User friendliness)

Ever increasing need for sharing information forced the technocrats and techno-architects to make the systems which almost satisfies all the major above said characters. Nowadays the Computer without Internet is being considered like having a car without road. So the network capability, design has to be given important weight while choosing hardware and peripherals. Nowadays even printers are coming as "Network Ready" without being connected physically to a computer.

Following Hardware is required to have full-fledged GIS:

1. **Computer** (233/300/450 MHZ Chip, 32/64/128 MB RAM, 2/4/10 GB HDD, 1.44MB FDD, 32x/48x CD-ROM Drive)
2. **Digitizer** (A3/A1/A0 size)
3. **Graphics Accelerator Card**
4. **Color Plotter / Printer**

5. External Storage Devices (4/6/8mm DAT drives)
6. B/W Scanner (A0 size)

Software: Before buying a S/W one should have a clear understanding of what the user really want the s/w to do for him or his project. Next step is to make sure that the GIS s/w can execute on your computer and under the control of the operating system you are using. Next step is to see its capabilities and its user friendliness. So the key terms used for validating software worthiness are

- User friendliness (easy graphical interface)
- Functionalities (Effectiveness & Efficiency)
- Compatibilities (operating system friendliness)
- Updativity (changeable with versions)
- Documentation (help on the software functions/algorithms)
- Cost_effectiveness (more functions with less price)

The following are some of the major GIS softwares available in the market:

1. Arc/Info (PC based, Workstation based)
2. ILWIS (PC based)
3. Mapinfo (PC based)
4. Modular Geographical Environment (Workstation Based)

GIS market is increasing and the available Software is innumerable. So user has to take care his need and above said characters. It is also recommended that the organization / institute which already using GIS systems can be asked for help during the procurement and implementation process. Department of Space is the leading agency in using and developing GIS based software and applications. Even it has developed many application oriented, user friendly software, derived from existing GIS software functionalities, namely GEO_SMART, DECISION_SPACE, BIO_CAP and more.

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DIGITIZING, EDITING & STRUCTURING OF MAP DATA

6.1 Introduction

The process of digitising existing maps may be regarded as one of secondary data acquisition, in the sense that it is a transformation from one (analogue) form of information storage to another (digital). This may be distinguished from primary data acquisition whereby new data are obtained by surveying. Ground-based and remote-sensing surveying methods are now heavily dependent upon computing technology, with the consequence that the survey results are readily available in digital formats.

Data input is the operation of encoding the data and writing them to the database. The creation of a clean, digital database is a most important and complex task upon which the usefulness of the GIS depends. Two aspects of the data need to be considered separately for geographical information systems, these are first the positional or geographical data necessary to define where the graphic or cartographic features occur, and second, the associated attributes that record what the cartographic features represent.

6.2 Entering the spatial data

There is no single method of entering the spatial data to a GIS rather, there are several, mutually compatible methods that can be used singly or in combination. The choice of method is governed largely by application, the available budget, and the type of data being input. The types of data encountered are existing maps, including field sheets and hand-drawn documents, aerial photographs, remotely-sensed data from satellite or airborne scanners, point-sample data (e.g. soil profiles), and data from censuses or other surveys in which the spatial nature of the data is more implicit than explicit. The actual method of data input is also dependent on the structure of the database of the geographical system.

6.2.1 Manual input to a vector system

The source data are envisaged as points, lines, or areas. The coordinates of the data are obtained from the reference grid already on the map, or from reference to a graticule or overlaid grid or point data using GPS. They can then be simply typed into a file or input to a program.

6.2.2 Digitising

A digitizer is an electronic or electromagnetic device consisting of a tablet upon which the map or document can be placed. The most common types currently used for mapping and high quality graphics are either the electrical orthogonal fine wire grid or the electrical wave phase type. Different sizes of digitizers are as follows:

Active Area	Digitizers
12" x 18"	A3 Size
24" x 36"	A1 Size
36" x 48"	A0 Size
42" x 60"	A00 Size

Digitizer accuracy is limited by the resolution of the digitizer itself and by the skill of the operator. The co-ordinates of a point on the surface of the digitizer are sent to the computer by a hand-held magnetic pen, a simple device called a 'mouse' or a 'puck'. For mapping, where considerable accuracy is required, a puck consisting of a coil embedded in plastic with an accurately located point are digitized by placing the cross -hairs over it and pressing a control button on the puck. The principal aim of the digitizer is to input quickly and accurately the coordinates of point and bounding lines.

6.2.2.1 Manual Digitising

Manually operated digitisers probably provide the most widely used means of converting pre-existing maps into digital form. Spatial data are recorded in the form of single coordinate pairs representing points, and series of coordinates representing lines and area boundaries.

The main components of a *manual digitiser* (Fig. 6.1) are a flat surface, ranging in size between small tablets about 30x30 cm to large tables 120x80 cm or more in dimension; a hand-held puck or cursor, used by the operator to indicate positions to be recorded; and a keyboard for entering alphanumeric data and possibly commands. It is the larger devices that are generally of most use in cartography. Exact positioning of the puck is made possible by a cross hair mounted within a flat glass panel, which may sometimes include a magnifying lens. Also mounted on the puck are buttons that may be used for controlling data entry.

The most commonly used technology for the digitising tables is electromagnetic, in which a table inlaid with a fine grid of wires is associated with the puck which contains a metal coil. The grid of wires in the table and the coil in the puck act either as transmitter and receiver, or receiver and transmitter, respectively. If the puck is the transmitter, the position of the cross hair is found by scanning the x- and y-coordinate grid wires to identify those nearest the puck. The exact position is then found by interpolating between the adjacent wires on the basis of the nature of the signals received. Small-format, lower resolution digitising tablets may sometimes use a stylus with a small coil in its tip, rather than a puck, as the locating device.

Operation of manual digitisers

Typically, the operating procedure for digitising a map starts by taping the source document firmly to the digitising surface. Grid or graticule reference points may then be digitised in order to register the map's coordinate system, before going on to digitise the map features themselves. An essential part of cartographic digitising is to ensure that the locational referencing information, represented by grids and geographic graticules on the map, is retained in the digital version of the map. Most medium- to largescale maps (say larger than 1:50,000) include a rectangular grid which can be used

as the basis of a linear transformation from digitiser coordinates to grid coordinates. If the map can be assumed to be undistorted, or accuracy is not a high priority, then this can be done by digitising at least three non-collinear (i.e. not on the same straight line) points on the map, the grid coordinates of which are known and may be typed in when digitising. Where higher standards of accuracy are required, and particularly when the source document is known to be distorted, a much higher number of coordinate control points should be digitised.

6.2.2.2 Semi-automatic line-following digitisers

Because manual digitising is such a time-consuming procedure, considerable effort has gone into attempts to develop automatic digitisers. This has resulted in the development of automated line-following devices, which in practice are only semi-automatic in that they must be positioned manually at the beginning of each linear feature to be digitised. They may sometimes also need to be guided manually when they encounter junctions between two or more linear features. More fully automatic devices which scan entire documents in a single pass are described in the next section.

The earliest line-following digitisers were based on mechanical designs which typically involved a flat surface on which the document lay and over which moved a sensing device mounted on a cross slide or gantry (Petric, 1990a). These were superseded by laser-based technology, exemplified by the LaserScan Company's Fastrak and Lasertrak systems. Here the source map was represented on a transparent sheet. A laser beam, deflected by mirrors, executed a local raster scanning pattern over a portion of the line to be digitised and recorded the image on film negative. This was automatically analysed to determine the path of the center of the line. The resulting coordinates then served the additional purpose of helping to determine where the next local scans should be centered in order to follow the line.

The Laser-Scan company improved on the efficiency of the laser-based line-following digitiser with the introduction of the VTRAK system which works entirely in raster mode, starting with a fully scanned image of the map to be digitised. The operator is able to monitor the progress of the digitiser on a conventional screen display and for this reason the process is sometimes referred to as *head-up digitising*. Lines that have been digitised are marked automatically by a change in colour or symbolisation. Tasks to be performed by the operator include selecting features to be vectorised, and describing them by means of codes and attributes. Guidance of the process may sometimes be needed where the automatic procedure is unable to follow the line successfully. The latter situation could arise due to poor definition on the source document or, more specifically, where lines are irregularly discontinuous due to annotation or to the presence of map symbols, which interrupt the line. Contours, for example, are often broken due to text giving height values, and where many contours merge together due to high topographic gradients. In the case of lines which are regularly discontinuous, due to a dashed symbolisation, it is possible to introduce sufficient 'intelligence' in the controlling software to cross the gaps automatically. The effectiveness of line-following digitisers is a function of the frequency with which the operator must intervene to guide it. Thus they are more inefficient on detailed urban maps, which have many line junctions at small intervals on the map. Conversely they have proved most useful for digitising contour

maps with long, relatively discontinuous and generally smooth lines. Ideally, for contour maps, the document to be digitised should be a separate sheet, with no other map data, apart from the contour values.

6.2.3 Automated scanning

Scanners that scan entire documents are designed to create a digital representation of the source in the form of a 2D array of pixel values. For the majority of cartographic and GIS applications, this array or raster must then be analysed to derive a vector representation of the geographical features and of the annotation as indicated above for the VTRAK system. In respect of their primary function, commercial scanners have usually been very effective in generating high-resolution rasters of either binary, or grey scale or colour values. It is only recently, however, that raster to vector conversion software has become sufficiently sophisticated to be able to identify and correctly digitise (in vector format) a significant proportion of the graphical and textual information found on topographic maps. Even so, considerable effort must often be expended in validation, feature coding and interactive graphical editing of the vectorised data.

Early application of scanner systems was confined to digitising simple high-quality line work, such as the colour separates of contours of published maps. Current systems use pattern recognition techniques to distinguish between, and hence provide feature identification codes for, a variety of point, line and area symbols. They can also interpret, to a high degree of success, both printed and hand-written text. It may be appreciated that the latest scanning systems have enormous potential for dealing with the backlog of traditional 'analogue' maps which must be digitised by many of the organisations wishing to take advantage of GIS technology. With the recent improvements in processing of scanned data it can be expected that these systems will continue to become more widely used.

Raster scanners (Fig 6.2) are usually based on either drum or flat-bed design (Petric, 1990a). Drum scanners, such as those manufactured by Optronics, Scitex and Tektronix, wrap the document on a drum that is rotated adjacent to a photo detector head which moves incrementally along the length of the drum. The documents may be monochromatic requiring a single detector, or full colour, in which case several photodetectors may be used simultaneously, each with their own colour filter. As an alternative to the relatively large and expensive scanners, there are available small-format devices which use movable linear or area arrays of charged couple devices (ccd). The ccds can be combined with a lens to form a camera which, in the case of the linear arrays, moves the length of the document in a single scan.

6.2.4 Spatial data already in digital raster form

All satellite sensors and multispectral sensing devices used in aeroplanes for low-altitude surveys use scanners to form an electronic image of the terrain. These electronic images can be transmitted by radio to ground receiving stations or stored on magnetic media before being converted to visual image by a computer system.

The scanned data are retained in the form of pixels. Each pixel has a value representing the amount of radiation within a given bandwidth received by the scanner from the area

of the earth's surface covered by the pixel. This value can be represented visually by a grey scale or colour. Because each cell can only contain a single value, many scanners are equipped with sensors that are tuned to a range of carefully chosen wavelengths. For example, the scanners on the original LANDSAT 1 were tuned to four wavebands (Band 1, 0.5-0.6 μm ; band 2, 0.6-0.7 μm ; band 3, 0.7-0.8 μm ; band 4, 0.8-1.1 μm) in order to be able to record differences in water, vegetation, and rock.

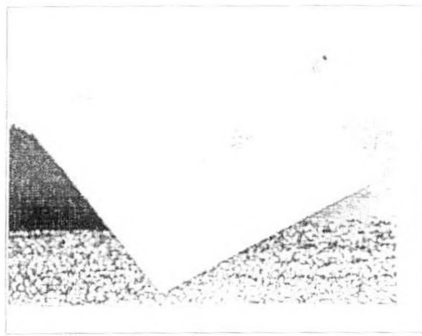


Fig.6.1 Digitiser

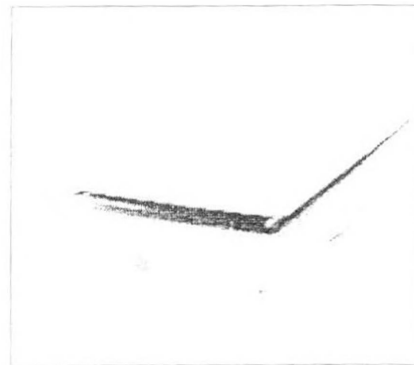


Fig.6.2 Scanner

6.3 Editing : Error Detection & Correction

All digital map data can be assumed to include errors of some sort. They arise from a combination of inaccuracy in the source data and from limitations of the digitiser operator and the computer system in use. Certain types of error, such as that due to inaccuracy of the original surveyed data, are implicit in the map source and cannot be rectified without obtaining another source of data. Other errors arise due to the operator failing to position the cursor accurately over the graphic object to be digitised or, more blatantly, missing objects from the map or wrongly entering the identity of an object. As a general rule, if an error can be detected at the time of data acquisition it will be easier to correct it then than if it is detected later, when someone is attempting to use the data. It is also the case that errors will usually be much easier to detect at the time of acquisition. Undoubtedly many digital data sets contain errors that may never be detected. In particular, locational errors often do not become apparent until similar data from different sources are combined

6.3.1 Identify digitizing errors

ARC/INFO marks potential node errors with special symbols. The two types of nodes and the potential errors they represent.

Pseudo Node drawn with a diamond symbol occurs where a single line connects with itself an (island) or where only two arcs intersect. Pseudo Node does not necessarily indicate an error or a problem. Acceptable Pseudo nodes may represent an island (a spatial pseudo node) or the point where a road changes from pavement to gravel (an attribute pseudo node). A dangling node, represented by a square symbol refers to the unconnected node of a dangling arc (Fig.6.3).

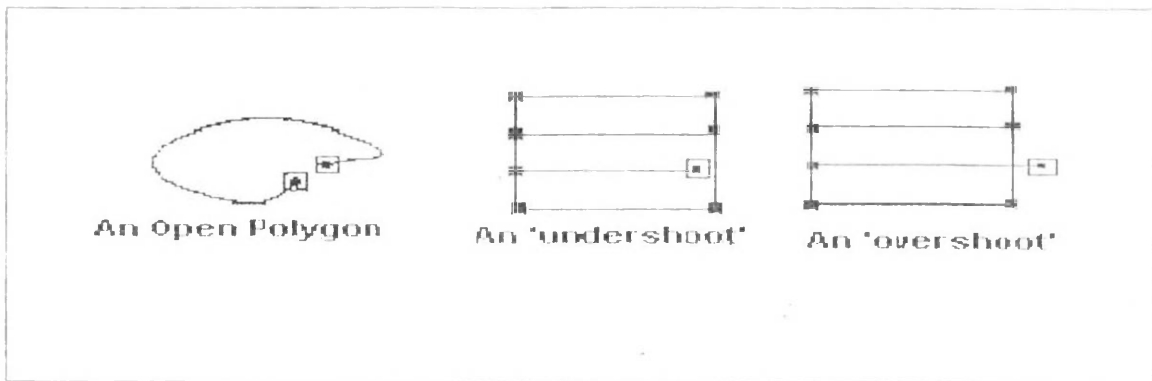


Fig.6.3 PseudoNode Error & Dangling Node Error

Here are the node and labels errors that are identified automatically (Fig.6.4).

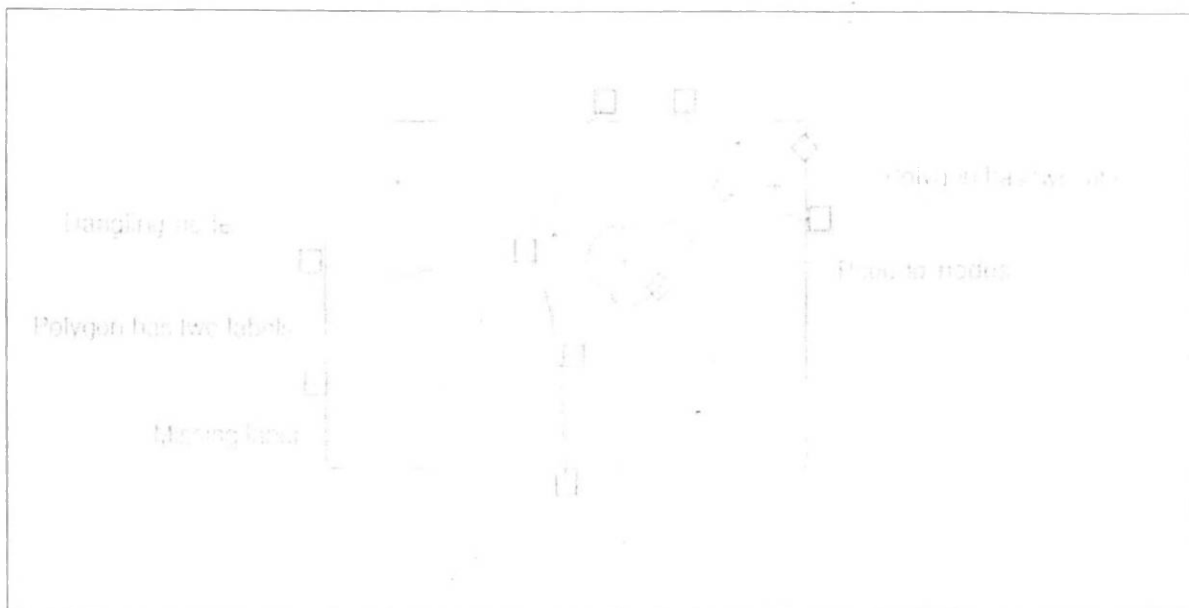


Fig.6.4 Errors identified automatically

Here are the same errors, as they would be interpreted by you (Fig.6.5).



