M.Sc. GEOGRAPHY LAB MANUAL

4th Semester

Prepared By

Pure & Applied Science Dept.

Geography

MIDNAPORE CITY COLLEGE

MIDNAPORE CITY COLLEGE

DEPARTMENT OF PURE AND APPLIED SCIENCES

LABORATORY MANUAL OF GEOGRAPHY

(MA/MSC, SEMESTER – IV)

PREFACE TO THE FIRST EDITION

This is the first edition of Lab Manual for PG Geography fourth Semester. Hope this edition will help you during practical. This edition mainly tried to cover the whole syllabus. Some hard topic are not present here that will be guided by responsive teachers at the time of practical.

ACKNOWLEDGEMENT

We are really thankful to our students, teachers, and non-teaching staffs to make this effort little bit complete. Mainly thanks to Director and Principal Sir to motivate for making this lab manual.

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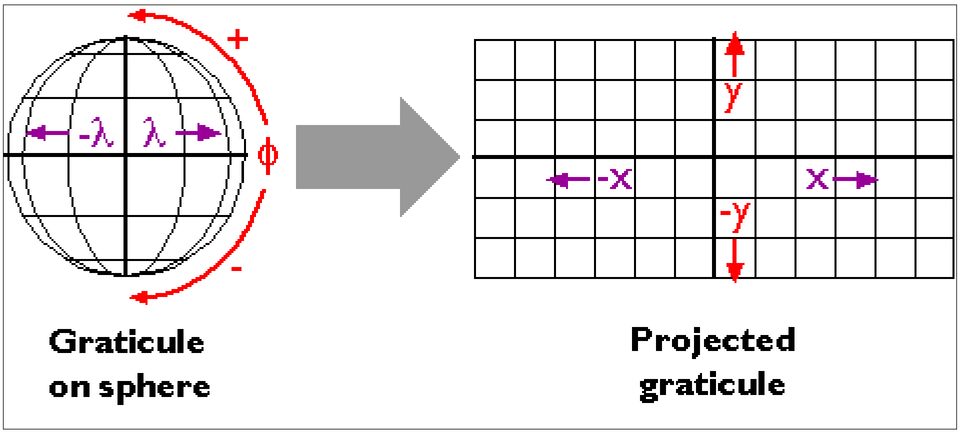
1. Map transformation: Scale factor; distortion types; systems of map projections; principles of choosing map projection; importance of map projection in GIS.

Map Transformation/Projection

A map projection is a systematic transformation of the latitudes and longitudes of locations from the surface of a sphere or an ellipsoid into locations on a plane. Maps cannot be created without map projections. All map projections necessarily distort the surface in some fashion. Depending on the purpose of the map, some distortions are acceptable and others are not; therefore, different map projections exist in order to preserve some properties of the sphere-like body at the expense of other properties. There is no limit to the number of possible map projections. More generally, the surfaces of planetary bodies can be mapped even if they are too irregular to be modelled well with a sphere or ellipsoid; see below. Even more generally, projections are a subject of several pure mathematical fields, including differential geometry, projective geometry, and manifolds. However, "map projection" refers specifically to a cartographic projection.

A map projection is one of many methods used to represent the 3-dimensional surface of the earth or other round body on a 2-dimensional plane in cartography (mapmaking). This process is typically, but not necessarily, a mathematical procedure (some methods are graphically based).

Latitude and longitude coordinates specify positions in a more-or-less spherical grid called the graticule. Plane coordinates like the eastings and northings in the Universal Transverse Mercator (UTM) and State Plane Coordinates (SPC) systems denote positions in flattened grids. This is why georeferenced plane coordinates are referred to as projected, and geographic coordinates are called unprojected. The mathematical equations used to transform latitude and longitude coordinates to plane coordinates are called map projections.



Scale Factor

The ratio between the principle scale and real scale at any point on the map is called the 'scale factor' at that point.

$$\textbf{Scale Factor (SF)} = \frac{\textbf{Denominator of the Principle Scale}}{\textbf{Denominator of the Real Scale}}$$

- The scale in which the generating globe (a 3-dimentional figure) is conceptualised is called the principle scale.
- The scale of the resultant map is termed as the real scale. it is the differential stretching and contortions of the generating globe that make the real scale unequal at each and every point of the map.

Types of scale factor:

Scale factors are mainly two types –

1. Tangential Scale Factor (TSF)
2. Radial Scale Factor (RSF)

1. Tangential Scale Factor (TSF)

The scale factor measured along a parallel is called the parallel scale factor or tangential scale factor. The equations for the derivation are:

$$\textbf{Tangential Scale Factor (TSF)} = \frac{\textbf{Denominator of the Principle Scale along a Parallae } (\emptyset)}{\textbf{Denominator of the Real Scale along the Same Parallae } (\emptyset)}$$

$$= \frac{\textbf{Length of a Parallel on Globe } (\mathbf{L_{\emptyset g}})}{\textbf{Length of the same Parallel on Map } (\mathbf{L_{\emptyset m}})}$$

Hence, along a parallel,∅, tangent scale factor,

$$\mathbf{TSF} = \frac{\mathbf{L_{\emptyset g}}}{\mathbf{L_{\emptyset m}}}$$

Tangential scale expressed by 1 : TSF

2. Radial Scale Factor (RSF)

While the scale factor measure along a meridian is called the meridional scale factor or radial scale factor. The equations for the derivation are:

$$\textbf{Radial Scale Factor } (\mathbf{RSF}) = \frac{\textbf{Denominator of the Principle Scale along a Meridian } (\lambda)}{\textbf{Denominator of the Real Scale along the Same Meridian } (\lambda)}$$

$$= \frac{\textbf{Length of a Meridian on Globe } (\mathbf{L_{\lambda g}})}{\textbf{Length of the same Meridian on Map } (\mathbf{L_{\lambda m}})}$$

Hence, along a meridian, ∅, tangent scale factor,

$$\mathbf{TSF} = \frac{\mathbf{L_{\lambda g}}}{\mathbf{L_{\lambda m}}}$$

Tangential scale expressed by 1 : RSF

Deformation/Distortion Types

Along the two principal directions, it is the balance of the scale factors that determines the nature and magnitude-of deformations on a projection. There are four principal types of deformations. These are deformations in area, shape, distance and direction, which are mutually exclusive in nature. On a projection transformation, scale factors are simple vectors, their products and resultants determine the specific property of a projection. On the basis of this, projections are classified into five types:

1. Equal-Area Projections

In these, the area of a segment on the generating globe is truly preserved on the corresponding segment of the graticules. At any point of such projections, the product of the two scale factors is unity, or, in other words.

$$RSF \times TSF = 1$$

These are also called authalic, homolographic or equivalent projections.

2. Orthomorphic Projections

Here, the shape of a segment on the generating globe is truly preserved on the corresponding segment of the graticules. At any point of such projections, the two scale factors are exactly equal in magnitude. The necessary condition of orthomorphism is therefore, the equality of scales along the two principal directions, i.e., RSF = TSF

These are also known as true-shape or conformal projections.

3. Equidistant Projections

In these, the distance between any two points on the generating globe is truly preserved between the corresponding points on graticules.

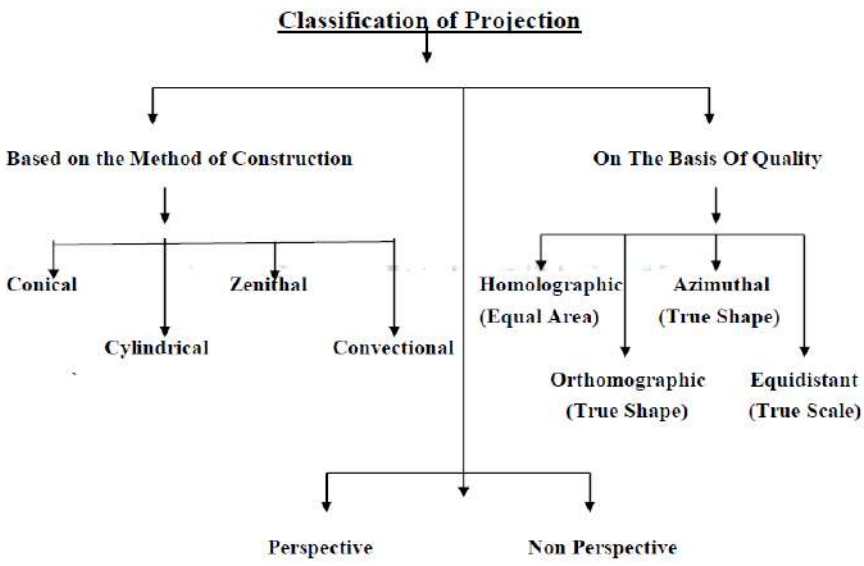
4. Azimuthal Projections

Here the azimuth defining the directions between any two points on the generating globe is truly preserved between the corresponding two points on the graticules.

5. Aphylactic Projections

In these, neither of the above four properties is truly and fully preserved. Such projections are genetically neither azimuthal equidistant, nor equivalent and nor conformal.

Classification of Projections



Principle of Choosing Map Projection

When you choose a projection, the first thing to consider is the purpose of your map. For general reference and atlas maps, you usually want to balance shape and area distortion. If your map has a specific purpose, you may need to preserve a certain spatial property—most commonly shape or area—to achieve that purpose.

1. Maps that preserve shape

On a conformal projection, all local angles measured from a point are correct and all local shapes are true. You should use a conformal projection when the map's main purpose involves measuring angles, showing accurate local directions, or representing the shapes of features or contour lines. This category includes:

- Topographic maps and cadastral (land parcel) maps
- Navigation charts (for plotting course bearings and wind direction)
- Civil engineering maps
- Military maps
- Weather maps (for showing the local direction in which weather systems are moving)

Most of the maps in the list above would be large or medium-scale. In fact, most large-scale maps nowadays are conformal, regardless of their purpose.

2. Maps that preserve area

On an equal-area projection, the size of any area on the map is in true proportion to its size on the earth. You should use equal-area projections to show:

- The density of an attribute with dots (for example, population density)
- The spatial extent of a categorical attribute (for example, land use maps)
- Quantitative attributes by area (for example, Gross Domestic Product by country)

Equal-area maps have also been used as world political maps to correct popular misconceptions about the relative sizes of countries.

3. Maps that preserve scale

No map provides true-to-scale distances for any measurement you might make. The Azimuthal Equidistant projection preserves true scale *from a single specified point* on the projection to all other points on the map. Possible uses for this property include:

- Maps of airline distances from a single city to several other cities
- Seismic maps showing distances from the epicenter of an earthquake
- Maps used to calculate costs or charges based on straight-line distance from a source
- Maps used to calculate ranges; for example, the cruising ranges of airplanes or the habitats of animal species

The Two-Point Equidistant projection preserves true scale *from two specified points* on the projection to all other points on the map. This projection could be used to determine the distance of a ship at sea from the start and end of a voyage.

4. Maps that preserve direction

On any azimuthal projection, all azimuths, or directions, are true from a single specified point to all other points on the map. (On a conformal projection, directions are locally true, but are distorted with distance.) Direction is not typically preserved for its own sake, but in conjunction with another property.

In navigation and route planning, however, direction matters for its own sake. The Gnomonic projection is unique among azimuthals in that every straight line drawn on it represents the arc of a great circle. Since a great circle is the shortest distance between two points, Gnomonic projections are useful for planning air and sea routes and for mapping phenomena, like radio waves, that follow shortest-distance paths.

5. True direction and constant direction revisited

On the Gnomonic projection, any straight line between two points is the arc of a great circle. While good for route planning, this property is not good for practical navigation, because to follow a great circle, you have to keep changing your bearings.

On the Mercator projection—which is not azimuthal—any straight line between two points is a line of constant bearing: you follow a single compass heading to get from one point to another, but the route is longer than a great circle.

For short routes, navigators rely on the Mercator. For long routes, they may plan their course on the Gnomonic, and then convert the great circle path to a series of shorter rhumb lines on the Mercator.

6. General purpose maps

Many compromise projections have been developed to show the world with a balanced distortion of shape and area. Among the most successful are:

- Winkel Tripel (currently used by the National Geographic Society for world atlas maps)
- Robinson
- Miller Cylindrical

For larger-scale maps, from continents to large countries, equidistant projections (equidistant in the sense of true scale along the meridians) are good at balancing shape and area distortion. Depending on your area of interest, you might use:

- Azimuthal Equidistant
- Equidistant Conic
- Plate Carrée

The National Geographic Society uses the Two-Point Equidistant projection to balance shape and area distortion for some maps of Asia.

The map's purpose narrows your choices, but doesn't determine a projection. After all, there are many conformal projections, many equal-area projections, and many compromise projections.

The next step in choosing a projection is to decide on the class of projection: cylindrical, conic, or azimuthal. A time-honored rule–dating to the 16th century–is to choose according to the latitude of your area of interest. The rule says:

- To map tropical regions, use a cylindrical projection
- To map middle latitudes, use a conic projection
- To map a polar region, use an azimuthal projection

The rule makes sense if you think about the line (or point) of zero distortion for each class of projection. In cylindrical projections, the line of zero distortion is the equator; in conic projections, it's a parallel of latitude; in azimuthal projections, it's one of the poles. Using a projection from the right class minimizes distortion for your area of interest.

Role of Map Projection in GIS

It is important for a GIS analyst to have a thorough understanding of map projections and coordinate systems. A GIS without coordinates would simply be a database like Microsoft Excel or Access. It is thanks to the coordinates that we can create overlays in a GIS and perform analyses that incorporate data from more than one layer. Without coordinates associated with the geographic data (points, lines, polygons or rasters) ArcMap would not know where to place the different layers in relation to each other.

GIS can convert data from one coordinate system to another. It is necessary for the users to understand of the characteristics of the various types of coordinate system that may be used. If you are a GIS practitioner, you have probably faced the need to superimpose unprojected latitude and longitude data onto projected data, and vice versa. For instance, you might have needed to merge geographic coordinates measured with a GPS receiver with digital data published by the USGS that are encoded as UTM coordinates.

Modern GIS software provides sophisticated tools for projecting and un-projecting data. To use such tools most effectively, you need to understand the projection characteristics of the data sets you intend to merge. Here, let's simply review the characteristics that are included in the "Spatial Reference Information" section of the metadata documents that (ideally!) accompany the data sets you might wish to incorporate in your GIS. These include:

Projection Name: Most common in the GIS realm is the Transverse Mercator, which serves as the basis of the global UTM plane coordinate system. Much map data, particularly in the form of printed paper maps, are based upon "legacy" projections (like the Polyconic in the U.S.) that are no longer widely used. A much greater variety of projection types tend to be used in small scale thematic mapping than in large scale reference mapping.

Central Meridian: Although no land masses are shown, let's assume that the graticule and projected grid shown above are centered on the intersection of the equator (0 latitude) and prime meridian (0° longitude). Most map projection formulae include a parameter that allows you to center the projected map upon any longitude.

Latitude of Projection: Origin Under certain conditions, most map projection formulae allows you to specify different aspects of the grid. Instead of the equatorial aspect illustrated above, you might specify a polar aspect or oblique aspect by varying the latitude of projection origin such that one of the poles, or any latitude between the pole and the equator, is centered in the projected map. As you might imagine, the appearance of the grid changes a lot when viewed at different aspects.

Scale Factor at Central Meridian: This is the ratio of map scale along the central meridian and the scale at a standard meridian, where scale distortion is zero. The scale factor at the central meridian is 0.9996 in each of the 60 UTM coordinate system zones since each contains two standard lines 180 kilometres west and east of the central meridian. Scale distortion increases with distance from standard lines in all projected coordinate systems.

Standard Lines: Some projections, including the Lambert Conic Conformal, include parameters by which you can specify one or two standard lines along which there is no scale distortion caused by the act of transforming the spherical grid into a flat grid. By the same reasoning that two standard lines are placed in each UTM zone to minimize distortion throughout the zone to a maximum of one part in 1000, two standard parallels are placed in each SPC zone that is based on a Lambert projection such that scale distortion is no worse than one part in 10,000 anywhere in the zone.

2. Principle, construction, properties and uses of following map projections: a) Conformal Projections- Mercator's Projection; Transverse Mercator Projection and Lambert's Conformal Conic (LCC) Projection.