Fig.6.5 Errors interpreted by User

6.3.2 Correcting the errors

Correcting the errors is one of the most important steps in constructing your database. Unless errors are corrected, your area calculations, any analysis and subsequent maps will not be valid.

Errors	What should be marked
Missing arc(s)	Draw them in
Missing label point(s)	Mark position and unique User-ID
More than one label	Identify which one(s) to delete
Point in a polygon	
A gap between two arcs	Indicate which arc to extend or which
Or an unclosed polygon	node to move
An overshoot	Indicate whether it should be deleted
Incorrect User-ID values	Mark the correct value

6.3.3 Tolerances to be checked

ARC/INFO uses tolerances, expressed in digitizer units, for coverage automation and update steps, such as coverage registration, feature snapping, coordinate spacing, and so

on. These tolerances affect the coverage resolution in that they specify the amount of coordinate movement allowed during an operation. The greater the movement allowed the lower the resulting resolution.

6.3.3.1 RMS (Root Mean Square) error

It is a measure of tic registration accuracy during digitizing and coverage transformation. ARC/INFO automatically calculates the root mean square error (or tic registration error) when tics are used to register a map on the digitizer and during TRANSFORM operations. The RMS value represents the amount of error between original and new coordinate locations calculated by the transformation process. The lower the RMS error, the more accurate the digitizing or transformation will be. To maintain highly accurate geographic data, the RMS 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.

6.3.3.2 TIC match tolerance

The tic match tolerance is used to ensure accurate map registration on a digitizer. It is the maximum allowed distance between an existing tic and a tic being digitized. Beyond this, the digitizing error is unacceptable and requires that the map be re-registered (Refer Fig.6.6). The tic match tolerance is used to ensure a low RMS error during map registration on a digitizer. It measures how accurately each tic location in the coverage matches the digitized location. A tic registration error is calculated automatically for each tic when the map is registered on the digitizer. A recommended tic match tolerance will vary depending on the quality of the data being automated. The value should be no higher than 0.004 inches (0.01016 cm) for highly accurate map data on 0.008 inches (0.02032 cm) for maps requiring less accuracy.

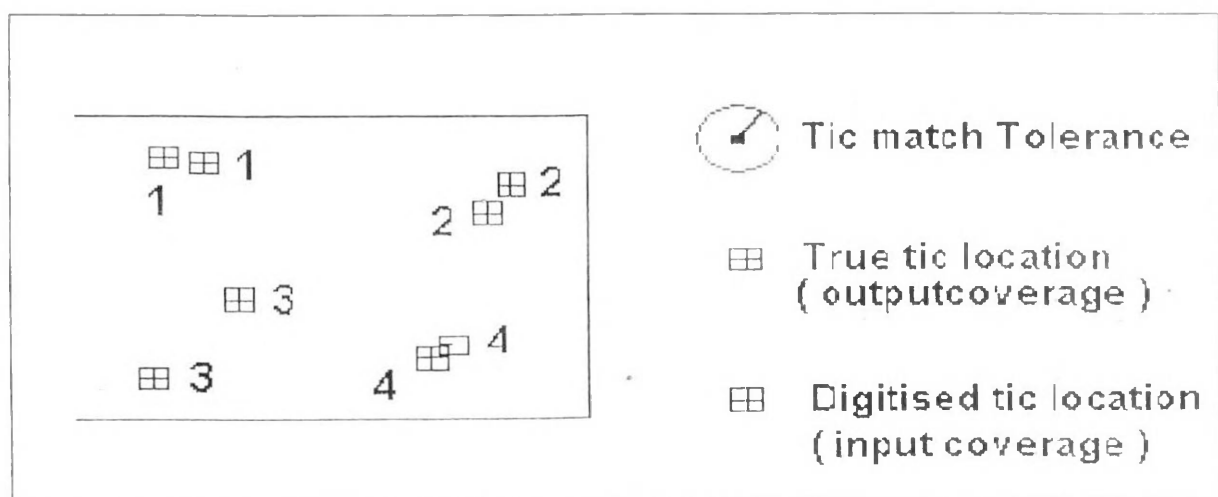


Fig. 6.6 TIC match tolerance

6.3.3.3 Fuzzy tolerance

The fuzzy tolerance 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 in exact 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 defined in the coverage BND) file.

Fuzzy tolerance is very useful in cleaning overshoots, undershoots, slivers and coordinate thinning along arcs (Fig.6.7). Normally, smaller (not too small) fuzzy tolerance (less than 0.002 inches) are recommended.

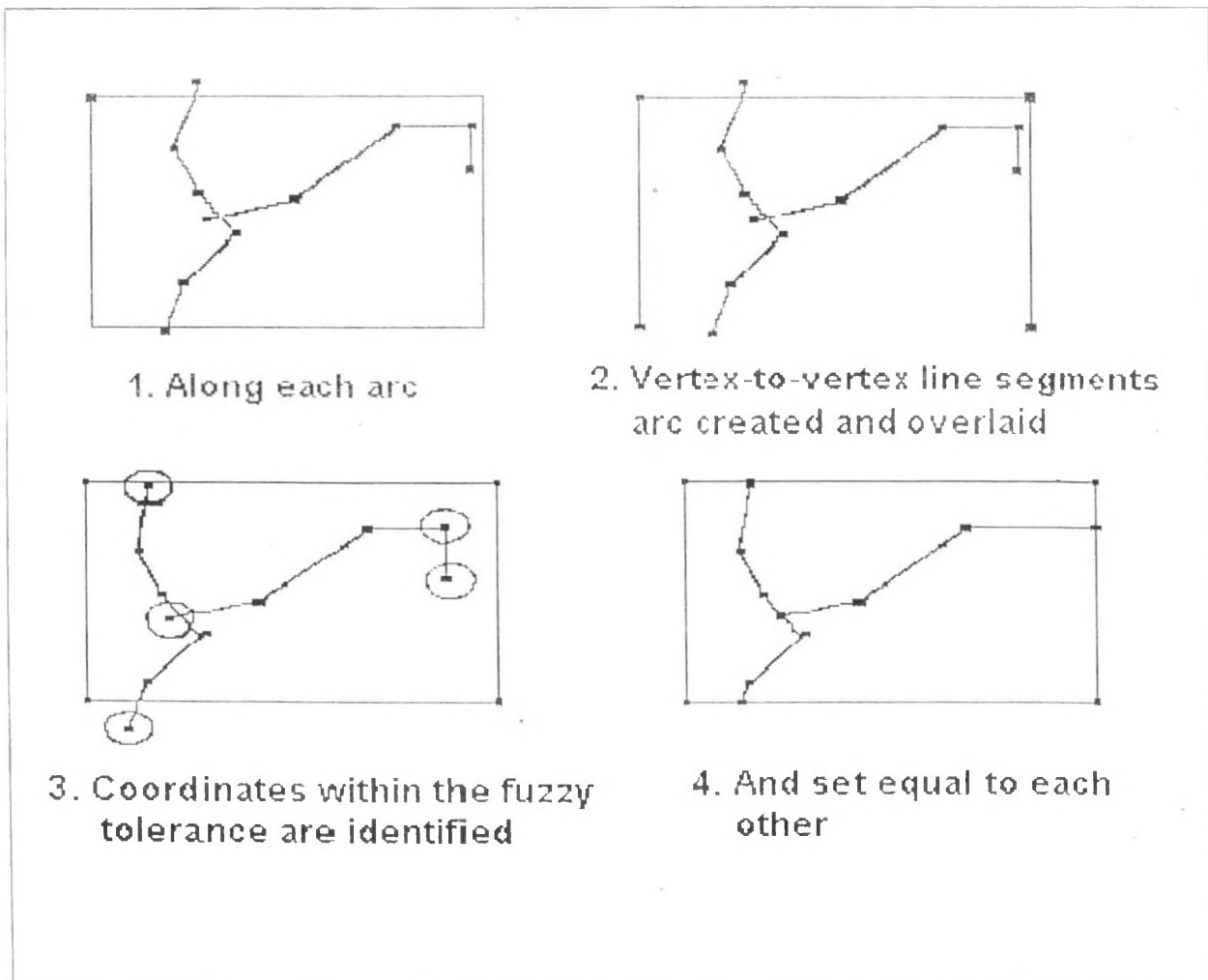


Fig.6.7 Fuzzy tolerance

Dangle length values vary with the type of feature to be cleaned. For a linear feature coverage 0.0 is recommended and for a polygon coverage 0.05 inches (0.127 cm) of equivalent coverage units is often recommended.

6.3.3.4 Node Snap Tolerance

The node snap tolerance is the minimum distance within which two nodes will be joined (matched) to form one node (Fig.6.8). The recommended value for NODESNAP is 0.05 inches (0.0127 cm).

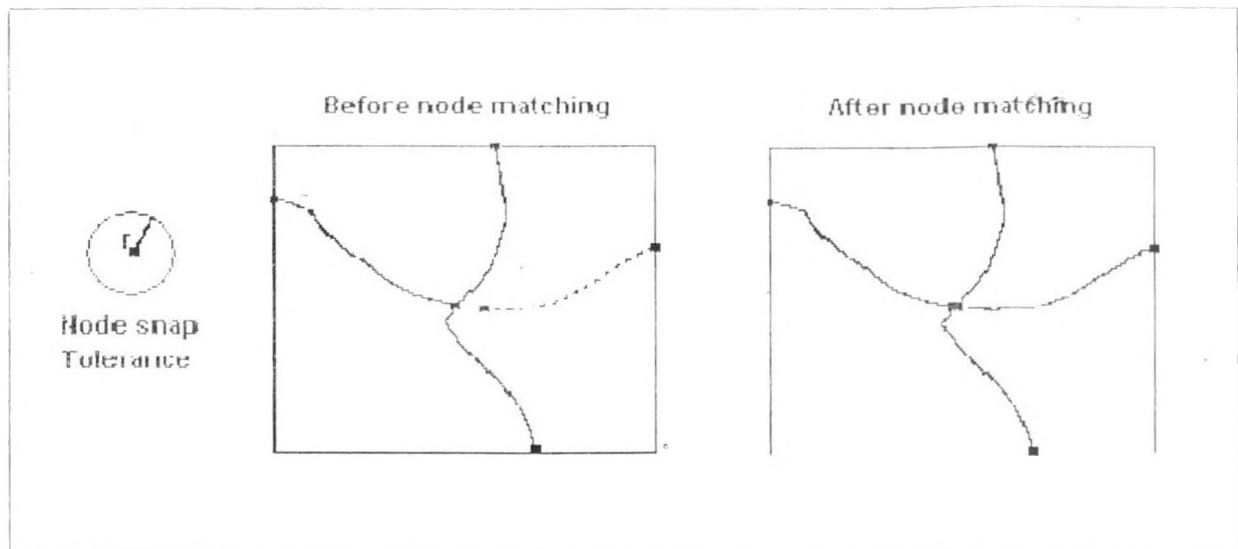


Fig.6.8 Node Snap tolerance

6.3.3.5 Arc Snap Tolerance

The distance within which a new arc will be extended to intersect an existing arc is called the arc snapping tolerance. A node is created at the new intersection of the connecting arcs (Fig.6.9). The recommended value for ARCSNAP tolerance is 0.05 inches.

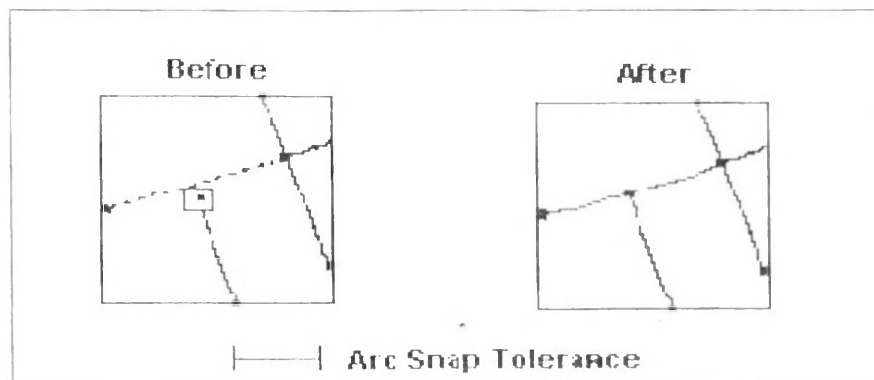


Fig.6.9 Arc Snap tolerance

6.3.3.6 Weed Tolerance

The weed tolerance is the minimum allowable distance between any two vertices along an arc. The weed tolerance is used to reduce the number of coordinates in an arc. The weed tolerance is a parameter that can be test before adding arc features or to generalize existing arcs. When adding a new arc, a new vertex within the weed tolerance of the previous vertex is disregarded (Fig.6.10). A weed tolerance value of 0.02 inches (0.0508 cm) or equivalent coverage is recommended.

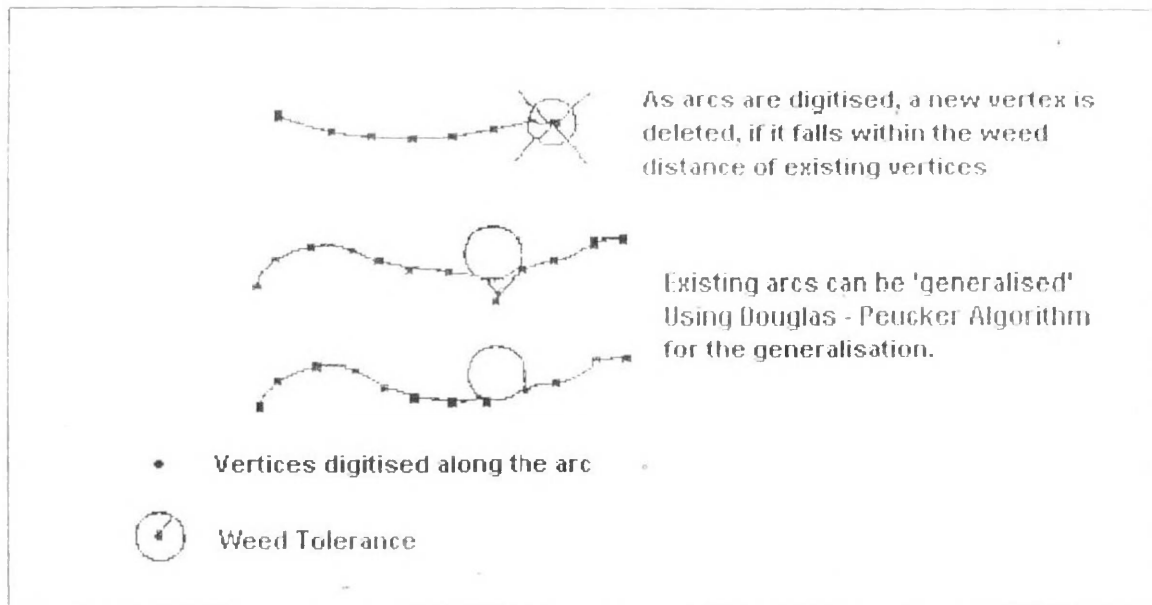


Fig.6.10 Weed tolerance

6.3.3.7 Grain Tolerance

The grain tolerance controls the number of vertices in an arc and the distance between them. 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 (Fig.6.11). 0.02 inches is a recommended value.

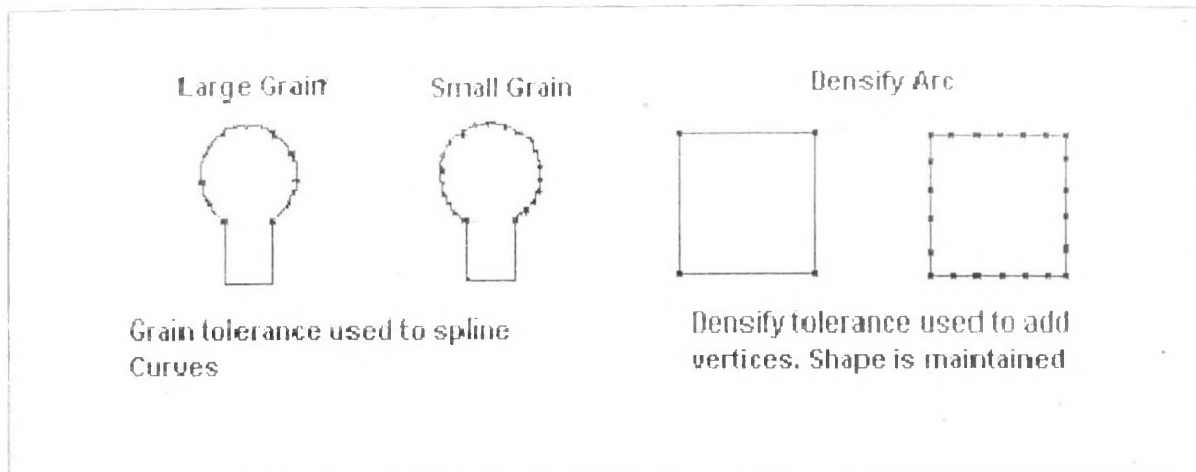


Fig.6.11 Grain tolerance

6.3.3.8 Dangle Length

A dangling arc has the same polygon on its left and right sides (as defined by the polygon internal number) and at least one dangling node. The dangle length defines the minimum allowed length for a dangling arc in a coverage. The CLEAN process deletes the dangling arcs less than the dangle length (Fig.6.12).

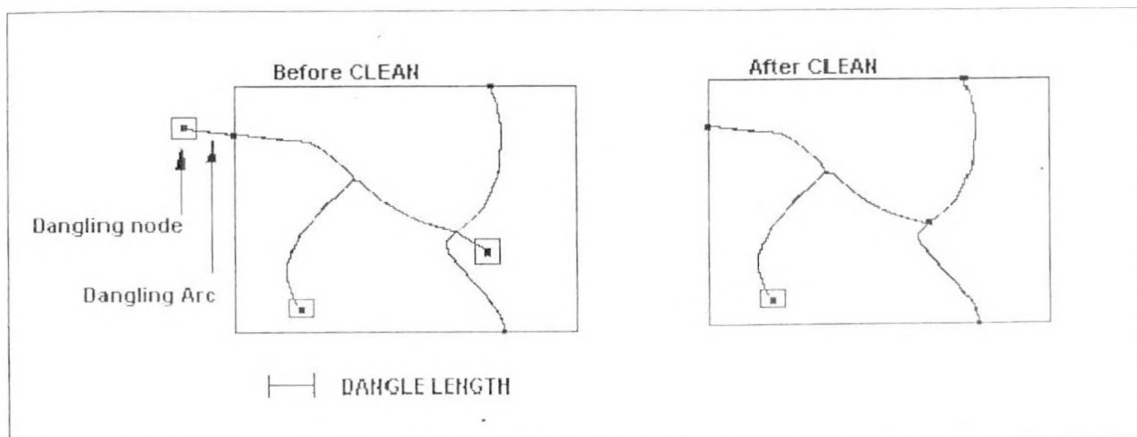


Fig.6.12 Dangle length

6.4 Topology creation – Structuring Map data

In a GIS, Topology is used to represent the spatial relationships that exist between geographic data. Spatial relationships are the associations between geographic data based on their relative locations to one another. People intuitively understand the spatial relationships that exist between objects. If you look at a road map, you know that road 'X' intersects road 'Y' because you can see that the two roads cross. The problem for a GIS is to take these intuitive relationships and make the GIS understand them. The intuitive relationships must be converted into physical relationships in order to describe the relationships in terms of finite definitions, such as **contiguity**, **containment or area definition** and **connectivity**. This is what topology does: it defines data, so that the intuitive relationships are physical relationships, thus the system understands the spatial relationships that exist between objects on a map. Finally we can say that **Topology** is the **mathematical representation of the physical relationships that exists between the geographical elements**.

The ability to create and store topological relationships has a number of advantages. Topology stores data more efficiently. This allows processing of larger data sets and faster processing. When topological relationships exist, you can perform analyses such as modeling the flow through connecting lines in a network, combining adjacent polygons that have similar characteristics and overlaying geographic features.

The three major topological concepts of a GIS are:

- Arcs connect to each other at nodes (Connectivity)
- Arcs that connect to surround an area define a polygon (Containment or area definition)
- Arcs have direction and left and right sides (Contiguity)

6.4.1 CONNECTIVITY:

The points (x,y pairs) along the arc, called **vertices**, define the shape of the arc. The endpoints of the arc are called **nodes**. Each arc has two nodes: from-node and to-node. Arcs join only at nodes. By tracking all the arcs that meet at any node, GIS understands which arcs connect.

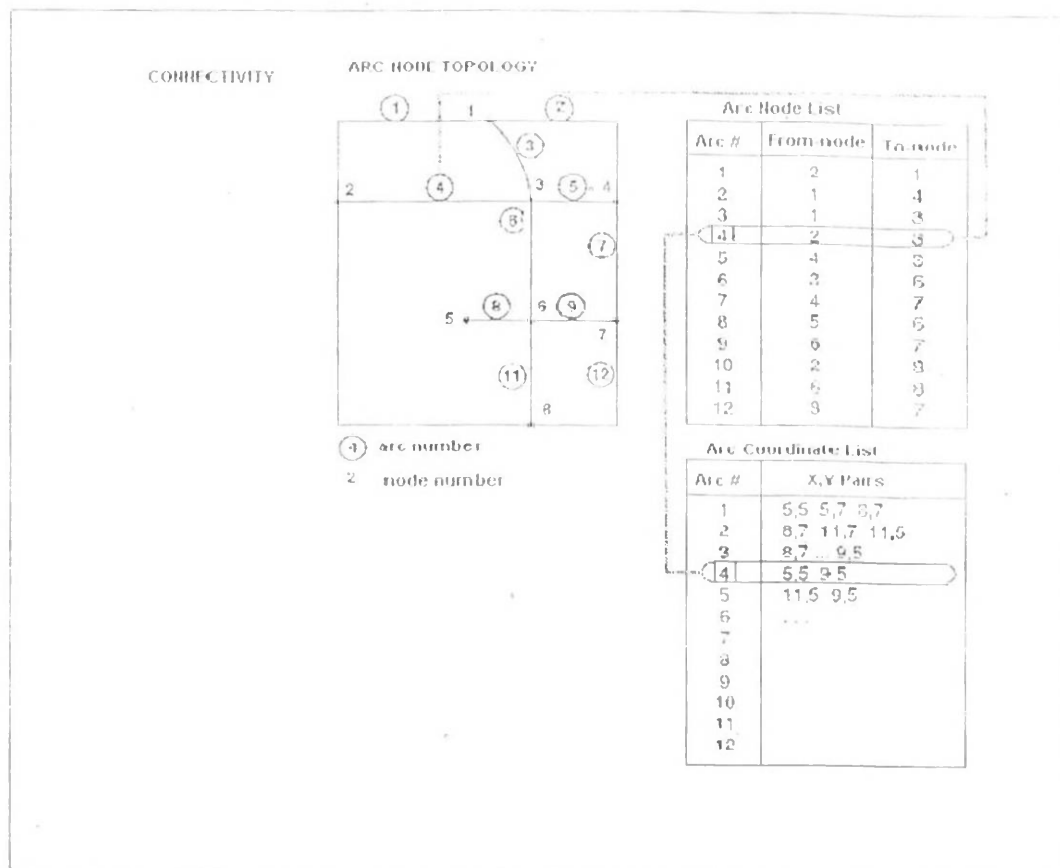


Fig.6.13 Connectivity- Arc Node topology

In the example (Fig. 6.13) given above, arcs 3,4,5 and 6 all join at node 3. With this information, the computer knows that it is possible to travel along arc 5 and turn onto arc 3 because they share a common node (3), but it is not possible to turn directly from arc 5 onto arc 9 because arc 5 and arc 9 don't share a common node.

6.4.2 CONTAINMENT:

Containment is nothing but an area definition. Polygons are represented as a series of x,y coordinates that connect to enclose an area. Generally most of the GIS software store polygons as in the figure given below. ARC/INFO, however, stores the arcs defining the polygon, rather than a closed set of x,y pairs. A list of the arcs that make up each polygon is also stored and used to construct the polygon when necessary.

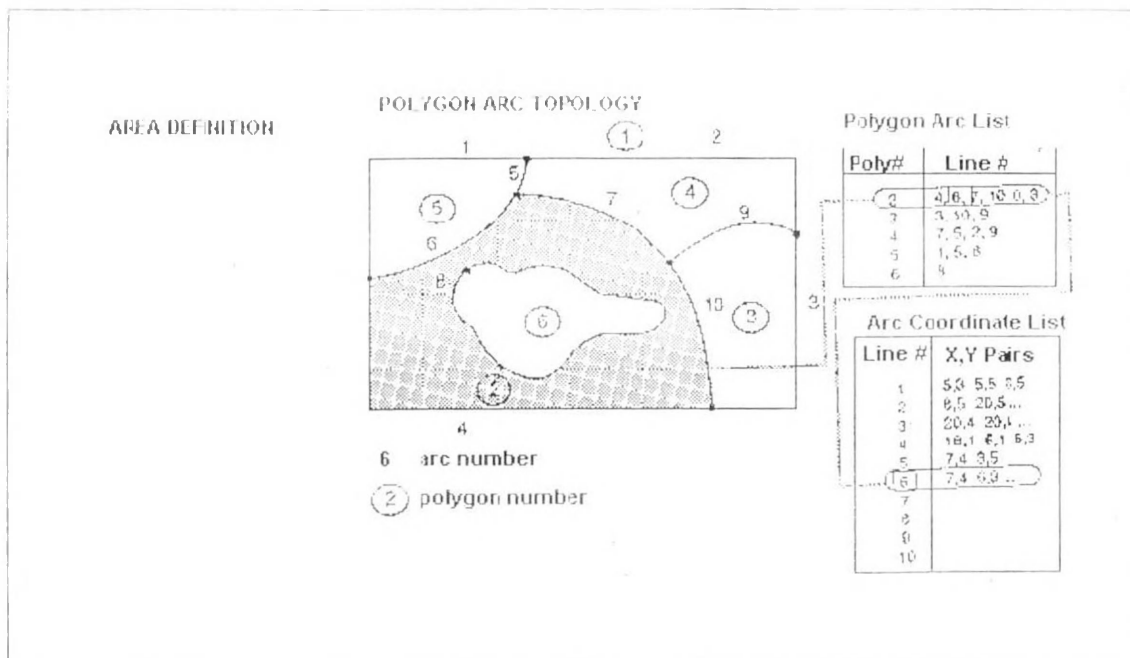


Fig.6.14 Containment- Polygon Arc topology

In the example (Fig.6.14) +given above, arc, 4,6,7 and 8 comprise polygon 2. (The 0 before the 8 indicates that this arc creates an island inside polygon 2). Though an arc may appear in the list of arcs for more than one polygon each is stored only once. Storing each arc only once reduces the amount of data in the database and also ensures that the boundaries of adjacent polygon do not overlap.

6.4.3 CONTIGUITY:

Contiguity defines the direction of each arc and neighbourhoodness. Because each arc has direction (a from-node and a to-node), GIS maintains a list of the polygons on the left and right sides of each arc (Fig.6.15). Polygon sharing a common arc is adjacent.

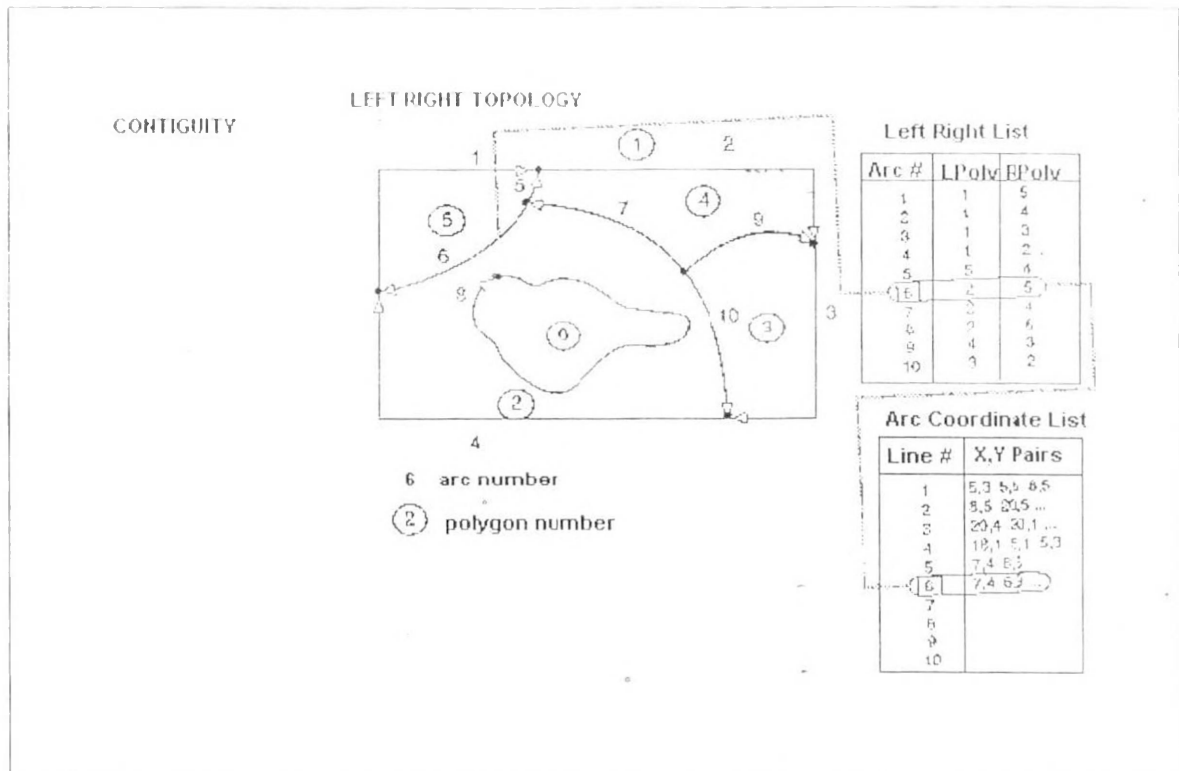


Fig.6.15 Contiguity- Left Right topology

REFERENCES (for Data Inputting ,Editing & Topology) :-

1. Understanding GIS ----- The Arc/Info Method.
2. Geographical Information System --- Volume 1 Edited by Paul A.Longley, Michael F.Goodchild, David J. Maguire & David W. Rhind.
3. Principles of GIS -----by P.A. Burrough.
4. PC Arc/Info Command Reference Guide.
5. PC Arc/Info User's Guide.
6. 'Introduction to GIS' to 'The Future of GIS' Web Site
<http://www.utdallas.edu/~briggs/poec6381.html>
7. 'Brief overview of GIS and its applications' Web Site ---
<http://www.usgs.gov/research/gis/>

MAPPING EXERCISE

Map Projections

One of the most neglected elements of map compilation is the map projection. Use of an appropriate map projection is essential in mapping as it is the foundation upon which the map is built. It quite literally, shapes the map.

A map projection is nothing more than a transformation of the three-dimensional Earth into a two-dimensional representation such as a piece of paper or computer display. The transformation may use a geometric form (cylinder, plane or cone) or mathematics. Regardless of the method of transformation, no map projections can be formed without distortion taking place. There are hundreds of map projections available to the cartographer and distortion will differ according to how the projection is created.

There are four families of map projections—azimuthal (planar), cylindrical, conic, and mathematical—and there are several individual projections belonging to each family. In the **azimuthal** family, the grid of a **generating globe** (a model based on spherical, ellipsoidal, or geoidal representations of the Earth) is projected onto a plane. **Cylindrical** projections are created by first wrapping a plane into a cylinder and then projecting the grid is projected onto that cylinder. The cylinder is then unrolled into a flat map. **Conic** projections are created by first wrapping a plane into a cone onto which the projecting the grid is projected. The cone is then unrolled into a flat map. **Mathematical** projections oftentimes resemble geometric projections but cannot be developed by projective geometry. Mathematical projections sometimes are sub-classified as pseudocylindrical, pseudoconic, and pseudoazimuthal.

Area, shape, distance, and direction are the properties of a projection. No projection can maintain all four of these properties simultaneously. There are map projections that do a good job at minimizing distortion of one of these properties. The two most commonly employed are equivalent (equal area) projections and conformal projections. **Conformal** map projections maintain the *angular relationships* of the globe the projection surface. On the globe, arcs of latitude and longitude intersect at right (90°) angles. Thus, on the map projection, graticule lines intersect at right angles creating a rectangular map and the *shapes* of small areas will be

maintained. **Equivalent** map projections maintain *size* relationships. *No* map projection can maintain both conformal and equivalent properties. Refer to Chapter 3 of the textbook for a detailed discussion on maintaining distance and direction as well as minimum error projections.

Projection **case** refers to the location that the projection surface comes in contact with the reference globe. In **tangent** projections, the projection surface touches the globe at one point (planar projections) or along one line (cylindrical and conic projections). In **secant** projections, the projection surface cuts through the globe, touching along two lines (cylindrical and conic projections) or one line for planar projections. **Reference lines** are the locations where the projection surface touches the globe. Distortion will be least on a map along the reference line(s).

Projection **aspect** refers to the “point of view” of the projection. A projection’s **normal aspect** is the aspect that produces the simplest geometry for the graticule. For example, a graticule made up of straight lines of latitude and longitude intersecting at right angles is geometrically simpler than a graticule made up of complex curves. There are four aspects a projection may have: **Polar, Equatorial, Oblique, and Transverse**. A polar aspect is one where the map is viewed at the poles, equatorial is viewed at the equator, and oblique is a view over latitude between the equator and a pole. The exception is in conic projections, where the aspect corresponds to the point on the earth over which the *point of the cone* lies (i.e., if the point of the cone is over the pole with the projection surface touching in the mid-latitudes, the aspect is polar not oblique). The transverse aspect is the view 90° from the normal aspect (polar instead of equatorial and vice versa).