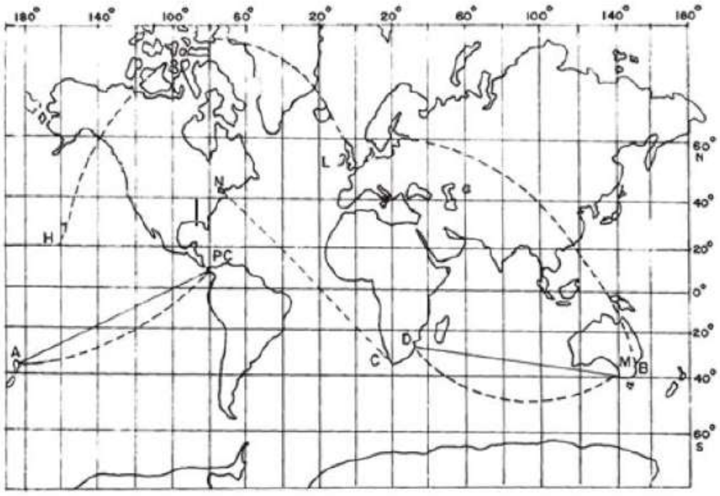
A. Mercator's Projection

Principle

This is a cylindrical orthomorphic projection designed by Flemish, Mercator and Wright. In this, a simple right circular cylinder touches the globe along the equator. All the parallels are of the same length equal to that of the equator and the meridians are equispaced on the parallels. Therefore, the tangential scale increases infinitely toward the pole. To maintain the property of orthomorphism, the radial scale is made equal to the tangential scale at any point. Hence parallels are variably spaced on the meridians and the poles can never be represented. The parallels and meridians are represented by sets of straight lines intersecting at right angles.

Construction

1. A straight line is drawn horizontally through the centre of the paper to represent the Equator.
2. It is then divided by d for spacing the meridians.
3. Through each of these division points, straight lines are drawn perpendicular to the Equator to represent the meridians.
4. On the Central Meridian, heights of different parallels (Y_{Φ}) from the Equator are marked.
5. Through each of these points straight lines are drawn perpendicular to the Central Meridian to represent the parallels.
6. The graticules are then accurately and properly labelled.



Straight lines are Laxodromes or Rhumb lines and

Dotted lines are great circles

Properties

1. All parallels and meridians are straight lines and they intersect each other at right angles.
2. All parallels have the same length which is equal to the length of equator.
3. All meridians have the same length and equal spacing.
4. Spacing between parallels increases towards the pole.
5. Scale along the equator is correct as it is equal to the length of the equator on the globe; For example, the 30º parallel is 1.154 times longer than the corresponding parallel on the globe.
6. Shape of the area is maintained, but at the higher latitude's distortion takes place.
7. The shape of small countries near the equator is truly preserved while it increases towards poles.
8. It is an azimuthal projection.
9. This is an orthomorphic projection as scale along the meridian is equal to the scale along the parallel.

Uses

1. More suitable for a world map and widely used in preparing atlas maps.
2. Very useful for navigation purposes showing sea routes and air routes.
3. Drainage pattern, ocean currents, temperature, winds and their directions, distribution of worldwide rainfall and other weather.

Example

Draw a Mercator's projection for the map of India with extension of 60°E to 100°E and 4°N to 40°N on the scale of 1:25 X 10^6 at 4° intervals.

Calculation

Step 1

Radius of the generating globe, R = Actual Radius of the Earth / Denominator of R.F.

Radius of the reduced earth is, $R = \frac{250{,}000{,}000 \text{ inches}}{250{,}000{,}00}$ = 10 inches.

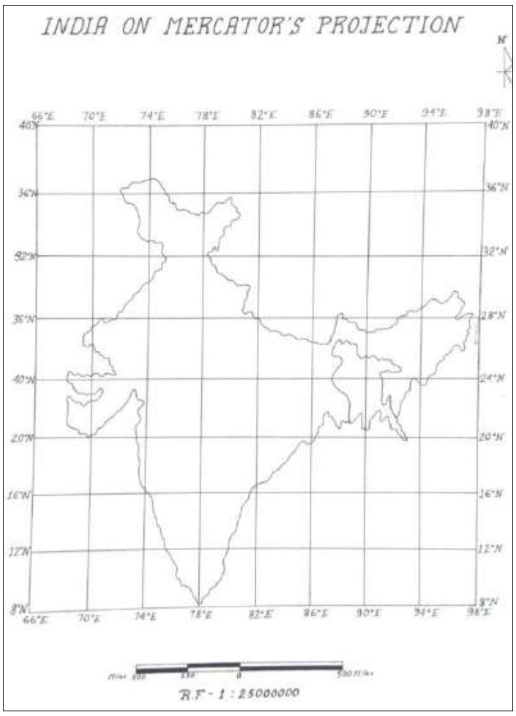
Step 2

Division along the equator for spacing the meridians at 4° interval, $d = \frac{2\pi R}{360^\circ} \times 4^\circ = 0.678 \text{ inch.}$

Step 3

Height of any parallel above the equator, $Y_\Phi = 23.026\, R \log \tan\left(\frac{90^\circ + \emptyset}{2}\right)$

Φ	4°N	8°N	12°N	16°N	20°N	24°N	28°N	32°N	36°N	40°N
$\left(\frac{90^\circ + \emptyset}{2}\right)$	47°	49°	51°	53°	55°	57°	59°	61°	63°	65°
$Y\Phi$	0.70	1.40	2.11	2.33	3.56	4.32	5.09	5.90	6.74	7.63



B. Transverse Mercator Projection

Classifications

- Transverse aspect of Mercator projection
- Cylindrical
- Conformal

Graticule

- **Meridians and parallels:** Central meridian, each meridian 90° from central meridian, and the Equator are straight lines. Other meridians and parallels are complex curves, concave toward the central meridian and the nearest pole, respectively.

- **Poles:** Points along the central meridian

- **Symmetry:** About any straight meridian or the Equator

Scale

- True along the central meridian or along two straight lines on the map equidistant from and parallel to the central meridian.

- Constant along any straight line on the map parallel to the central meridian. (These lines are only approximately straight for the projection of the ellipsoid.)

- Increases with distance from the central meridian Becomes infinite 90° from the central meridian

Distortion

At a given distance from the central meridian in figure 2A, the distortion in area is identical with that at the same distance from the Equator in figure 1A.

Figure 1A: Mercator projection with Tissot indicatrices, 30" graticule. All indicatrices are circular (indicating conforrnality), but areas vary.

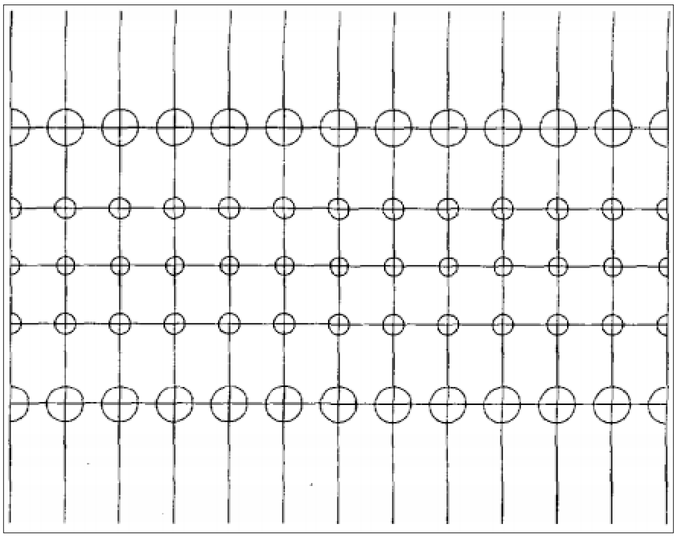
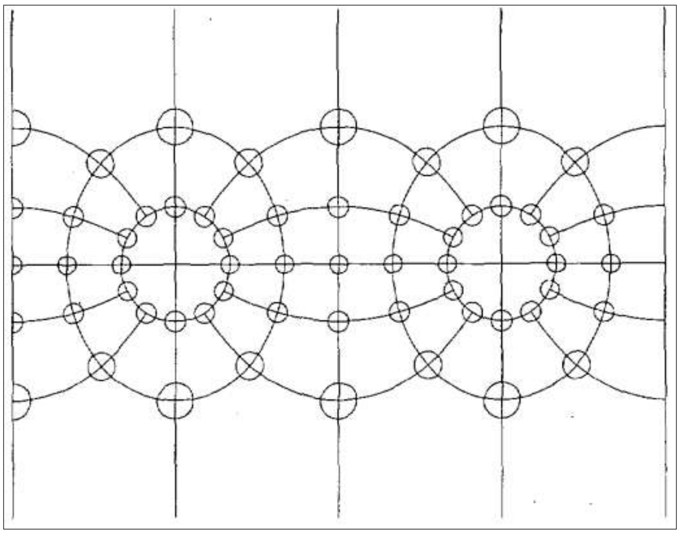


Figure 2A: Transverse Mercator projection, with Tissot indicatrices, 30° graticule



Other features

- Conceptually projected onto a cylinder wrapped around the globe tangent to the central meridian or secant along two small circles equidistant from the central meridian
- Cannot be geometrically (or perceptively) projected Rhumb lines generally are not straight lines.