In this exercise, you will:

- ✓ Change the projection of a map
- ✓ Explore the various projection families
- ✓ Change the central meridian of a map projection
- ✓ Change the display units of your map
- ✓ Resize your data frame in a layout to specific dimensions
- ✓ Insert a neatline

Projections in ArcMap

- Start ArcMap (Start All Programs >ArcGIS >ArcMap); if there is an icon on the computer desktop, you can start ArcMap by double-clicking it. You will be shown a window asking whether you want to open a new empty map, a template, or an existing map.
- Make sure the **An existing map:** radio button is selected and click OK. If you did not see this window, click **File >Open**.
- Browse to where you saved the **projections.mxd** project file and open it. You will see a map of the world with the graticule displayed in the Table of Contents. You also will see an additional layer, **Circles**, in the Table of Contents that is not turned currently displayed.

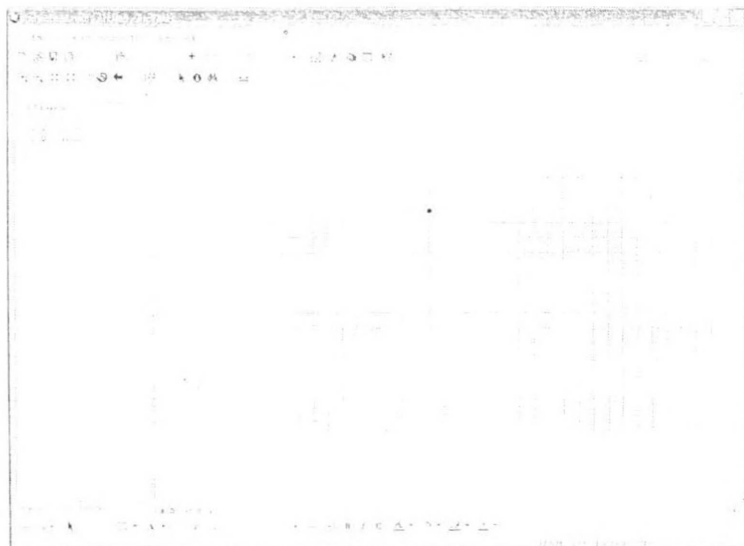


Figure 1. The map of the world with the graticule.

The portrayal of the world seen in Figure 1 is the default display for all new projects in ArcMap. Even without experience in working with projections, it should be obvious that this display is not

appropriate for all mapping applications. Note, in particular, the distortion of land areas in the high latitudes.

- **Move the cursor around the data view.** As you do this, look in the status bar at the bottom of the screen. If you cannot see the status bar, turn it on by selecting **View >Status Bar**). **Notice how the numbers change as the cursor moves.** These numbers indicate the location of the cursor. Depending on the properties of your map projection, the units displayed may be DMS (degrees, minutes, seconds), decimal degrees, or coordinates using a linear measurement (like meters).



Figure 2. The values will change as your cursor moves.

You will explore some of the projections available to you in ArcMap and observe distortion that occurs in the various projections. There are two methods that cartographers use to determine distortion of map projections. The first method is to overlay geometric symbols, usually circles, on the map at multiple locations. When the projection changes, the distortion of the symbols is noticeable. The second method is to employ *Tissot's indicatrix*. Tissot's indicatrix uses a small circle with two perpendicular radii placed on a map. As with the first method, the circle may change shape as the map is reprojected. The difference between the two methods lies in the fact that Tissot's indicatrix employs mathematics to quantitatively describe the distortion.

You will use the first method in this exercise to observe map distortion.

- Turn on the **Circles** layer by clicking its check box in the Table of Contents. You will see 23 circles distributed throughout the graticule. Along individual lines of latitude or longitude, the circles are spaced 80° apart.

Figure 3. Your map with 23 identical circles.

To get a sense of the types of map projections available to you, let's experiment with selecting different projections and see what happens with our map.

- Right click the **Layers** data frame in the Table of Contents and select **Properties**.

A data frame may use either a geographic coordinate system or a projected coordinate system. A geographic coordinate system (GCS) is a geometric model, commonly an ellipsoid, are used as a reference surface for determining location on the Earth's surface. A projected coordinate system, or projection, is the specific transformation of the 3-D earth to the 2-D flat surface. All projections use a GCS.

Note that the data frame currently employs the GCS_WGS_1984 coordinate system using the WGS_1984 datum. Refer to Chapter 2 for more information regarding ellipsoids and datums.



Figure 5. The coordinate system for the data frame.

You will first select a projection from the **azimuthal** family. Cartographers use azimuthal projections primarily to map the polar regions.

- In the Select a coordinate system box, select the following: **Predefined >Projected Coordinate Systems >Polar >North Pole Azimuthal Equidistant**.

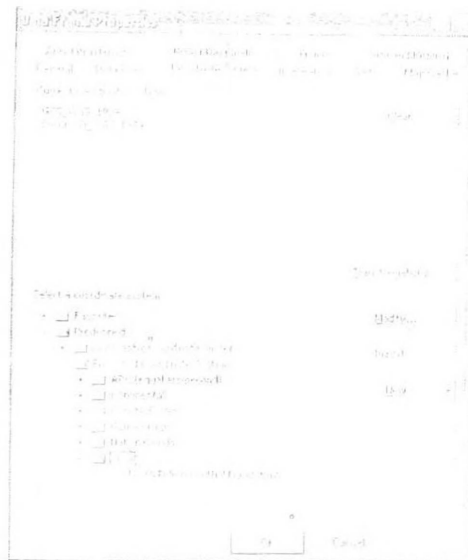


Figure 6. Selecting the North Pole Azimuthal Equidistant projection.

- Click **OK** to register the change and close the Properties window.
- You may need to adjust the view of the map to see the full extent of the mapped area. To do this click the **Full Extent** button on the Tools toolbar.

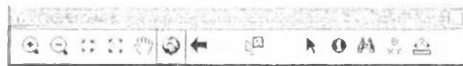


Figure 7. The Full Extent tool.

- Make a note of the appearance of the graticule. Are the latitude and longitude lines straight lines intersecting at right angles? Are the geometric symbols still circles? How are they distorted? Is the distortion the same in all parts of the map?



The exercise questions at the end of this exercise include those asking you describe the graticule and circle transformations of each of the projections you will employ. If your instructor requires you to submit the answers to the exercise questions, it is more convenient to answer them as you progress through this exercise rather than once you have completed it.

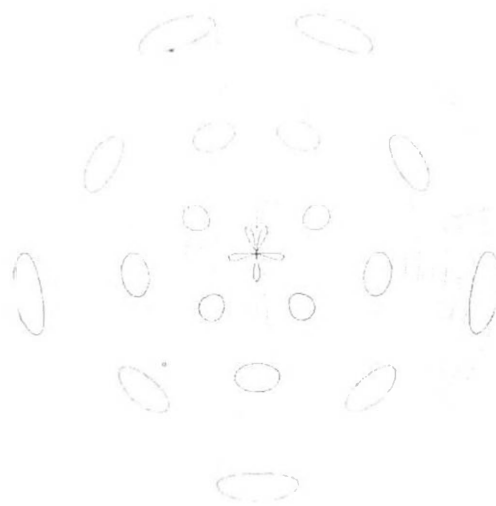


Figure 8. The North Pole Azimuthal
Equidistant projection.

It should be apparent why azimuthal projections are not suitable for mapping the entire world. Note the distortion in the southern hemisphere, particularly that of Antarctica.

Next you will select a projection from the **conic** family. Cartographers use conic projections primarily to map the areas in the mid-latitudes, especially those with wide east-west dimensions.

- Right click the **Layers data frame** in the Table of Contents and select **Properties**.
- If it is not already selected, click the **Coordinate System** tab.
- In the Select a coordinate system box, select the following: **Predefined >Projected Coordinate Systems >Continental >Asia >Asia North Albers Equal Area Conic**.
- Click **OK** to register the change and close the Properties window.
- You may need to adjust the view of the map to see the full extent of the mapped area.

Make a note of the appearance of the graticule and circles.



Figure 9. The Asia North Albers Equal Area Conic projection.

As with azimuthal projections, conic projections are not well suited for mapping the entire world. Use conic projections for continental areas or larger scales (e.g., countries or country subdivisions).

Next you will select a projection from the **cylindrical** family. Cartographers use cylindrical projections primarily to map the polar regions.

- Right click the **Layers data frame** in the Table of Contents and select **Properties**.
- If it is not already selected, click the **Coordinate System** tab.
- In the Select a coordinate system box, select the following: **Predefined >Projected Coordinate Systems >World >Miller Cylindrical**.
- Click **OK** to register the change and close the Properties window.
- You may need to adjust the view of the map to see the full extent of the mapped area.

Make a note of the appearance of the graticule and circles.



Figure 9. The Asia North Albers Equal Area Conic projection.

As with azimuthal projections, conic projections are not well suited for mapping the entire world. Use conic projections for continental areas or larger scales (e.g., countries or country subdivisions).

Next you will select a projection from the **cylindrical** family. Cartographers use cylindrical projections primarily to map the polar regions.

- Right click the **Layers data frame** in the Table of Contents and select **Properties**.
- If it is not already selected, click the **Coordinate System** tab.
- In the Select a coordinate system box, select the following: **Predefined >Projected Coordinate Systems >World >Miller Cylindrical**.
- Click **OK** to register the change and close the Properties window.
- You may need to adjust the view of the map to see the full extent of the mapped area.

Make a note of the appearance of the graticule and circles.

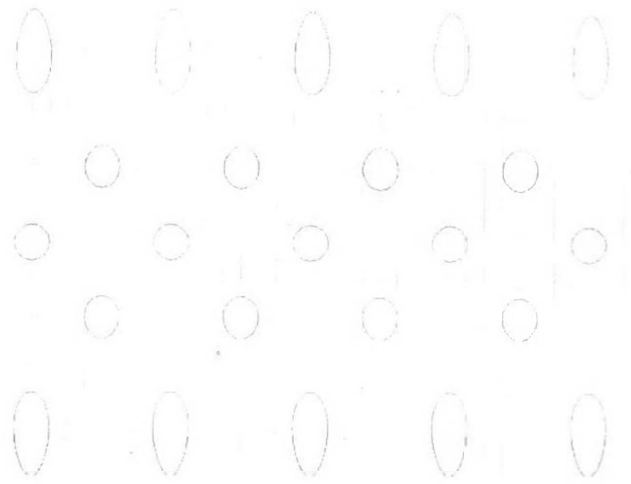


Figure 10. The Miller cylindrical projection.

Every map projection has a default *central meridian*. By default, the world map projections use the Prime Meridian (0°). When making your own maps, use the default central meridian **only** if it is appropriate to your map. In most cases, especially when mapping at large scales, you will need to adjust your central meridian.

Let's change the central meridian of the Millar Projection so that it passes through Asia.

- Right click the **Layers data frame** in the Table of Contents and select **Properties**.
- If it is not already selected, click the **Coordinate System** tab.
- Click the **Modify** button. The Projected Coordinate System Properties window opens.
- Change the **Central Meridian** value to **90** and click **OK** to register the change and return to the Layer Properties window.
- Click **OK** to close the Properties window and return to the map.



In the Coordinate System window you can customize the projection so that it is centered on a particular area, simply by redefining the central meridian, standard parallel(s), reference latitude, or false eastings and northings. The choice of parameters varies depends on which projection is being used. Let's briefly define these terms.

- **Central meridian** – the longitude on which a map is centered (x-origin). Do not confuse the central meridian with the Prime Meridian, which is 0° longitude. Many world maps use the Prime Meridian as the central meridian, but the central meridian may be *any* meridian.
- **Latitude of origin** – the latitude on which a map is centered (y-origin).
- **Standard parallel(s)** – for conic projections, the parallel(s) along which the cone touches the earth.
- **False easting** – in ArcMap, the x-coordinate value for the x-origin. For example, if the central meridian for your projected map is -96.00, and the false easting is set to 0.00, then all locations along that meridian are assigned a value of 0.00. All locations to the west of the central meridian (x-origin) are assigned a negative value, and all locations to the east of the central meridian are assigned a positive value, as in a typical Cartesian plane.
- **False northing** – in ArcMap, the y-coordinate value for the y-origin. For example, if the reference latitude for a conic projection is 37.00, then all locations along that parallel are assigned a value of 0.00. All locations to the south of the reference latitude (y-origin) are assigned a negative value, and all locations to the north of the reference latitude are assigned a positive value, as in a typical Cartesian plane.



When specifying longitude and/or latitude values in the various properties widow, you do so in **decimal degrees**. If you have a location where the coordinates are given in degrees, minutes, and seconds (DMS), you will need to convert to decimal degrees. When converting, remember that there are 60 seconds in a minute and 60 minutes in a degree. Also note that positions *west of the Prime Meridian* and *south of the Equator* are assigned **negative** values. For example, Denver, Colorado's DMS coordinates of

39° 45' N, 104° 52' W would convert to 39.27°, -104.87°.

- Move your cursor around the map and note the position of the cursor in the status bar at the bottom of the window.

As you can see, the values given are in meters, which is not particularly useful for simple exploration of map coordinates. You will next change your display units to DMS.

- Right click the **Layers** data frame in the Table of Contents and select **Properties**.
- This time, click the **General** tab.
- In the Units area change the **Display** to **Decimal Degrees**.



Figure 11. Changing the map display units to decimal degrees.

- Click **OK** to close the Properties window and return to the map.

Now notice the change in the display of the coordinates in the status bar as you move your mouse around the map. Be sure to move the cursor west of the Prime Meridian and south of the Equator to see the negative longitude and latitude values in those locations.

Cylindrical projections are much better for mapping the entire world than azimuthal or conic projections. However, most cartographers dissuade using cylindrical projections for world mapping because of the substantial distortion in the high latitudes. For world mapping, cartographers prefer **mathematical** projections.

You will next view your map using two different mathematical projections. The first is the Robinson projection. The Robinson projection is a compromise projection that is commonly used for world mapping.

- Right click the **Layers** data frame in the Table of Contents and select **Properties**.
- If it is not already selected, click the **Coordinate System** tab.
- In the Select a coordinate system box, select the following: **Predefined >Projected Coordinate Systems >World >Robinson**.
- Click **OK** to register the change and close the Properties window.
- You may need to adjust the view of the map to see the full extent of the mapped area.

Make a note of the appearance of the graticule and circles.

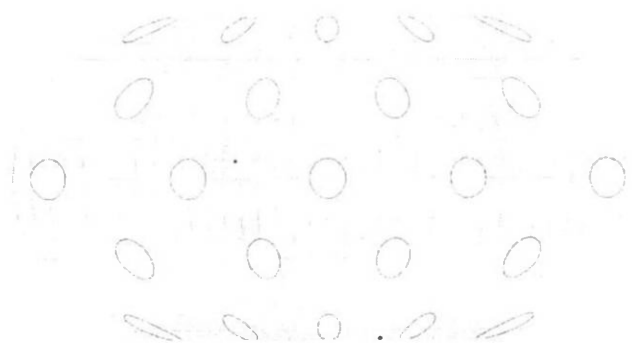


Figure 12. The Robinson projection.

It is important to note that not all the projections listed in the World subsection of the projected coordinate systems are ideal for maps of the world. The Bonne projection is an equal area conical projection is noteworthy for its distinct heart (cordiform) shape.

- Right click the **Layers data frame** in the Table of Contents and select **Properties**.
- If it is not already selected, click the **Coordinate System** tab.
- In the Select a coordinate system box, select the following: **Predefined >Projected Coordinate Systems >World >Bonne**.
- Click **OK** to register the change and close the Properties window.
- You may need to adjust the view of the map to see the full extent of the mapped area.

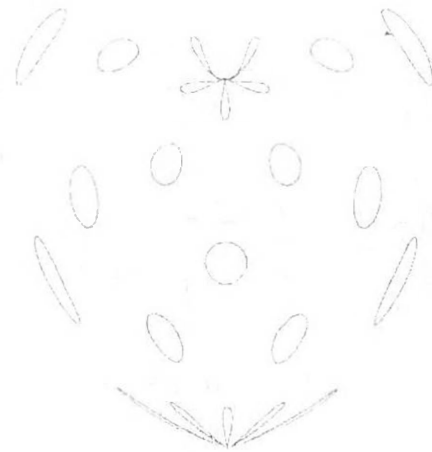


Figure 13. The Bonne projection.

Cartographers use the Bonne projection for continental areas and countries in the mid-latitudes.

Creating a Map to Turn In

The final projection you will use in this exercise is the Orthographic projection. Referred to as the Vertical Perspective projection in ArcMap, this projection is used primarily to view the Earth as if from space.

- Before changing the projection, **turn off** the circles layer.
- Right click the **Layers data frame** in the Table of Contents and select **Properties**.
- If it is not already selected, click the **Coordinate System** tab.
- In the Select a coordinate system box, select the following: **Predefined >Projected Coordinate Systems >World >Vertical Perspective**.
- Click **OK** to register the change and close the Properties window.

It may take slightly longer to draw the map using this projection than the other projections. If so, be patient, it will draw completely.

- The map may appear relatively small in the data view. If so, click the **Full Extent** button to enlarge it.

You will now see the world as if you were in a position in space above the intersection of the Prime Meridian and the Equator.



Figure 14. The Vertical Perspective
(Orthographic) projection.

Next you will change the aspect of the projection so that you are viewing the Earth from above *your current position*. Use an atlas, online site (such as www.lat-long.com for U.S. cities), or program like Google Earth (if you have it installed) to determine your coordinates. Your instructor may also provide coordinates for you to use.

- Return to the **Coordinate System** tab of the **Data Frame Properties** window.
- Click the **Modify** button. The Projected Coordinate System Properties window will open.
- Change the values of both **Longitude Of Center** and **Latitude Of Center** to your **coordinates**. Remember that you must use **decimal degrees** and also use **negative numbers** for longitudes west of the Prime Meridian and latitudes south of the equator. Do not change the Height or Linear Unit values.



Figure 15. The Orthographic projection reoriented over Macomb, Illinois.

- Click OK to register the change

Creating the Layout

- Switch to the **Layout View** (**View >Layout View**).
- Using the **Page and Print Setup** menu item (right-click outside the page in the layout view to get the context menu where this is located), **change the Orientation to Landscape**. Also make sure the **Use Printer Paper Settings** and **Show Printer Margins on Layout** boxes are checked.



Figure 16. Page and Print Setup.

- Click **OK** to register your changes and close the window.

When you changed the orientation of the page from portrait to landscape, your data frame did not resize. You will need to resize the data frame to fit in the layout. Resizing is accomplished in one of two ways: clicking and dragging one of the sizing handles (boxes that appear along the edge of the data frame when the data frame is selected) or adjusting the size of the frame in the Data Frame Properties window. You will do the latter.

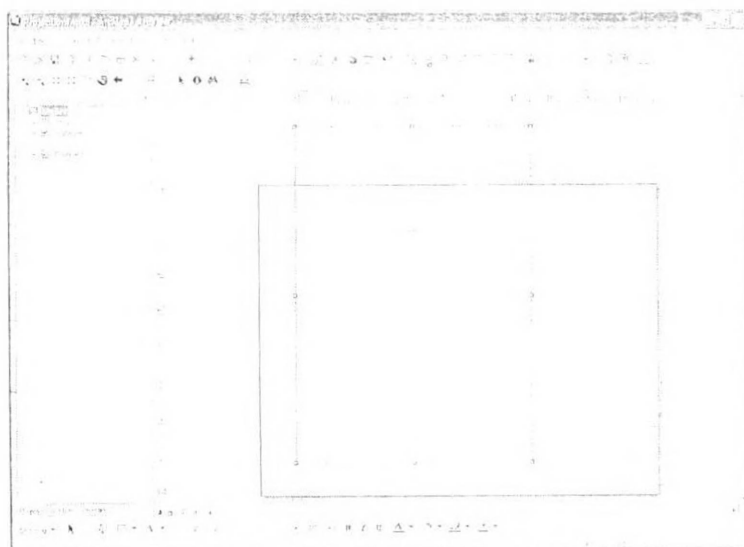


Figure 17. Your data frame no longer fits the layout following the switch to landscape orientation.

- **Right-click** the data frame (mapped area) and select **Properties**.

- Click the **Size and Position** tab.
- Change both the width and height to 7.5 in.

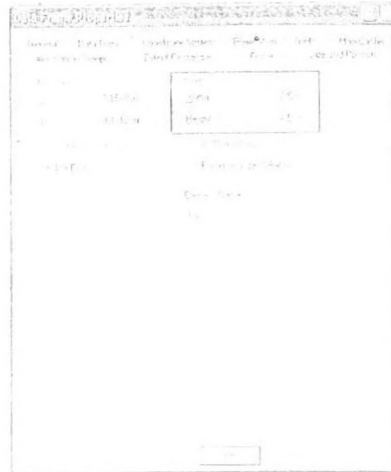


Figure 18. Setting the dimensions of the data frame.

- Before closing the Data Frame Properties window, click the **Frame** tab.
- Change the Border to <None>.



Figure 19. Click the Border box to make the change.

- Click **OK** to register your changes and close the Data Frame Properties window.

By resizing the data frame, the scale of the map may have changed—it is common for you to be at a smaller scale than you were in the data view following the resizing.

- If necessary, zoom to fill the data frame with the mapped area. Use the *Full Extent* button (it looks like a globe) to do so.
- Click OK to register your changes and close the Properties window.
- Insert a **neatline** (**Insert > Neatline**). Make it **2 points** thick and place it inside the print margins with a **5 point** gap.
- Next, reposition the data frame so it is near the right edge of the layout, inside the neatline.
- Add the **map title** (**Insert > Title**). Make your map title **Orthographic Projection of the World**.
- Reposition the title so it is in the space to the left of the mapped area.

The current size of the text used in the title should be a little bigger but making the title bigger will likely cause overlap with the map. The solution to the dilemma of how to make the title bigger but not overlap the map is to use multiple lines for the title.

- To change your text to multiple lines, **double-click** the **title**. The Text Properties window opens.
- Place your cursor **between** Orthographic and Projection and press the **Enter** key on your keyboard. Make sure you delete the space that was between the two words.
- Repeat the procedure to put “of the World” on a third line.

- Keep the alignment as center-aligned.

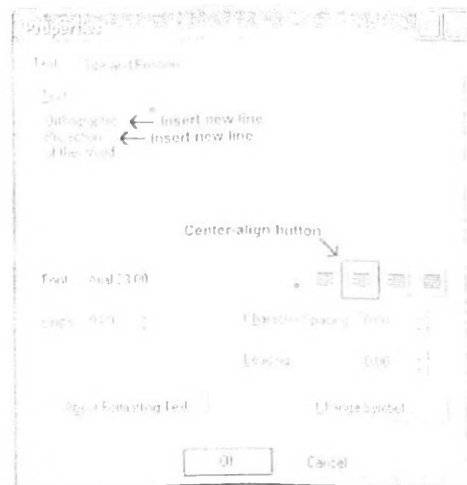


Figure 20. The title on multiple lines.

- Using the Drawing toolbar (placed by default at the bottom of the ArcMap window), make the title text **bold** and increase its **size** (try between 28 and 34 points).
- Reposition the title if necessary to fit in the available space.
- Next, add a new text element indicating the orientation of the map (substitute your information for the items in brackets):

Map oriented on [your location]
[your latitude and longitude coordinates]

- Position this text below the title.
- In the lower left-hand corner of the page, add the cartographer information (two lines, left-aligned):

Your name
Today's date

To print a hard-copy of the map:

- Click on the **print button** or select **File >Print** (you may also print preview using **File >Print Preview**)

To create a PDF document (for digital submissions):

- Export the map by selecting **File >Export Map...**
- Change the **Save as type:** to **PDF (*.pdf)**.
- The Resolution should be 300 dpi and the **Output Image Quality** should be **best**. Keep these settings unless directed otherwise.

Sources of Spatial Data

Most projects begin with a search for base data. This listing will begin with a few sure-fire sources of data that you can use to build a contextual dataset for a city. We will then work up to strategies for finding more detailed data. One thing to always keep in mind: since you are going to invest time in pulling data together to study a place, you should organize your data well so that you and others can build on what you have done!

Planning GIS Data

The great thing about geographically referenced data is that datasets compiled by independent agencies can be combined together and will align, spatially in a coherent way. In addition to representing things graphically, GIS data records attributes reflecting information that is critical to understanding what things are. Discovering these resources can be as easy as doing a web search. Many cities and government agencies now have sections of their web sites focused on Geographic Information Systems data. The likelihood of your finding free information about a particular area is usually proportional to the importance of that area to a government agency, and the willingness of that agency to make that information available.

Exploring GIS Data

When you finally find some GIS data, you will want to understand whether the data is suitable for your purposes or not. Critical aspects of a dataset should be addressed in the data documentation, or **Metadata** for example:

- The subject of the dataset?
- What time period is represented?
- Who collected the data and why?

You should always be sure to save the metadata for datasets that you download from the web! Without documentation the data that you download will be of little use later on. For a good tutorial on exploring GIS data and metadata, see [Exploring Geographically Referenced Data](#)

Every project needs to begin with a study of the overall context. Data such as general shorelines and transportation.

The OpenStreetmap is a project that engages the public in the project of developing digital map data comparable with Google maps. The great thing about this project is that the data are freely available for applications outside of the web browser -- so, for example you can download GIS databases of the openstreetmap data from GeoFabrik Web Site

The Tufts Open Geo Portal is an exciting project that lets you search and discover thousands of datasets from several libraries.

As our quest for data becomes more specific, the next most reliable source of data are national and international mapping agencies. Some of these public service agencies are very secretive or charge exorbitant prices for their data (for example, the British Ordnance Survey and its descendants around the world) which is a shame. But other agencies set a good example. For example:

Elevation Data The US Federal Government has very good information of a level of detail. You can find loads of useful information, including low cost aerial photography for the entire United States, at The National Map Viewer and Download Tool. is a new and growing source of information regarding terrain and land cover information, nationwide, and aerial photography for selected areas.

Global Terrain Information: can be downloaded from THE USGS Distributed Archive Center.

Bathymetry Data: For U.S. coastal bathymetry, check out The NOAA Estuarine Bathymetry download site.

A world-wide bathymetry dataset has been compiled by [The General Bathymetric Chart of the Oceans \(GEBCO\)](#). Their data is available for download from [British Oceanographic Data Centre](#). Though this process is a bit convoluted and poorly documented, Users on the GSD network are encouraged to use our local copy of the GEBCO Bathymetry dataset with the GridView extraction software located in [goliath://geo/gebco_worldwide_bathymetry](#).

A technical tutorial on downloading and transforming elevation data is covered in more detail on the web page, [Digital Elevation Models](#).

A good Source of data for Europe and Africa is found at [The United Nations Environment Program GIS Data Bank](#).

Also see the [The EDENext Data Portal](#) and [Links from the DIVA Project](#)

A vast amount of information about places can be found in the form of digital images, either scanned maps or digital aerial photographs. Many sources of these are discussed on the [The GIS Manual Page on Geographic Images](#). Some of these images may have imbedded georeferencing information that allows it to be aligned with other data in the GIS. If not, then images may be georeferenced using techniques discussed on the [Georeferencing Images](#).

The GSD has **Google Earth Pro** installed on our lab computers. The pro version accesses the same imagery as the free version but lets you download imagery at much higher resolution (using the File>Save>Image option). Although these images are not georeferenced, a trick for georeferencing these images very precisely is discussed on the page, [Georeferencing Images and CAD Data](#).

The more detailed the information you want, the less likely it is that you will find it for free on the web. At the state level, you may get lucky, and find a site like the [Massachusetts GIS](#). These

days, even city governments are making their data available on the web. Find the GIS section of the state, city, or county's official web site.

For local data, it helps to have connections. Studio instructors should cultivate their local connections well in advance of the start of their studio to try to obtain detailed local data. Obtaining local data involves a number of steps. First, you should have a clear idea of the types of layers that are desired (e.g. building footprints, trees, edge of pavement, property parcels, contours, aerial photography, etc.) Then think about what local agencies might have these data. Of course, you would look on the web to see if data are available easily -- or to find contact information of the probable custodians of the data. Then one would write letters or make phone calls. When requesting data you should be very specific about what you would like to find. If you simply ask for GIS data you are likely to get a file of zip code boundaries for the area in question. Of course, you should also ask for metadata! [Click Here](#) for a boiler-plate data request letter that you can tailor to meet your purposes.

The NASA Mission to Planet Earth project has produced nicely georeferenced series of relatively cloud free imagery covering the whole globe. The imagery, which can be downloaded from [The University of Maryland Global Land Cover Facility](#), is of fairly coarse resolution (30-60 meter cell size) but contains higher spectral resolution than most imagery, with a channel for infrared reflectance. These multi-channel images can be tricky to work with, but if you are very patient, you can meld the various channels into useful graphical products and even do some classification of land cover and land use change, see [Classifying Multispectral Images](#)

Spatial and non-spatial data

GIS DATA TYPES

The basic data type in a GIS reflects traditional data found on a map. Accordingly, GIS technology utilizes two basic types of data. These are:

➡	Spatial data	describes the absolute and relative location of geographic features.
➡	Attribute data	describes characteristics of the spatial features. These characteristics can be quantitative and/or qualitative in nature. Attribute data is often referred to as tabular data.

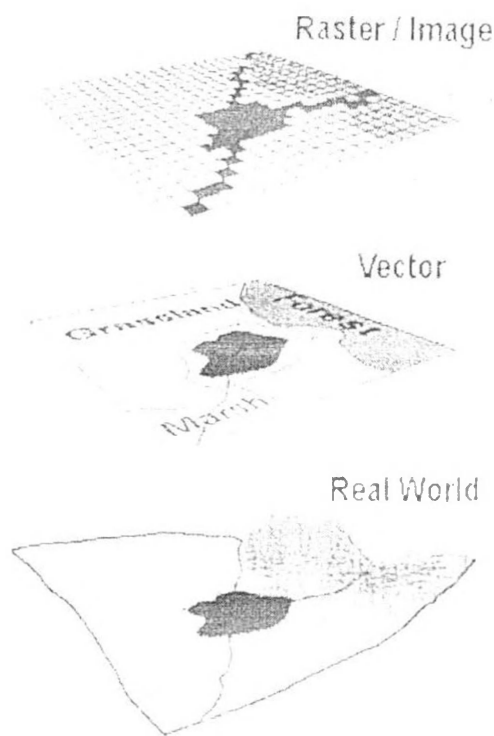
The coordinate location of a forestry stand would be spatial data, while the characteristics of that forestry stand, e.g. cover group, dominant species, crown closure, height, etc., would be attribute data. Other data types, in particular image and multimedia data, are becoming more prevalent with changing technology. Depending on the specific content of the data, *image data* may be considered either spatial, e.g. photographs, animation, movies, etc., or attribute, e.g. sound, descriptions, narration's, etc.

SPATIAL DATA MODELS

Traditionally spatial data has been stored and presented in the form of a map. Three basic types of spatial data models have evolved for storing geographic data digitally. These are referred to as:

➡	Vector;
➡	Raster;
➡	Image.

The following diagram reflects the two primary spatial data encoding techniques. These are vector and raster. Image data utilizes techniques very similar to raster data, however typically lacks the internal formats required for analysis and modeling of the data. Images reflect *pictures* or *photographs* of the landscape.



Representation of the real world and showing differences in how a vector and a raster GIS will represent this real world.

VECTOR DATA FORMATS

All spatial data models are approaches for storing the spatial location of geographic features in a database. Vector storage implies the use of vectors (directional lines) to represent a geographic feature. Vector data is characterized by the use of sequential points or *vertices* to define a linear segment. Each vertex consists of an X coordinate and a Y coordinate.

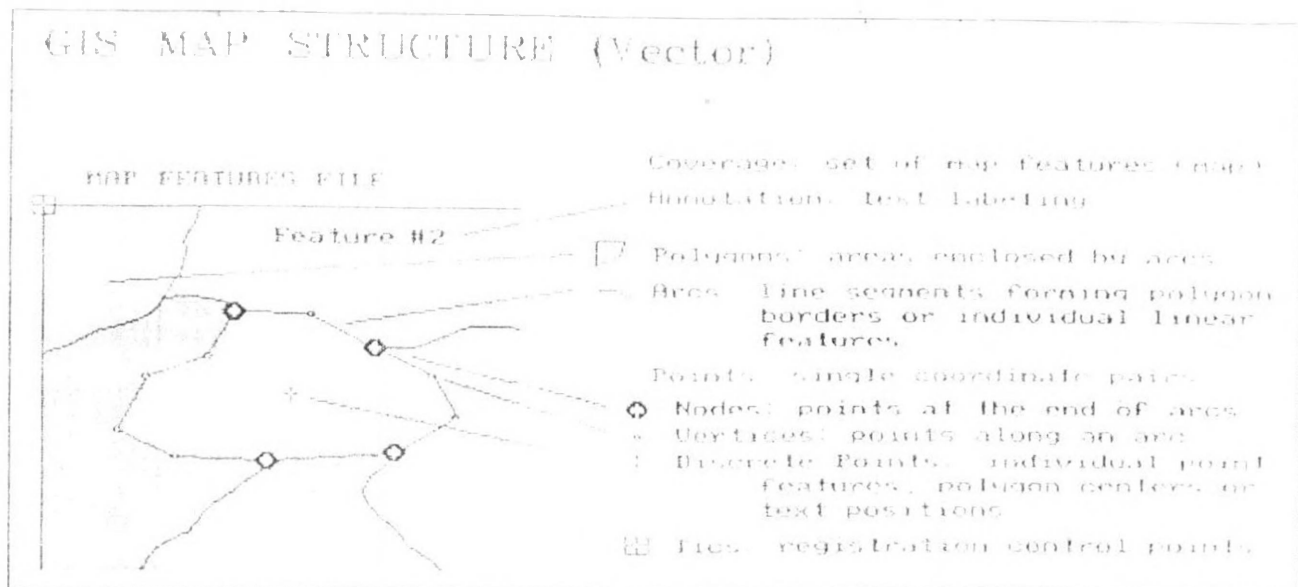
Vector lines are often referred to as *arcs* and consist of a string of vertices terminated by a *node*. A node is defined as a vertex that starts or ends an arc segment. Point features are defined by one coordinate pair, a vertex. Polygonal features are defined by a set of closed coordinate pairs. In vector representation, the storage of the vertices for each feature is important, as well as the connectivity between features, e.g. the sharing of common vertices where features connect.

Several different vector data models exist, however only two are commonly used in GIS data storage.

The most popular method of retaining spatial relationships among features is to explicitly record adjacency information in what is known as the topologic data model. Topology is a mathematical concept that has its basis in the principles of feature adjacency and connectivity.

The **topologic data structure** is often referred to as an *intelligent data structure* because spatial relationships between geographic features are easily derived when using them. Primarily for this reason the topologic model is the dominant vector data structure currently used in GIS technology. Many of the complex data analysis functions cannot effectively be undertaken without a topologic vector data structure. Topology is reviewed in greater detail later on in the book.