Usage

- Many of the topographic and planimetric map quadrangles throughout the world at scales of

1:24,000 to 1:250,000.

- Basis for Universal Transverse Mercator (UTM) grid and projection Basis for State Plane Coordinate System in U.S. States having predominantly north-south extent

- Recommended for conformal mapping of regions having predominantly north-south extent

Origin

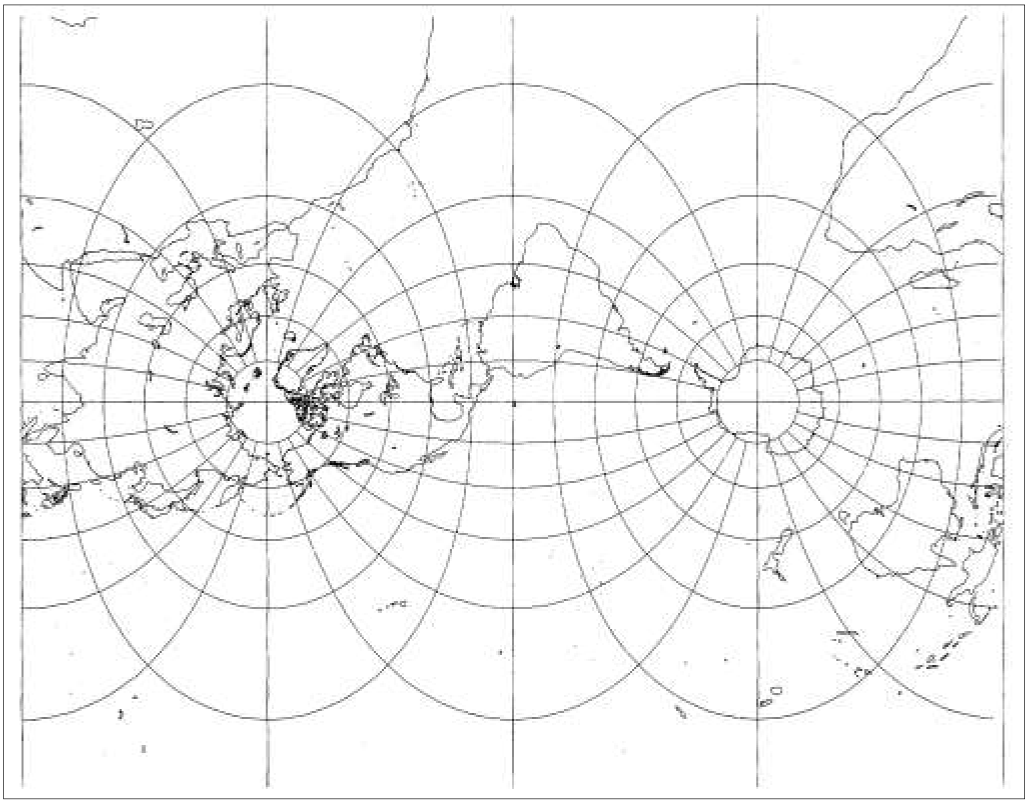
Presented by Johann Heinrich Lambert (1728- 77) of Alsace in 1772. Formulas for ellipsoidal use developed by Carl Friedrich Gauss of Germany in 1822 and by L. KrOger of Germany, L.P. Lee of New Zealand, and others in the 20th century.

Other names

- Gauss Conformal (ellipsoidal form only)
- Gauss-Kruger (ellipsoidal form only)
- Transverse Cylindrical Orthomorphic

Transverse Mercator projection, with shorelines, 15° graticule

(Central meridian 90° E. and W. North Pole at -90° longitude on base projection)

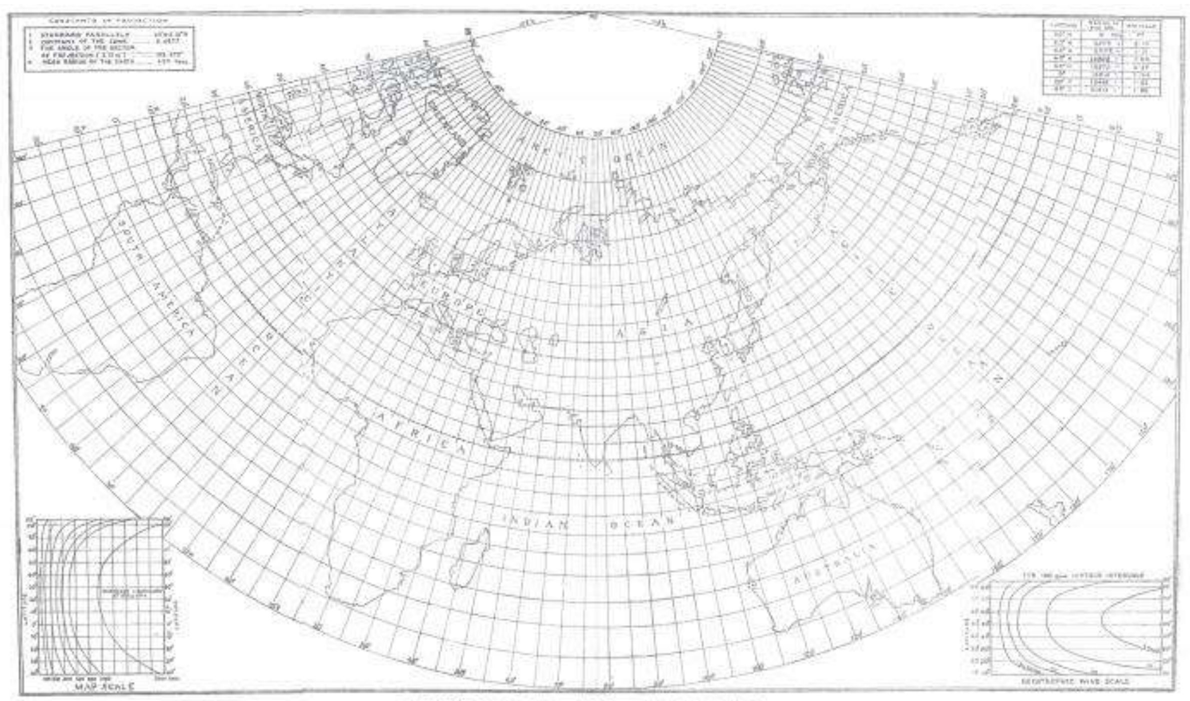


C. Lambert's Conformal Conic (LCC) Projection

Principle

Conceptually, the projection seats a cone over the sphere of the Earth and projects the surface conformally onto the cone. The cone is unrolled, and the parallel that was touching the sphere is assigned unit scale. That parallel is called the reference parallel or standard parallel.

By scaling the resulting map, two parallels can be assigned unit scale, with scale decreasing between the two parallels and increasing outside them. This gives the map two standard parallels. In this way, deviation from unit scale can be minimized within a region of interest that lies largely between the two standard parallels. Unlike other conic projections, no true secant form of the projection exists because using a secant cone does not yield the same scale along both standard parallels.



WORLD MAP

LAMBERT'S CONFORMAL CONICAL PROJECTION WITH SCALE TRUE AT 40°N & 10°N

Properties

1. Lambert conformal conic is a conic projection.
2. All the meridians are equally spaced straight lines converging to a common point, which is the nearest pole to the standard parallels.
3. The parallels are represented as circular arcs centered on the pole. Their spacing increases away from the standard parallels. The other pole projects to infinity and cannot be shown.

4. When the standard parallels are set in the northern hemisphere, the fan-shape of the graticule is oriented up and when standard parallels are in the southern hemisphere, the fan-shape of the graticule is oriented down.
5. The graticule is symmetric across the central meridian.
6. Lambert conformal conic is a conformal map projection.
7. Directions, angles, and shapes are maintained at infinitesimal scale.
8. Distances are accurate only along the standard parallels.
9. Scale, area, and distances are increasingly distorted away from the standard parallels, but they are the same along any given parallel and symmetric across the central meridian.
10. The projection is not conformal at the poles.