The secondary vector data structure that is common among GIS software is the **computer-aided drafting (CAD) data structure**. This structure consists of listing elements, not features, defined by strings of vertices, to define geographic features, e.g.: points, lines, or areas. There is considerable redundancy with this data model since the boundary segment between two polygons can be stored twice, once for each feature. The CAD structure emerged from the development of computer graphics systems without specific considerations of processing geographic features. Accordingly, since features, e.g. polygons, are self-contained and independent, questions about the adjacency of features can be difficult to answer. The CAD vector model lacks the definition of spatial relationships between features that is defined by the topologic data model.



GIS MAP Structure - VECTOR systems (Adapted from Berry)

RASTER DATA FORMATS

Raster data models incorporate the use of a *grid-cell* data structure where the geographic area is divided into cells identified by row and column. This data structure is commonly called *raster*. While the term raster implies a regularly spaced grid other *tessellated* data structures do exist in grid based GIS systems. In particular, the quadtree data structure has found some acceptance as an alternative raster data model.

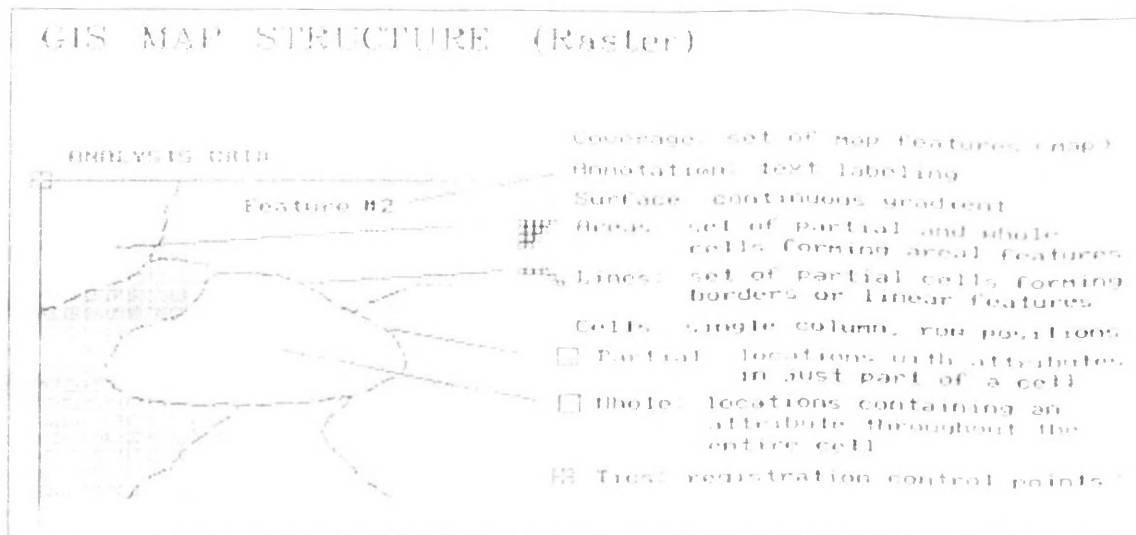
The size of cells in a tessellated data structure is selected on the basis of the data accuracy and the resolution needed by the user. There is no explicit coding of geographic coordinates required since that is implicit in the layout of the cells. A raster data structure is in fact a matrix where any coordinate can be quickly calculated if the origin point is known, and the size of the grid cells is known. Since grid-cells can be handled as two-dimensional arrays in computer encoding many analytical operations are easy to program. This makes tessellated data structures a popular choice for many GIS software. Topology is not a relevant concept with tessellated structures since adjacency and connectivity are implicit in the location of a particular cell in the data matrix.

Several tessellated data structures exist, however only two are commonly used in GIS's. The most popular cell structure is the regularly spaced matrix or *raster* structure. This data structure involves a division of spatial data into regularly spaced cells. Each cell is of the same shape and size. Squares are most commonly utilized.

Since geographic data is rarely distinguished by regularly spaced shapes, cells must be classified as to the most common attribute for the cell. The problem of determining the proper resolution for a particular data layer can be a concern. If one selects too coarse a cell size then data may be overly generalized. If one selects too fine a cell size then too many cells may be created resulting in a large data volume, slower processing times, and a more cumbersome data set. As well, one can imply accuracy greater than that of the original data capture process and this may result in some erroneous results during analysis.

As well, since most data is captured in a vector format, e.g. digitizing, data must be converted to the raster data structure. This is called *vector-raster conversion*. Most GIS software allows the user to define the raster grid (cell) size for vector-raster conversion. It is imperative that the original scale, e.g. accuracy, of the data be known prior to conversion. The accuracy of the data, often referred to as the resolution, should determine the cell size of the output raster map during conversion.

Most raster based GIS software requires that the raster cell contain only a single discrete value. Accordingly, a data layer, e.g. forest inventory stands, may be broken down into a series of raster maps, each representing an attribute type, e.g. a species map, a height map, a density map, etc. These are often referred to as *one attribute maps*. This is in contrast to most conventional vector data models that maintain data as *multiple attribute maps*, e.g. forest inventory polygons *linked* to a database table containing all attributes as columns. This basic distinction of raster data storage provides the foundation for quantitative analysis techniques. This is often referred to as *raster or map algebra*. The use of raster data structures allow for sophisticated mathematical modelling processes while vector based systems are often constrained by the capabilities and language of a relational DBMS.



GIS MAP Structure - RASTER systems (Adapted from Berry)

This difference is the major distinguishing factor between vector and raster based GIS software. It is also important to understand that the selection of a particular data structure can provide advantages during the analysis stage. For example, the vector data model does not handle continuous data, e.g. elevation, very well while the raster data model is more ideally suited for this type of analysis. Accordingly, the raster structure does not handle linear data analysis, e.g. shortest path, very well while vector systems do. It is important for the user to understand that there are certain advantages and disadvantages to each data model.

VECTOR AND RASTER - ADVANTAGES AND DISADVANTAGES

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

Vector Data

Advantages :

- Data can be represented at its original resolution and form without generalization.
- Graphic output is usually more aesthetically pleasing (traditional cartographic representation);
- Since most data, e.g. hard copy maps, is in vector form no data conversion is required.
- Accurate geographic location of data is maintained.
- Allows for efficient encoding of topology, and as a result more efficient operations that require topological information, e.g. proximity, network analysis.

Disadvantages:

- The location of each vertex needs to be stored explicitly.
- For effective analysis, vector data must be converted into a topological structure. This is often processing intensive and usually requires extensive data cleaning. As well, topology is static, and any updating or editing of the vector data requires re-building of the topology.
- Algorithms for manipulative and analysis functions are complex and may be processing intensive. Often, this inherently limits the functionality for large data sets, e.g. a large number of features.
- Continuous data, such as elevation data, is not effectively represented in vector form. Usually substantial data generalization or interpolation is required for these data layers.

- ✚ Spatial analysis and filtering within polygons is impossible

Raster Data

Advantages :

- ✚ The geographic location of each cell is implied by its position in the cell matrix. Accordingly, other than an origin point, e.g. bottom left corner, no geographic coordinates are stored.
- ✚ Due to the nature of the data storage technique data analysis is usually easy to program and quick to perform.
- ✚ The inherent nature of raster maps, e.g. one attribute maps, is ideally suited for mathematical modeling and quantitative analysis.
- ✚ Discrete data, e.g. forestry stands, is accommodated equally well as continuous data, e.g. elevation data, and facilitates the integrating of the two data types.
- ✚ Grid-cell systems are very compatible with raster-based output devices, e.g. electrostatic plotters, graphic terminals.

Disadvantages:

- ✚ The cell size determines the resolution at which the data is represented.;
- ✚ It is especially difficult to adequately represent linear features depending on the cell resolution. Accordingly, network linkages are difficult to establish.
- ✚ Processing of associated attribute data may be cumbersome if large amounts of data exists. Raster maps inherently reflect only one attribute or characteristic for an area.
- ✚ Since most input data is in vector form, data must undergo vector-to-raster conversion. Besides increased processing requirements this may

introduce data integrity concerns due to generalization and choice of inappropriate cell size.

- Most output maps from grid-cell systems do not conform to high-quality cartographic needs.

It is often difficult to compare or rate GIS software that use different data models. Some personal computer (PC) packages utilize vector structures for data input, editing, and display but convert to raster structures for any analysis. Other more comprehensive GIS offerings provide both integrated raster and vector analysis techniques. They allow users to select the data structure appropriate for the analysis requirements. Integrated raster and vector processing capabilities are most desirable and provide the greatest flexibility for data manipulation and analysis.

ATTRIBUTE DATA MODELS

A separate data model is used to store and maintain attribute data for GIS software. These data models may exist internally within the GIS software, or may be reflected in external commercial Database Management Software (DBMS). A variety of different data models exist for the storage and management of attribute data. The most common are:

- Tabular
- Hierarchical
- Network
- Relational
- Object Oriented

The tabular model is the manner in which most early GIS software packages stored their attribute data. The next three models are those most commonly implemented in database management systems

(DBMS). The object oriented is newer but rapidly gaining in popularity for some applications. A brief review of each model is provided.

Tabular Model

The simple tabular model stores attribute data as sequential data files with fixed formats (or comma delimited for ASCII data), for the location of attribute values in a predefined record structure. This type of data model is outdated in the GIS arena. It lacks any method of checking data integrity, as well as being inefficient with respect to data storage, e.g. limited indexing capability for attributes or records, etc.

Hierarchical Model

The hierarchical database organizes data in a *tree* structure. Data is structured downward in a *hierarchy* of tables. Any level in the hierarchy can have unlimited *children*, but any *child* can have only one *parent*. **Hierarchical DBMS have not gained any noticeable acceptance for use within GIS.** They are oriented for data sets that are very stable, where primary relationships among the data change infrequently or never at all. Also, the limitation on the number of parents that an element may have is not always conducive to actual geographic phenomenon.

Network Model

The network database organizes data in a network or *plex* structure. Any column in a plex structure can be linked to any other. Like a tree structure, a plex structure can be described in terms of *parents* and *children*. This model allows for children to have more than one parent.

Network DBMS have not found much more acceptance in GIS than the hierarchical DBMS. They have the same flexibility limitations as hierarchical databases; however, the more powerful structure for representing data relationships allows a more realistic modelling of geographic phenomenon. However, network databases tend to become overly complex too easily. In this regard it is easy to lose control and understanding of the relationships between elements.

Relational Model

The relational database organizes data in *tables*. Each table, is identified by a unique table name, and is organized by *rows* and *columns*. Each column within a table also has a unique name. Columns store the values for a specific attribute, e.g. cover group, tree height. Rows represent one record in the table. In a GIS each row is usually linked to a separate spatial feature, e.g. a forestry stand. Accordingly, each row would be comprised of several columns, each column containing a specific value for that geographic feature. The following figure presents a sample table for forest inventory features. This table has 4 rows and 5 columns. The forest stand number would be the *label* for the spatial feature as well as the *primary key* for the database table. This serves as the linkage between the spatial definition of the feature and the attribute data for the feature.

UNIQUE STAND NUMBER	DOMINANT COVER GROUP	AVG. TREE HEIGHT	STAND SITE INDEX	STAND AGE
001	DEC	3	G	100
002	DEC-CON	4	M	80
003	DEC-CON	4	M	60
004	CON	4	G	120

Data is often stored in several tables. Tables can be joined or referenced to each other by common columns (relational fields). Usually the common column is an identification number for a selected geographic feature, e.g. a forestry stand polygon number. This identification number acts as the *primary key* for the table. The ability to join tables through use of a common column is the essence of the relational model. Such relational joins are usually ad hoc in nature and form the basis of for querying in a relational GIS product. Unlike the other previously discussed database types, relationships are implicit in the character of the data as opposed to explicit characteristics of the database set up.

The relational database model is the most widely accepted for managing the attributes of geographic data.

There are many different designs of DBMSs, but in GIS the relational design has been the most useful. In the relational design, data are stored conceptually as a collection of tables. Common fields in different tables are used to link them together. This surprisingly simple design has been so widely used primarily because of its flexibility and very wide deployment in applications both within and without GIS.

Common Fields

Attributes of California Counties				
Fips	Ch2m id	Chr fips	Sub region	Stat flag
6001	1525	1	Pacific	1
6003	1364	3	Pacific	1
6005	1430	5	Pacific	1
6007	1053	7	Pacific	1
6009	1466	9	Pacific	1
6011	1179	11	Pacific	1
6013	1502	13	Pacific	0
6015	1472	15	Pacific	1
6017	636	17	Pacific	1
6019	1325	19	Pacific	1
6021	1783			

income.dbf		
Fips	Chr name	Inc p cap
6001	Alameda	12463
6003	Alpine	11039
6005	Amador	9365
6007	Butte	9047
6009	Calaveras	9554
6011	Colusa	6791
6013	Contra Costa	14563
6015	Del Norte	7554
6017	El Dorado	10927
6019	Fresno	9238

In the relational design, data are stored conceptually as a collection of tables. Common fields in different tables are used to link them together.

In fact, most GIS software provides an *internal* relational data model, as well as support for *commercial off-the-shelf* (COTS) relational DBMS'. COTS DBMS' are referred to as *external* DBMS'. This approach supports both users with small data sets, where an internal data model is sufficient, and customers with larger data sets who utilize a DBMS for other corporate data storage requirements. With an external DBMS the GIS software can simply *connect* to the database, and the user can make use of the inherent capabilities of the DBMS. External DBMS' tend to have much more extensive querying and data integrity capabilities than the GIS' internal relational model. The emergence and use of the external

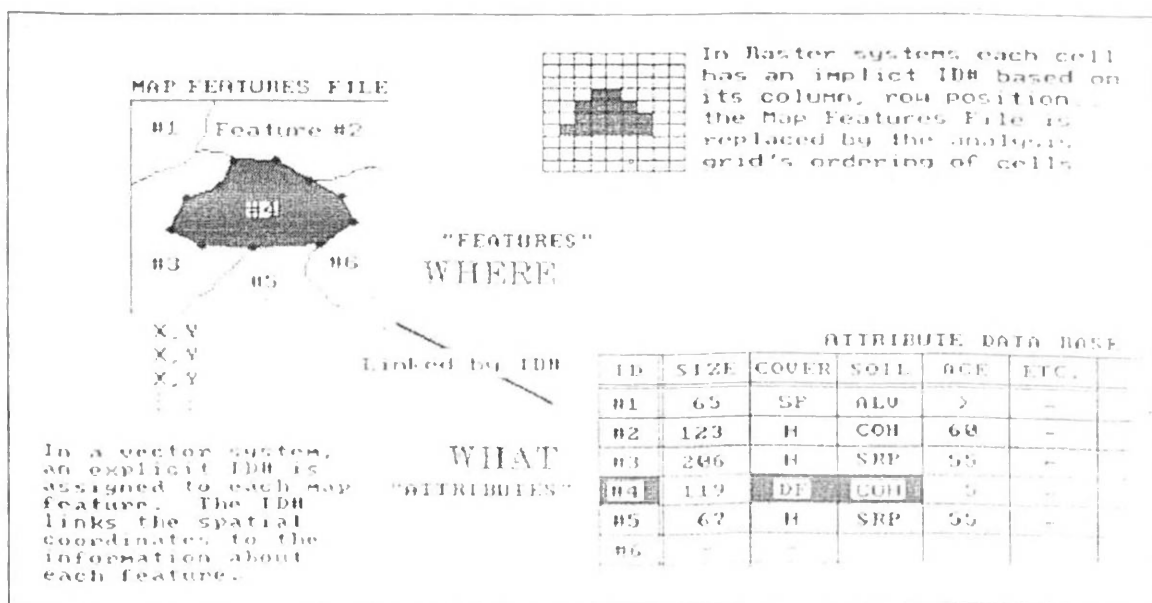
DBMS is a trend that has resulted in the proliferation of GIS technology into more traditional data processing environments.

The relational DBMS is attractive because of its:

- ✦ simplicity in organization and data modelling.
- ✦ flexibility - data can be manipulated in an ad hoc manner by joining tables.
- ✦ efficiency of storage - by the proper design of data tables redundant data can be minimized; and
- ✦ the non-procedural nature - queries on a relational database do not need to take into account the internal organization of the data.

The relational DBMS has emerged as the dominant commercial data management tool in GIS implementation and application.

The following diagram illustrates the basic linkage between a vector spatial data (topologic model) and attributes maintained in a relational database file.



Basic linkages between a vector spatial data (topologic model) and attributes maintained in a relational database file (From Berry)

Object-Oriented Model

The object-oriented database model manages data through *objects*. An object is a collection of data elements and operations that together are considered a single entity. The object-oriented database is a relatively new model. This approach has the attraction that querying is very natural, as features can be bundled together with attributes at the database administrator's discretion. To date, only a few GIS packages are promoting the use of this attribute data model. However, initial impressions indicate that this approach may hold many operational benefits with respect to geographic data processing. Fulfilment of this promise with a commercial GIS product remains to be seen.

MAP DESIGN

Most thematic maps contain these map elements: titles, legends, scales, credits, mapped areas, graticules, borders, symbols, and place names. (See Table 13.1) The task of the designer is to arrange these into a meaningful, aesthetically pleasing design – not an easy task.

Table 13.1 typical elements of the thematic map

Name of Element	Description and Primary Function
Title (and subtitle)	Usually draws attention by virtue of its dominant size; serves to focus attention on the primary content of the map; may be omitted where captions are provided but are not part of the map itself
Map legend	The principal symbol-referent description on the map; subordinate to the title, but a key element in map reading; serves to describe all unknown or unique symbols used
Map scale	Usually included on a thematic map; it provides the reader with important information regarding linear relations on the map; can be graphic, verbal, or expressed as an RF
Credits	Can include the map's data source, an indication of its reliability, dates, and other explanatory material
Mapped and unmapped areas	Objects, land, water, and other geographic features important to the purpose of the map; make the composition a map rather than simply a chart or diagram
Graticule	Often omitted from thematic maps today; should be included if their locational information is crucial to the map's purpose; usually treated as background or secondary forms
Borders and neatlines	Both optional; borders can serve to restrain eye movement; neatlines are finer lines than borders, drawn inside them and often rendered as part of the graticule; used mostly for decoration
Map symbols	Wide variety of forms and functions; the most important elements of the map, along with the geographic areas rendered; designer has little control over their location because geography must be accurate
Place names and labeling	The chief means of communicating with maps; serve to orient the reader on the map and provide important information regarding its purpose

Map design is a complex affair involving many decisions, each of which affects all the others. Good design is simply the best solution among many, given a set of constraints imposed by the problem. The best design will likely be a simple one that works well with the least amount of trouble. The optimum solution may not be achievable, and what is good design today may be ineffective in the future.

Important design principles include *simplicity*, *appropriateness* in a functional context, *pleasing appearance*, and considerations of economy. The designer's tools of creativity, visualization, ideation, and problem solving are used to sift through the map elements in order to bring these principles into a proper balance.

Design levels on the map

It is useful at the outset to imagine the thematic map as composed of different planes or levels. Usually the levels are differentiated by visual prominence. Each component of the map belongs to a specific level. More than one map element can be placed on a particular level, but a single element should never be assigned to more than one level. Thinking of the map in this way will facilitate the map's overall design.

Map composition: the arrangement of the map's elements, takes place at each level and between levels. The arrangement at a given level may be called *planar organization* and the between level may be called *hierarchical organization*.

Elements of map composition

The map's graphic composition is the arrangement or organization of its elements. The composition principles introduced in this chapter include the purpose of map composition, planar organization, figure and ground organization, contrast, and visual acuity. Knowledge of these principles and their application assists the cartographer in seeking better design solutions.

Planar Organization of the Visual Elements

The three aspects of planar visual organization are *balance*, *focus of attention*, and *internal (intraparallel) organization*. Each is important to the designer's language, and their visual possibilities and effects must be explored.

1. Balance

Balance involves the visual impact of the arrangement of image units in the map frame. Do the units appear all on one side, causing the map to "look heavy" on the right or left, top or bottom? An image space has two centers: a geometric center and an optical center (as shown in figure 13.6). The designer should arrange the elements of the map so that they balance visually around the optical center.

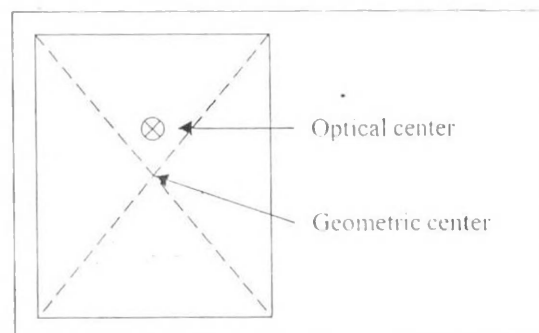


Figure 13.6 The two centers of an image space

Rudolf Arnheim, a noted author on the psychological principles of art, has suggested in his writings that visual balance results from two major factors: weight and direction. Objects in the visual field (e.g., within the border of a map) take on weight by virtue of their location, size, and shape. Direction is also imposed on objects by their relative location, shape, and subject matter. Arnheim stresses that balance is achieved when everything appears to have come to a standstill, “in such a way that no change seems possible, and the whole assumes the character of ‘necessity’ in all its parts.” In Arnheim’s view, unbalanced compositions appear accidental and transitory.

Arnheim’s observations on balance resulting from visual weight and direction can be summarized as follows.

1. Visual weight depends on location.
 - a. Elements at the center of a composition pull less weight than those lying off the tracks of the structural net. (see figure 13.7a)
 - b. An object in the upper part of a composition is heavier than one in the lower part
 - c. Objects on the right of the composition appear heavier than those on the left
 - d. The weight of an object increases in proportion to its distance from the center of the composition.
2. Visual weight depends on size
 - a. Large objects appear visually heavier than small objects
3. Visual weight depends on color, interest, and isolation.
 - a. Color affects visual weight. Red is heavier than blue. Bright colors appear heavier than dark ones. White seems heavier than black.
 - b. Objects of intrinsic interest, because of intricacy or peculiarity, seem visually heavier than objects not possessing these features.
 - c. Isolated objects appear heavier than those surrounded by other elements
4. Visual weight depends on shape.
 - a. Objects of regular shape appear heavier than irregularly shaped ones
 - b. Objects of compact shape are visually heavier than those not so shaped.
5. Visual direction depends on location
 - a. Weight of an element attracts neighborhood objects, imparting direction to them. (see figure 13.7b)
6. Visual direction depends on shape
 - a. Shapes of objects create axes that impart directional forces in two opposing directions.
7. Visual direction depends on subject matter
 - a. Objects opposing intrinsic directional forces can impart visual direction to other elements in the composition.

Of course, Arnheim recognizes that the elements of compositional balance operate together in complex fashion. He also advises not to forsake the content of a composition simply in order to create balance: "The function of balance can be shown only by pointing out the meaning it helps to make visible." Once again, this underscores the idea that map content is more important than the map's design.

It is often difficult to achieve balance on the map. Cartography is not an expressive art form in which the graphic elements may be rearranged at will. Many of the shapes and their locations are imposed by geographical or locational facts. The guidelines presented by Arnheim should nevertheless be applied whenever possible.

Graphic-art professionals who work with two dimensional design often speak of the golden section. This method of devising proportions is attributed to classic Greek architects and sculptors. In the golden section, the proportion of a smaller unit to a large is the same as that of the larger unit to the whole. This method of sectioning can be duplicated any number of times (See Figure 13.8a). Proportion is the relationship of a part of the visual field to the remainder or whole. Balance is achieved when pleasing proportions among the parts are maintained. In fact, one author has noted that the great violin maker Stradivarius employed the golden section in his violin proportions.

Visual balance can be looked at from a different point of view. Writing more than 50 year ago, Richard Surrey, an advertising artist, developed important ideas about composition. Surrey observed that layout involves not only the arrangement of units (balance) but also the division of space. "In other word, instead of layout being a process of addition (putting together units), it is much more easily grasped when considered as a process of division." (See figure 13.8b) His further thoughts on this idea may be summarized:

Cartographers should bear proportion in mind in arranging the different elements of the map. Applying the golden section in cartographic design is an intuitive matter, not subject to rigid quantification.

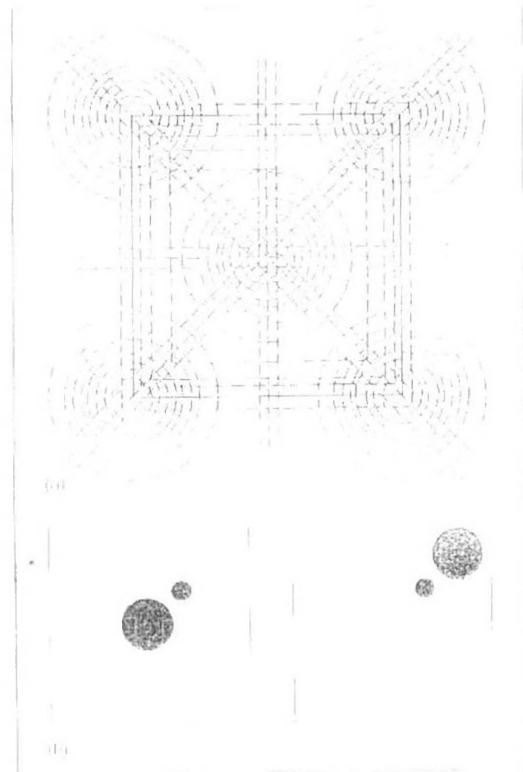


Figure 13.7 Balance in the visual field
Arnheim stresses that a structural net, as in (a), determines balance. Objects on the main axes or at the centers will be in visual balance. An object is given direction by other objects adjacent to it. In (b), the small disc's directional element is shifted as the large disc's position is changed. Each thematic map will have a unique structural net created by the locational patterns of its elements.

1. Equal divisions of space are the least interesting. In equality and the pursuit of equilibrium make layout visually alive.
2. Small spaces struggling against large spaces are visually alive.
3. Variety, for example the division of the image space into ~~four~~ unequal parts, creates interest. Complex designs may be more exciting than simple ones.

To illustrate how balance can affect the impression one has when viewing a map, several different locations of the shape of Africa are included in Figure 13.9. Which appears better balanced within the map frame?

Achieving visual balance, of course, is not always as simple as the case just illustrated. Normally, thematic maps contain most of the elements mentioned earlier, and all must be handled in terms of balance. Visual weight caused by texture, solid black and white areas, and other elements must figure in the planning. Open spaces take up "balance space" and must be used effectively in the overall design. Complex designs require careful planning to use all spaces efficiently while retaining a visually harmonious balance. Acceptable balance is reached when the relation of any one element would cause visual disturbance. Balance is a state of equilibrium

In at least one study using thematic map, the balance of the map's elements is shown to have an initial effect on the way the map reader goes about looking at those elements. However, the longer the reader views the map, the less importance balance seems to have on map-reading behavior. Better balance also leads to less reading difficulty and to somewhat better memory of the map's message. It is not altogether clear exactly what constitutes good and poor balance in such studies because these extremes are subjective at best. Nonetheless, the balance of the map's elements is a vital concern for the cartographic designer.

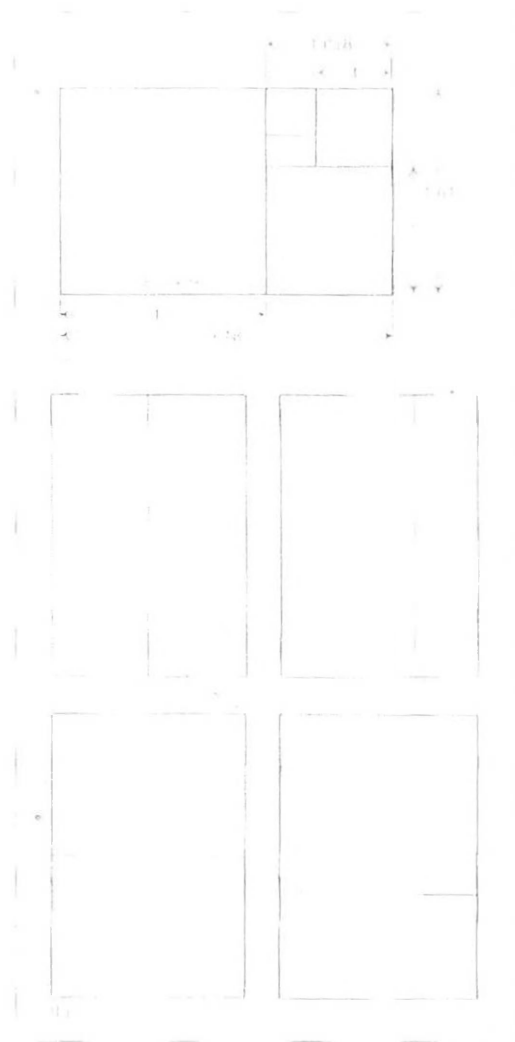


Figure 13.8 Methods of achieving balance Balance is dynamic and will result from appropriate proportioning of the image space. The method of arriving at the golden section is illustrated in (a) and several alternatives are pictured in (b). In (b), notice that unequal division of space are more interesting.

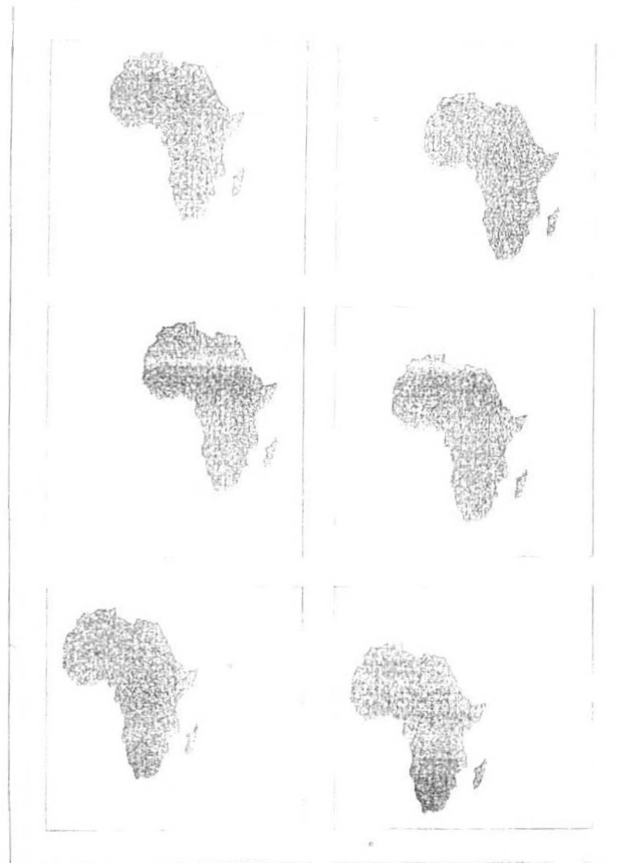


Figure 13.9 Map balance

Position of map elements in the image space affects the balance of the map. The difference can be visually subtle, as this illustration shows. In which image does a natural visual equilibrium appear to exist?

Focus of Attention

As previously mentioned, the optical center of an image area is a point just above the geometric center. This attracts the viewer's eye, unless other visual stimuli in the field distract attention. Surrey mentioned earlier makes several other points that are significant for questions of design. He says that the reader's eye normally follows a path from upper left to lower right in the visual field and passes through the optical center. (See figure 13.10.) Further more, the point of greatest natural emphasis is where a line of space division intersects either the focus or field circles of attention. (See figure 13.11.)

Surrey's ideas were based on intuitive judgments and personal observations and have not been scientifically proven. Yet they do have appeal for the designer. An examination of recent print advertisements attests to the general applicability of his ideas. We can learn from these and other graphic designs. The map is a visual instrument, so the designer must learn what works in the visual world.

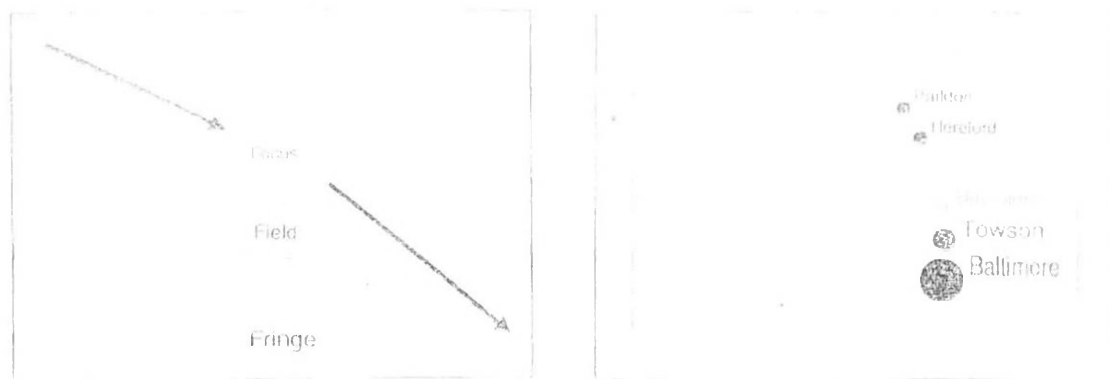


Figure 13.10 Eye movement through the image space (upper)

In normal viewing, the reader's eyes enter through the image space at the upper left, proceed through the visual center (focus), and exit the space at the lower right. Cartographic designers may use this pattern when arranging the map's elements, so that the positions of important objects on the map correspond to natural eye movements.

Figure 13.11 Recentering for greater clarity (right)
If possible, it is a good idea to recenter the map to place the central focus (in this case, the town of Timonium) closer to the optical center.



2. Contrast and Design

Closely associated with figure and ground organization, and of nearly equal importance, is the feature called contrast. Contrast is fundamental in developing figure and ground but can be considered a design principle in its own right. Visual contrast leads to perceptual differentiation, the ability of the eye to discern differences. A lack of visual contrast detracts from the interest of the image and makes it difficult to distinguish important from unimportant parts of the communication. Map elements that have little contrast with their surroundings are easily lost in the total visual package. Contrast must be a major goal of the designer.

Contrast can be achieved through several mechanisms: line, texture, value, detail, and color. All of these could be used in one design, but the result might be visual disharmony and tension – potentially as unrewarding as having no contrast at all.

Line contrast

Lines may be put to a variety of uses on maps. They can function as labels, borders, neatlines, political boundaries, quantitative or qualitative symbols, special symbols to divide areas, or graphic devices to achieve other goals. Line contrast can be of two kinds: character and weight. Line character derives from the nature of the line and its segments, or its value or color. (See figure 13.14a.) The order of visual importance of various line characters has not been well established. The subject and purpose of the map very often

restrict choice of line character. On some maps, there may be no lines. For example, some recent designs use edges rather than lines to evoke a response.