Uses

Pilots use aeronautical charts based on LCC because a straight line drawn on a Lambert conformal conic projection approximates a great-circle route between endpoints for typical flight distances. The US systems of VFR (visual flight rules) sectional charts and terminal area charts are drafted on the LCC with standard parallels at 33°N and 45°N.

The European Environment Agency and the INSPIRE specification for coordinate systems recommends using this projection (also named ETRS89-LCC) for conformal pan-European mapping at scales smaller or equal to 1:500,000. In Metropolitan France, the official projection is Lambert-93, a Lambert conic projection using RGF93 geodetic system and defined by references parallels that are 44°N and 49°N.

The U.S. National Geodetic Survey's "State Plane Coordinate System of 1983" uses the Lambert conformal conic projection to define the grid-coordinate systems used in several states, primarily those that are elongated west to east such as Tennessee. The Lambert projection is relatively easy to use: conversions from geodetic (latitude/longitude) to State Plane Grid coordinates involve trigonometric equations that are fairly straightforward and which can be solved on most scientific calculators, especially programmable models. The projection as used in CCS83 yields maps in which scale errors are limited to 1 part in 10,000.

Limitations

The implementation of Lambert conformal conic in ArcGIS does not display the whole range of the world. The standard parallels can be at any latitude, except set at opposite poles.

Example

Draw a graticules of Lambert Conformal Conical Projection with extension of 80°N to 40°N and 66°E to 98°E at 4° intervals. Scale is 1 : 25 X 10^6.

Calculation

Step 1

Radius of the generating globe, R = Actual Radius of the Earth / Denominator of R.F.

Radius of the reduced earth is, $R = \frac{250{,}000{,}000 \text{ inches}}{25{,}000{,}000}$ = 1 inches.

Step 2

Parallels are to be drawn 8°N, 12°N, 16°N, 20°N, 24°N, 28°N, 32°N, 36°N, and 40° N.

Two Standard Parallels are: r_1 = 16°N and r_2 = 32°N

Meridians are to be drawn 66°E, 70°E, 74°E, 78°E, 82°E, 86°E, 90°E.

Step 3

$$n = \frac{\log \text{Cos } 16°\text{N} - \log \text{Cos} 32°\text{N}}{\log \tan\left(\frac{90° - 16°}{2}\right) - \log \tan\left(\frac{90° - 32°}{2}\right)}$$

$$= \frac{-0.0395 - (-0.1648)}{-0.2830 - (-0.5900)}$$

$$= \frac{0.1253}{0.307}$$

$$= 0.4081$$

Step 4

Radius of the 16°N (r_1) = $\frac{\text{R Cos } 16°}{\text{n}} = 23.55 \text{ inches.}$

Radius of the 16°N (r_2) = $\frac{\text{R Cos } 32°}{\text{n}} = 26.78 \text{ inches.}$

Step 5

Division along the Standard Parallel, 16°N $= \frac{2\pi R.Cos16°}{360°} \times 4° = 0.67$ inch.

Division along the Standard Parallel, 32°N $= \frac{2\pi R.Cos32°}{360°} \times 4° = 0.62$ inch.

Step 6

Radius of the parallel, *Φ*

Φ (N)	8°	12°	16°	20°	24°	28°	32°	36°	40°
r (inch)	24.27	23.97	23.55	23.05	22.39	29.64	20.78	19.82	18.77

Step 7

Value of $m_1 = \frac{r_1}{\tan\left(\frac{90° - \emptyset_1}{2}\right)^n}$

$= \frac{23.55}{\tan(37°)^{0.4081}} = \frac{23.55}{0.0763} = 308.52$ inches.

Value of $m_2 = \frac{r_2}{\tan\left(\frac{90° - \emptyset_2}{2}\right)^n} = \frac{20.78}{0.0691} = 300.80$ inches.

Step 8

Radius of $r_1 = m_1.\tan\left(\frac{90° - \emptyset_1}{2}\right)^n = 308.52\tan\left(\frac{90° - 16°}{2}\right)^{0.4081} = 28.55$ inches.

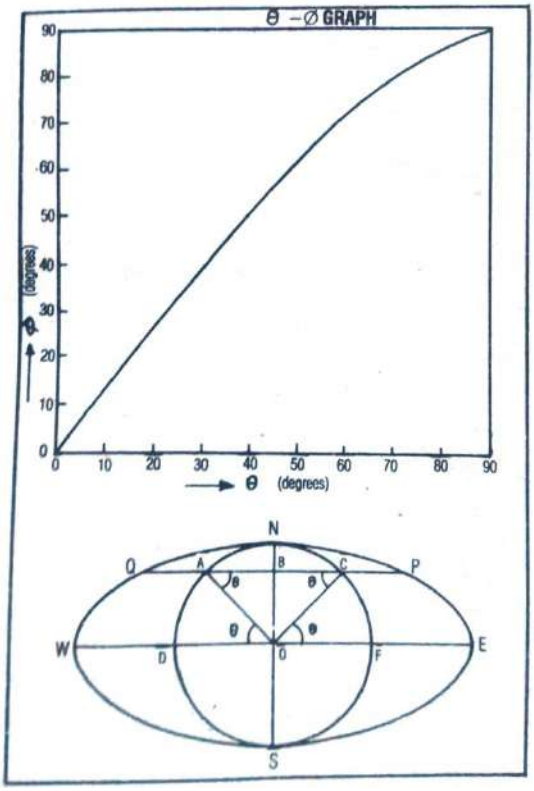
Radius of $r_2 = m_1.\tan\left(\frac{90° - \emptyset_2}{2}\right)^n = 300.80\tan\left(\frac{90° - 32°}{2}\right)^{0.4081} = 20.78$ inches.

3. Principle, construction, properties and uses of following map projections a) Equal Area Projection- Mollweide's Projection; b) Conical Projection- Simple Conical Projection with Two Standard Parallels.

A. Mollweide's Projection

Principle

This is an elliptical projection with homolographic property, devised by K. Mollweide (1805). The Central Meridian is a straight line exactly half the length of the Equator. The 90th meridian forms a complete circle while the remaining meridians form ellipses. The meridians are equispaced on the parallels. The parallels are projected as horizontal straight lines perpendicular to the Central Meridian and lie at varying distances away from the Equator (see following figure). The distance of any parallel *Φ* is calculated on the basis of the angle (θ) made by parallel *Φ* on the central circle. Hence parallels are doubly projected—from ellipse to central circle.

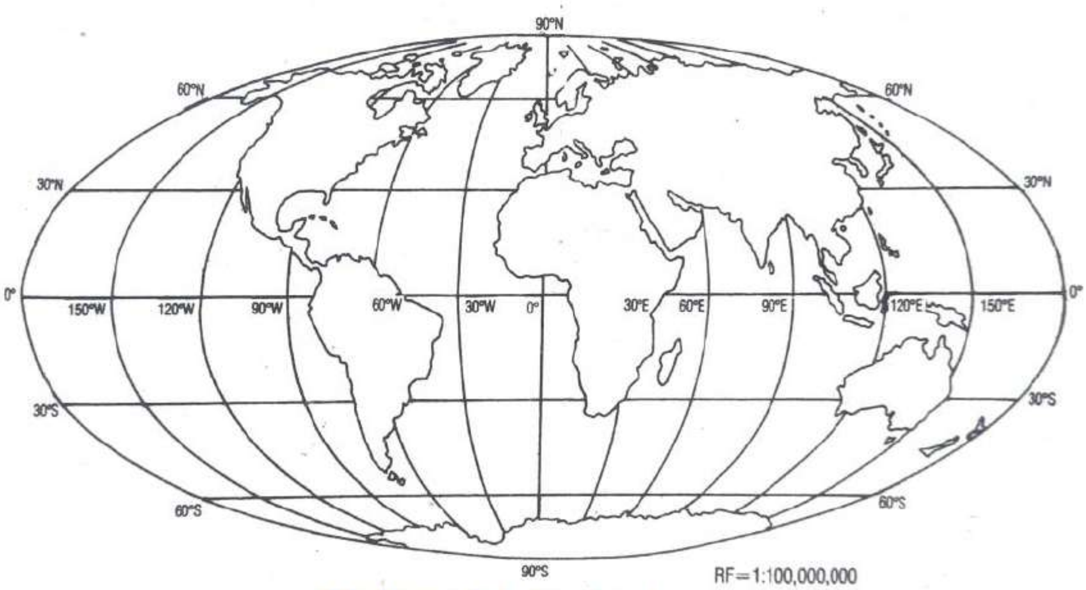


Construction

1. A straight line of length 4√2R is drawn horizontally through the centre of the paper to represent the Equator.
2. Through the mid-point of this, another straight line of length √2R is drawn at right angle to represent the Central Meridian.
3. A circle of radius √2R is drawn with centre at the intersection of the Equator and Central Meridian to represent the 90th meridians.
4. The divisions are marked on the Central Meridian with Y_{Φ} from the Equator.
5. Through each of these, straight lines are drawn parallel to the Equator to represent the parallel of latitude.
6. All the parallels are divided with the corresponding d_{Φ} for spacing the meridians.
7. Smooth curves are then drawn through the corresponding division points on the parallels to represent the remaining meridians.
8. The graticules are then accurately and properly labelled.

Properties

1. It is an elliptical projection.
2. It is a double projection.
3. It is an equal-area projection.
4. The parallels are straight lines variably spaced on the Central Meridian.
5. Inter-parallel spacing slowly decreases pole-ward.
6. The Central Meridian is a straight line half in length (2√2R) as that of Equator (4√2R).
7. The 90th meridian forms a circle with radius 4√2R and equivalent to one hemisphere as well.
8. The remaining meridians are ellipses of varying eccentricity.
9. The distortion of shape near the Poles is relatively less.
10. At any point the product of the two principal scales is unity.
11. The parallels are a little smaller near the Equator but relatively large near the Pole corresponding to their true lengths.
12. It is extensively used for world maps.



Mollweide's Projection

Example

Draw graticules for the world map on Scale 1 : 250 X 10^6 at 20° interval.

Calculation

Step 1

Radius of the generating globe, R = Actual Radius of the Earth / Denominator of R.F.

Radius of the reduced earth is, $R = \frac{250{,}000{,}000 \text{ inches}}{250{,}000{,}000}$ = 1 inch.

Step 2

Radius of the central circle, r = √2R = 1.4142 inches.

Step 3

Calculation of θ corresponding to *Φ*. *(*π Sin Φ = 2θ + Sin2θ)

Calculation of θ corresponding to Φ

Φ	10°N/S	20°N/S	30°N/S	40°N/S	50°N/S	60°N/S	70°N/S	80°N/S	90°N/S
π Sin Φ	0.5455	1.0745	1.5708	2.0194	2.4066	2.7207	2.9521 1	3.0938	3.1416 1
θ	7° 52'	15°37'	23°50'	32°04'	40°38'	49°41'	S9°32'	70°39'	90°

2θ + Sin2θ	**0.5455**	**1.0745**	**1.5708**	**2.0194**	**2.4066**	**2.72071**	**2.9521**	**3.0938**	**3.14161**

Step 4

The height of any parallel Φ above Equator, (Y_{Φ}) = √2. R Sin θ

Calculation of Y_{Φ}

Φ	20°N/S	60°N/S	70°N/S	80°N/S	90°N/S
θ	15°37'	32°04'	49°41'	70°39'	90°
Y_{Φ} (inch)	**0.38071**	**0.75081**	**1.0783**	**1.3343**	**1.4142**

Step 5

Division on any parallel Φ for spacing the meridian at 20° interval, d_{Φ} = $\frac{4\sqrt{2}RCos\emptyset}{360°} \times i°$

Calculation of d_{Φ}

Φ	20°N/S	40°N/S	60°N/S	80°N/S	80°N/S
θ	15°37'	32°04'	49°41'	70°39'	90°
d_{Φ} (inch)	**0.3027**	**0.2663**	**0.2033**	**1.1041**	**-**

B. Simple Conical Projection with Two Standard Parallels

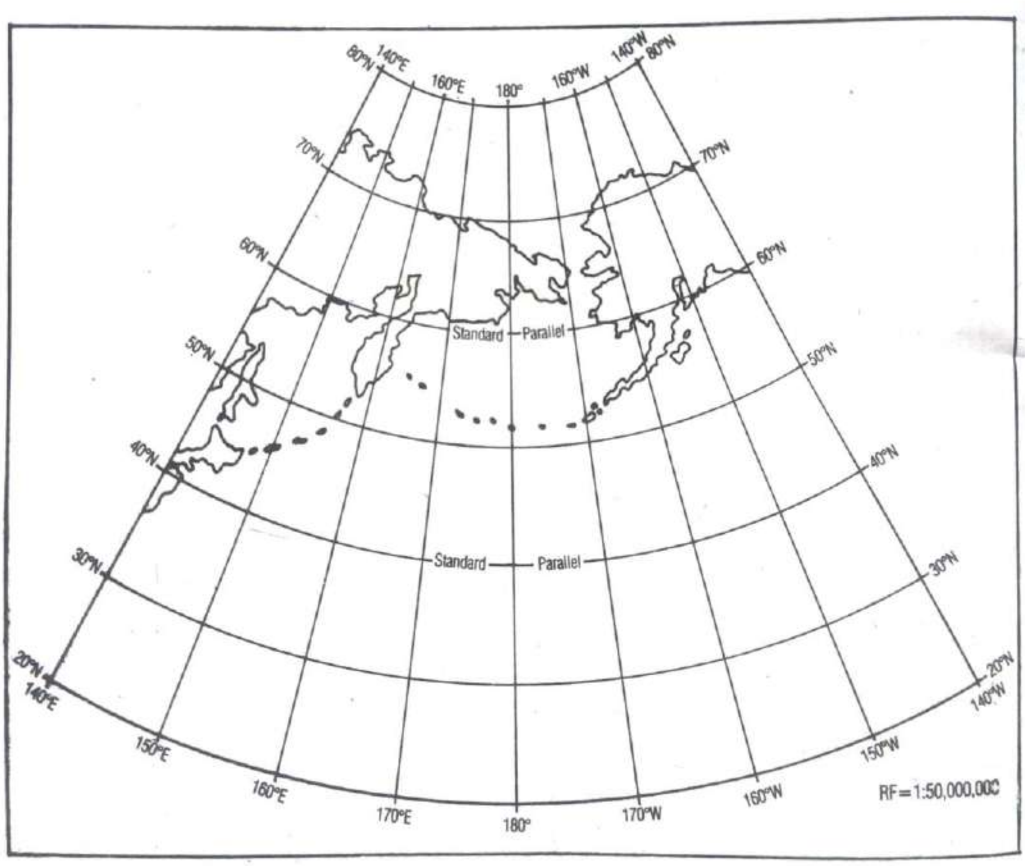
Principle

In this projection, a simple right circular cone is taken as the projection plane. Two circles of the cone correspond to two different parallels on the generating globe and form an ordinary cone independent of the globe. These are the standard parallels which are so selected as to cover two-thirds of the latitudinal extent of the area to be mapped. The parallels appear as concentric arcs of circle while meridians appear as straight lines converging at the vertex of the cone.

Construction

1. A straight line is drawn vertically through the centre of the paper to represent the Central Meridian.

2. It is then divided by d for spacing the parallels.
3. An arc of circle of r_1 radius centred on the Central Meridian is drawn passing through the Φ_1, division-mark on the Central Meridian to represent the first Standard Parallel.
4. Similarly, with r_2 radius the Standard Parallel Φ_2 is drawn.
5. From the centre of the Standard Parallels, concentric arcs of circles are drawn through the remaining division-marks to represent the other parallels.
6. By d_1, the Standard Parallel, Φ_2 is divided for spacing the meridians.
7. Similarly by d_2, the Standard Parallel, Φ_2, is divided for spacing the meridians.
8. Straight lines are drawn through the corresponding division points on the Standard Parallels to represent the meridians.
9. The graticules are then accurately and properly labelled.



Simple Conical Projection (with Two Standard Parallel)

Properties

1. This is a non-perspective projection.
2. The parallels are concentric arcs of circles truly spaced on the Central Meridian.
3. The Pole is represented by an arc of circle.

4. Radial scale is true along the Central Meridian.
5. The parallels are equidistant from one another.
6. The meridians are straight lines truly spaced on the Standard Parallels.
7. The meridians converge at the vertex of the cone.
8. Tangential scale is true along the Standard Parallels.
9. Deformation is negative within the inter-standard parallel area while it is positive beyond the Standard Parallels.
10. It is the most suitable projection for mid-latitude countries with latitudinal extent relatively smaller than the longitudinal extent.