The thickness of a line is its line weight, although no clear-cut relationship exists between thickness and visual or intellectual importance. Although a broader line generally carries more intellectual importance, very fine lines also can be visually dominant. Strike a balance, keeping the map's purpose firmly in mind.

Contrast of line character and weight introduces visual stimulation to the map. A map having lines of all one weight is boring and lacks potential for figure formation. (See figure 13.14b.) On the other hand, a map with lines of several weights and characters focuses attention, is lively, and aids the map reader's perceptual organization of the material. (See figure 13.14c.) Guidelines can assist the designer in choosing lines so that discrimination between weights is possible. Generally, a line-weight difference exceeding .05 in is discernible by more than half of all map readers. A difference of .15 in is easily noticed by practically all readers.

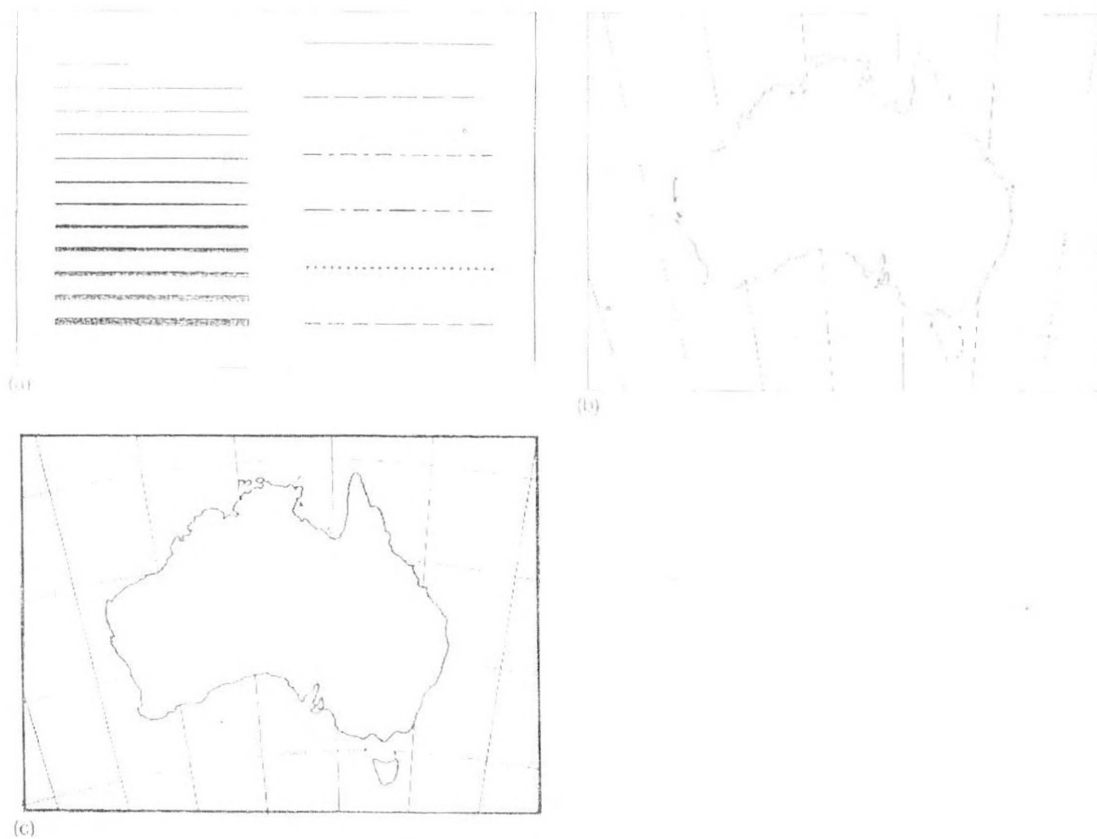


Figure 13.14 Line contrast

In (a), several different line weights and line characters are shown. The visual effect of varying line weights on a map is illustrated by comparing (b) and (c). More visual interest is achieved with greater contrast of weight. In this case, the figure and ground organization is strengthened.

Texture contrast

Contrast of texture involves area patterns and how they are chosen for the map. In this context, texture is a pattern of small symbols (e.g., dots) repeated in such a way that the eye can perceive the individual elements. Texture is often determined by the selection of quantitative symbols for the map. Contrast considerations should be part of symbol selection. In some instances, patterns are selected and applied to the map solely to provide graphic contrast (e.g., in the differentiation of land and water). Texture is sometimes applied in order to direct the reader's attention to a particular part of the map.

Another possibility, not often used, is textured lettering. This differentiates labels from other lettering, enabling the designer to use more lettering in the design. Textured lettering is possible only when the letters are geometric, not composed of many thick and thin strokes.

Value Contrast

Texture is observable because the individual dots or other elements of the pattern are easily seen. Reducing such a pattern to the point where the elements are below the threshold of visual resolution acuity results in the perception of a visual tone or value. Contrast of value is another design technique used by cartographers, although some of the contrast is often dictated by the nature of the data (qualitative or quantitative). In cases not determined by the data, contrast of value can be used in ways similar to contrast of texture. (See figure 13.16.) Contrast of value leads to light and dark areas on the map. A good place to use this contrast type is in the development of figures and grounds. To stand out strongly, figures should have values considerably different than grounds. Land areas, for example, should be made lighter or darker than water areas.

Variation of Detail

Although designers seldom think of it as a positive design consideration, contrast of detail can be employed effectively, especially in combination with other techniques. Along a continuum ranging from little detail at one end to great detail at the other, the reader's eye will be attracted to those areas of the map with the most detail.

This feature can work against the designer, however. Exquisite detail rendered to an unimportant feature can distract the reader's attention from the communication effort. By judicious use of extra detail in important areas of the map, the designer can subtly lead the reader to them. (See figure 13.17.) Detail can also be used to strength figure formation.

Color Contrast

Employment of color is one of the chief techniques in the development of contrast in design. Color can differentiate areas on the map for a variety of purposes.

Visual Hierarchy and the Figure-Ground Relationship

There is probably no perceptual tendency more important to cartographic design than **figure and ground organization**. A person's underlying perceptual tendency is to organize the visual field into categories: figures (important objects) and grounds (things less important). This concept was first introduced by Gestalt psychologists early in this (20th) century. Figures become objects of attention in perception, standing out from the background. Figures have "thing" qualities; grounds are formless. Figures are remembered better; grounds are often lost in perception.

The visual hierarchy (or organizational hierarchy) is the intellectual plan for the map and the eventual graphic solution that satisfies the plan. Each design activity should contain such a hierarchy. In this phase of design, the cartographer sorts through the components of the map to determine the relative intellectual importance of each, then seeks a visual solution that will cast each component in a manner compatible with its position along the intellectual spectrum. Objects that are important intellectually are rendered so that they are visually dominant within the map frame. (See figure 13.18.)

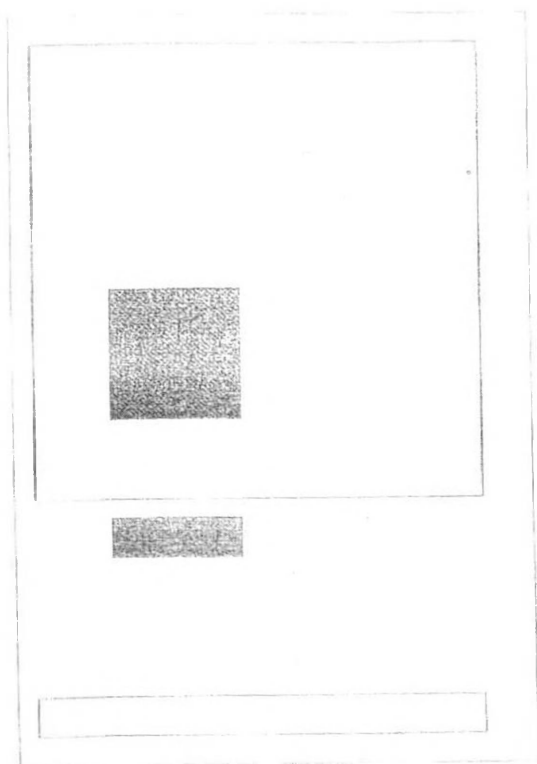


Figure 13.18 The visual hierarchy. Objects on the map that are most important intellectually are rendered with the greatest contrast to their surroundings. Less important elements are placed lower in the hierarchy by reducing their edge contrasts. The side view in this drawing further illustrates this hierarchical concept.

Thematic map and Map symbolization

A **thematic map** is a type of especially designed to show a particular theme connected with a specific. These maps "can portray physical, social, political, cultural, economic, sociological, agricultural, or any other aspects of a city, state, region, nation, or continent"

A thematic map is a map that focuses on a specific theme or subject area. This is in contrast to general reference maps, which regularly show the variety of phenomena—geological, geographical, political—together.[2][3] The contrast between them lies in the fact that thematic maps use the base data, such as coastlines, boundaries and places, only as points of reference for the phenomenon being mapped. General maps portray the base data, such as landforms, lines of transportation, settlements, and political boundaries, for their own sake.

Thematic map are sometimes referred to as graphic essays that portray spatial variations and interrelationships of geographical distributions. Location, of course, is important to provide a reference base of where selected phenomena are occurring.

Thematic maps serve three primary purposes.

They provide specific information about particular locations.

They provide general information about spatial patterns.

They can be used to compare patterns on two or more maps.

Common examples are maps of demographic data such as population density. When designing a thematic map, cartographers must balance a number of factors in order to effectively represent the data. Besides spatial accuracy, and aesthetics, quirks of human visual perception and the presentation format must be taken into account.

In addition, the audience is of equal importance. Who will “read” the thematic map and for what purpose helps define how it should be designed. A political scientist might prefer having information mapped within clearly delineated county boundaries (choropleth maps). A state biologist could certainly benefit from county boundaries being on a map, but nature seldom falls into such smooth, man-made delineations. In which case, a dasymetric map charts the desired information underneath a transparent county boundary map for easy location referencing.

Data terminology

A thematic map is univariate if the non-location data is all of the same kind. Population density, cancer rates, and annual rainfall are three examples of univariate data. Bivariate mapping shows the geographical distribution of two distinct sets of data. For example, a map showing both rainfall and cancer rates may be used to explore a possible correlation between the two phenomena. More than two sets of data leads to multivariate mapping. For example, a single map might show population density in addition to annual rainfall and cancer rates.

Methods of thematic mapping

Cartographers use many methods to create thematic maps, but five techniques are especially noted.

Choropleth

Choropleth mapping shows statistical data aggregated over predefined regions, such as counties or states, by coloring or shading these regions. For example, countries with higher rates of infant mortality might appear darker on a choropleth map. This technique assumes a relatively even distribution of the measured phenomenon within each region. Generally speaking, differences in hue are used to indicate qualitative differences, such as land use, while differences in saturation or lightness are used to indicate quantitative differences, such as population.

Proportional symbol

The proportional symbol technique uses symbols of different sizes to represent data associated with different areas or locations within the map. For example, a disc may be

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shown at the location of each city in a map, with the area of the disc being proportional to the population of the city.

Isarithmic or Isopleth

Isarithmic maps, also known as contour maps or isopleth maps depict smooth continuous phenomena such as precipitation or elevation. Each line-bounded area on this type of map represents a region with the same value. For example, on an elevation map, each elevation line indicates an area at the listed elevation. An Isarithmic map is a planimetric graphic representation of a 3-D surface. Isarithmic mapping requires 3-D thinking for surfaces that vary spatially.

Dot

A dot distribution map might be used to locate each occurrence of a phenomenon, as in Dr. Snow's map where each dot represented one death due to cholera. Where appropriate, a dot may indicate any number of entities, for example, one dot for every 100 voters.

Dasymetric

A dasymetric map is an alternative to a choropleth map. As with a choropleth map, data are collected by enumeration units. But instead of mapping the data so that the region appears uniform, ancillary information is used to model internal distribution of the phenomenon. For example, population density will be much lower in forested area than urbanized area, so in a common operation, land cover data (forest, water, grassland, urbanization) may be used to model the distribution of population reported by census enumeration unit such as a tract or county.

Map symbolization

Map symbolization is the characters, letters, or similar graphic representations used on a map to indicate an object or characteristic in the real world.

Cognitive issues

There are many cognitive issues involved in the cartographic process and symbolization.[1] Some people may perceive certain objects differently from others, so cartographers try not to use symbols that could be easily confused. For example, red and blue are universally known to depict hot and cold.

In cartography, the principles of cognition are important since they explain why certain map symbols work. In the past, mapmakers did not care why they worked. This behaviorist view treats the human brain like a black box. Modern cartographers are curious why certain symbols are the most effective. This should help develop a theoretical basis for how brains recognize symbols and, in turn, provide a platform for creating new symbols.

Topographic maps

Topographic maps show the shape of Earth's surface by using contour lines, the lines on the map that join points of equal elevation. They are among the most well-known symbols on modern maps as they are self-explanatory and accurately represent their phenomena. They make it possible to depict height, depth, and even slope. Contour lines will be closer together or spaced apart to show the steepness of the area. If the line is spaced closer together, it means that there is a steeper slope. If they are farther apart, the area has a low slope. An area of low slope generally uses contour intervals of 40 feet or less. Areas that contain mountain or other high slope can use an interval of 100 feet.

Apart from showing just contour lines, topographic maps also use a lot of map symbols to represent its features. Features are represented by using point, line, and area symbols. Individual features, such as houses, are shown as point symbols like a small dot or square. However, a cluster of houses or neighborhood can be shown as a shaded area or polygon. Areas of importance or landmarks may receive special symbols that represent what they are. For instance, a church may be symbolized as a picture of a little church or cross or the town hall may have a special color or symbol.

Rules to follow

There are certain rules to follow with map symbols. The representative symbols should always be placed on the left and defined to the right. This allows for the reader to view the symbol first, then its definition, which is customary in English dictionaries. In most cases, representative symbols should be vertically displayed and the symbols should be horizontally centred. The symbols should be vertically centred with the definitions. The definitions are supposed to be horizontally centred to the left.

Representing spatial phenomena

Symbols are used to represent geographic phenomena. Most phenomena can be represented by using point, line, or area symbols.[4] It is necessary to consider the spatial arrangement of the phenomena to determine what kind of symbolization it will require. Discrete phenomena occur at isolated points, whereas continuous phenomena occur everywhere. Both of these can also be broken down into either smooth or abrupt. For example, rainfall and taxes for states are both continuous in nature, but rainfall is smooth because it does not vary at state boundaries, leaving the tax to be considered abrupt. It is important to distinguish between real world and the data we use to represent it. There are basically five types of spatial dimensions that are used to classify phenomena for map symbolization. Point phenomena are assumed to have no spatial extent and are said to be zero-dimensional. These use point symbols on a map to indicate their location. An example of these would be fire hydrants or trees in a park. Linear phenomena are one-dimensional and have a length. This would include any line feature on a map like roads or sidewalks. Areal phenomena are 2-D that has both a length and a width. The best example of this would be a lake or other body of water. When volume comes into consideration, it is broken down into two types, 2 ½ dimensions and 3-D. A good example of 2 ½ D would be the elevation of a place above sea level, while 3-D being any three-dimensional objects.

Ranking

An important factor in map symbols is the order in which they are ranked according to their relative importance. This is known as intellectual hierarchy. The most important hierarchy is the thematic symbols and type labels that are directly related to the theme. Next comes the title, subtitle, and legend.[4] The map must also contain base information, such as boundaries, roads, and place names. Data source and notes should be on all maps. Lastly, the scale, neat lines, and north arrow are the least important of the hierarchy of the map. From this we see that the symbols are the single most important thing to build a good visual hierarchy that shows proper graphical representation. When producing a map with good visual hierarchy, thematic symbols should be graphically emphasized. A map with a visual hierarchy that is effective attracts the map user's eyes to the symbols with the most important aspects of the map first and to the symbols with the lesser importance later.

The legend of the map also contains important information and all of the thematic symbols of the map. Symbol that need no explanation, or do not coincide with the theme of the map, are normally omitted from the map legend. Thematic symbols directly represent the maps theme and should stand out.

Choropleth maps

Choropleth mapping is commonly used to show data for counties, states, or other enumeration units. Data collected for choropleth maps is usually grouped into separate classes based on attributes or other forms of classification. The classes are given a specific color or shading based on their values and what they are trying to portray. Choropleth maps are most effective when the data or classes change abruptly at each enumerated boundary.

A proportional symbol map is better than choropleth maps for showing raw data totals. A proportional symbols map uses symbols that are proportional the data that they are representing with point locations. These symbols can be true points or conceptual points. True points represent real objects or the exact location of a tangible object. This could be an oil well or fire hydrant. A conceptual point represents the center of the enumeration unit,

such as a corn field. The raw data on proportional symbol maps go hand in hand with the data shown on choropleth maps.

Isopleth maps

Isopleth maps use isolines that connect points of equal values. A good example of isolines is connecting areas with similar temperatures. As with choropleth maps, Isopleth maps require standardized data to be appropriately contoured.

Dot maps

Dot maps use one single dot to represent where a single phenomenon is the most likely to occur. The total amount of dots can cover a single area or multiple areas. The density of the dots is interpreted by the user as areas of high value. This method is more accurate than proportional and Isopleth maps.