Example

Draw graticules of Simple Conical Projection with Two Standard Parallels for extension, 20°N to 80°N and 140°E to 140°W at 10° interval. Scale is 1 : 50 X 10^6.

Calculation

Step 1

Radius of the generating globe, R = Actual Radius of the Earth / Denominator of R.F.

$\text{Radius of the reduced earth is, R} = \frac{250{,}000{,}000 \text{ inches}}{50{,}000{,}000}$ = 5 inches.

Step 2

The division along the Central Meridian for spacing the parallel at interval 10°,

$$d = \frac{\pi R}{180^\circ} \times i^\circ = 0.8727 \text{ inch}$$

Step 3

For 20°N to 80°N parallels at 10° interval, Standard Parallels chosen are:

$$\Phi_1 = 20°\text{N} + \frac{(80° - 20°)\text{N}}{3} = 20°\text{N} + 20°\text{N} = 40°\text{N}$$

And

$$\Phi_2 = 80°\text{N} - \frac{(80° - 20°)\text{N}}{3} = 80°\text{N} - 20°\text{N} = 60°\text{N}$$

Step 4

Parallels to be drawn – 20N, 30N, 40N, 50N, 60N, 70N and 80N

Meridians to be drawn – 140E, 150E, 160E, 170E, 180E, 170W, 150W, and 140W

Step 5

The radius of the Standard Parallel, $\Phi_{1,}$

$$r_{\emptyset_1} = R(\emptyset_1 - \emptyset_2)^c \times \frac{Cos_{\emptyset_1}}{Cos_{\emptyset_1} - Cos_{\emptyset_2}}$$

$$r_{40} = 5.(60° - 40°)^c \times \frac{Cos40°}{Cos40° - Cos60°} = 5.0255 \text{ inches}$$

$$r_{60} = 5.(60° - 40°)^c \times \frac{Cos60°}{Cos40° - Cos60°} = 3.2801 \text{ inches}$$

Step 6

The division on the Standard Parallel, $\Phi_{1,}$ for spacing the meridian at 10° interval,

$$d_1 = \frac{2\pi RCos\emptyset_1}{180°} \times i°$$

$$d_1 = \frac{2\pi RCos40°}{360°} \times 10° = 0.6685 \text{ inch}$$

$$d_2 = \frac{2\pi RCos60°}{360°} \times 10° = 0.4363 \text{ inch}$$

4. Geodesy: Scope and application; concept of Geoid, reference ellipsoid and spheroid - WGS 84, Everest Spheroid.

Geodesy: Scope and Applications

Geodesy

Geodesy is the science of accurately measuring and understanding three fundamental properties of the Earth: its geometric shape, its orientation in space, and its gravity field— as well as the changes of these properties with time. By using GPS, geodesists can monitor the movement of a site 24 hours a day, seven days a week.

Geodesy involves the theory and measurement of the size, shape and gravity field of the Earth. Modern geodesy is also concerned with temporal (time) variations in these quantities, notably through contemporary observations of geodynamic phenomena such as plate tectonics. Geodesy is a branch of applied mathematics that forms the scientific basis of all positioning and mapping.

In particular, it looks at:

- **Shape** - the geometric object it resembles in both general and specific terms. In general terms, we know it's a sphere, but in specific terms, mountains and valleys skew that representation.
- **Orientation** - the relative position of key features, like the magnetic poles, in relation to other things in the solar system and galaxy.
- **Gravity Field** - the effects of gravity as we move away from the surface, whether it is constant over the entire surface, and other factors.

Geodesy focuses on taking measurements of these aspects, and tracking this information over time.

The classical definition, according to Helmert (1880), is: “Geodesy is the science of measuring and portraying the Earth’s surface”. Since then, the scope of geodesy has broadened (Vaníček and Krakiwsky, 1986): “Geodesy is the discipline that deals with the measurement and representation of the Earth, including its gravity field, in a three-dimensional time-varying space”.

Since geodesy is now quite a diverse discipline, it is often broken down into subclasses. In this author's opinion, the four key pillars of modern geodesy are (not in any order of preference):

1. Geophysical Geodesy: geodetic techniques are used to study geodynamic processes, such as plate tectonic motions, postglacial rebound (now called glacial isostatic adjustment) or variations in Earth rotation and orientation.

2. Physical Geodesy: the observation and use of gravity measurements (from ground, air and space) to determine the figure of the Earth, notably the geoid, which involves the formulation and solution of boundary-value problems.

3. Geometrical/Mathematical Geodesy: computations, usually on the reference ellipsoid, to yield accurate positions from geodetic measurements, including map projections, which involves aspects from differential geometry.

4. Satellite/Space Geodesy: determination of the orbits of satellites (hence inferring the gravity field) or for determining positions on or near the Earth's surface from ranging measurements to navigation satellites.

Scope and Application of Geodesy

The International Association of Geodesy (IAG) has proposed four following scopes of Geodesy, comprising:

1: Reference Frames

a. Establishment, maintenance and improvement of geodetic reference frames
b. Advanced terrestrial and space observation technique development
c. International collaboration for the definition and deployment of networks of terrestrially-based space-geodetic observatories
d. Theory and coordination of astrometric observation for reference frame definition and realisation
e. Collaboration with space-geodesy/reference-frame-related international services, agencies and organisations

2: Gravity Field

a. Terrestrial, marine, and airborne gravity measurements (gravimetry)
b. Satellite-based gravity field observations

c. Global and regional gravity field modelling
d. Time-variable gravity field observation
e. Geoid and quasi-geoid determination
f. Satellite orbit modelling and determination

3: Earth Rotation and Geodynamics

a. Earth orientation (Earth rotation, polar motion, nutation and precession)
b. Earth tides
c. Tectonics and crustal deformation
d. Sea surface topography and sea-level change
e. Planetary and lunar dynamics
f. Effects of the Earth's fluid layers (e.g., postglacial rebound, surface loading)

4: Positioning and Applications

a. Terrestrial- and satellite-based positioning systems development
b. Navigation and guidance of platforms
c. Interferometric laser and radar applications (e.g., synthetic aperture radar)
d. Applications of geodetic positioning using 3D geodetic networks (passive and active), including monitoring of deformations
e. Applications of geodesy to engineering
f. Atmospheric investigations using space-geodetic techniques

Application of Geodesy

As you might imagine, the information gathered has a number of uses. Some notable ones include:

- **Map Shorelines** - Geodesy can help determine the physical boundary between a land mass, and the water it meets. This can be difficult with water levels rising and falling. You see examples of this in the maps we use.
- **Determine Land Boundaries** - at a macro level, this use comes into play between countries and provinces/states. At a micro level, it determines the property lines for home and your neighbor's.
- **Improve Transportation** - Geodesy contributes to things like route determination, shortest routes, traffic patterns, and such. You see this in trip planning software, and in services like taxis and buses.

- **Increase Navigational Safety** - this use affects navigation, especially in areas where landmarks are at a minimum, like over water. You see this in things like cargo ship and cruise line navigation.

Reference Surfaces

The physical surface of the earth contains variety of land forms like plains, valley, mountains, water features etc. It has excursions of +8,000 m (Mount Everest) and −11,000 m (Mariana Trench). Although this is the surface on which actual earth measurements are made, it is irregular and complex showing large vertical variations. Topographers and hydrographers are interested in this topographic surface as it provides topographic information for them. Due to irregular topographic nature of the Earth, there are two reference surfaces used to approximate the shape of the Earth: the Geoid and the Ellipsoid.

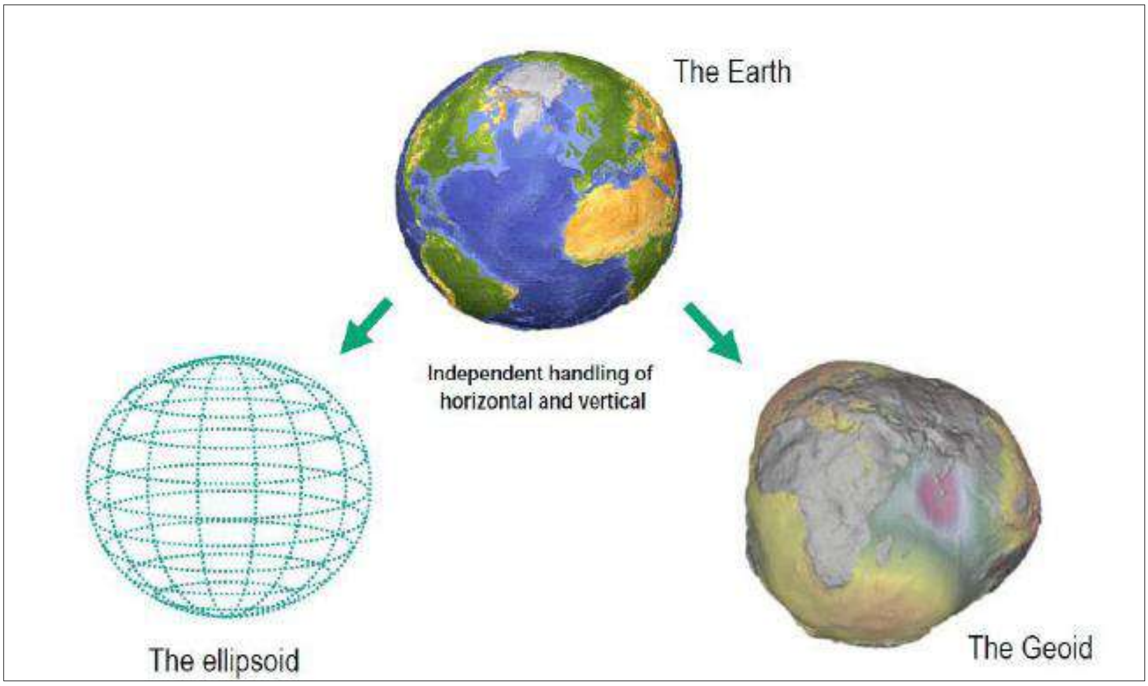
- The geoid or mean sea level - the level surface to determine heights (vertical reference).
- The ellipsoid - the reference frame to determine locations (horizontal reference).

Geoid:

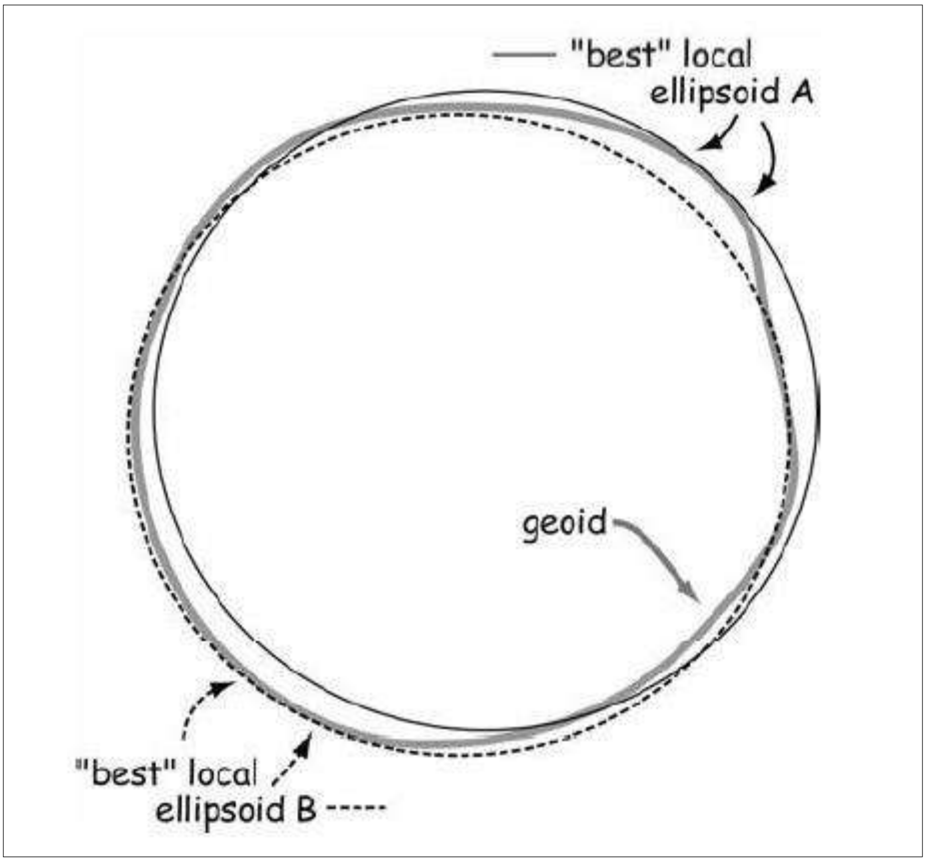
The true shape of the Earth varies slightly from the mathematically smooth surface of an ellipsoid. Differences in the density of the Earth cause variation in the strength of the gravitational pull, in turn causing regions to bulge above or below a reference ellipsoid. This undulating shape is called a geoid as a representation of the earth's gravity field. Figure 4-1 shows the undulations, greatly exaggerated, in the Earth‘s gravity, and hence the geoid. The Geoid is the equipotential surface of the earth's gravity field which best fits, in a least squares sense, global mean sea level (MSL) used for measuring heights. Essentially this is a representation of the surface of the earth in terms of sea level for every position on earth, in a more complex manner than an ellipsoid. The starting point for measuring these heights is MSL points established at coastal places represent the Geoid.

Note:

A GPS receiver on a ship may, during the course of a long voyage, indicate height variations, even though the ship will always be at sea level (tides not considered). This is because GPS satellites, measure heights relative to a geocentric reference ellipsoid (WGS84). To obtain receiver‘s geoidal height, a raw GPS reading must be corrected. Modern GPS receivers facilitate to implement geoid models inside (e.g. Earth gravitational model 96, EGM-96). These geoid models include the height differences of the geoid with respect to WGS84 ellipsoid. Then the user is able to correct the heights above WGS ellipsoid to the heights above geoid. In that case when the height is not zero on a ship it is because of the tides.



The Geoid, exaggerated to illustrate the complexity of its surface and its relationship with the ellipsoid

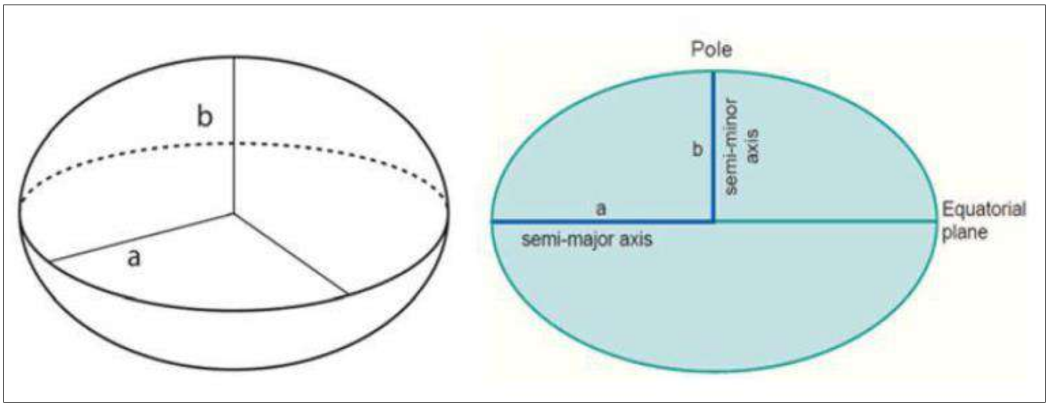


An ellipsoid that fits well in one portion of the Earth may fit poorly in another

Reference ellipsoid:

Since both topographic surface and geoid are irregular in shape, and complex in mathematically, they are unsuitable for exact mathematical computations. If the calculations take into account these irregularities, the formulas would be unnecessarily complicated. Therefore, the necessity for the reference model that allows such topographic irregularities to be recorded was in demand. Then the mathematical representation or horizontal reference of this physical earth was generated by rotating an ellipse about its shorter axis (minor axis) and is called the reference ellipsoid.

The reference ellipsoid can be defined by using two parameters; the semi-major axis and flattening. The size is represented by the radius at the equator; the semi-major axis of the cross- sectional ellipse and designated by the letter a. The shape of the ellipsoid is given by the flattening, f, which indicates how much the ellipsoid departs from spherical shape. Flattening ‘f ‘indicates how much the ellipsoid departs from spherical shape.



A cross section of an ellipsoid, used to represent the Earth surface, defined by its semi-major axis ‘a ‘and semi-minor axis ‘b ‘.

The flattening is the ratio of the semi-major axis a, minus the semi minor axis b, to the semi-major axis; and often expressed as a fraction - written as:

$$f = \frac{a-b}{a}; OR \quad f = 1 - \left(\frac{a}{b}\right)$$

The Earth is slightly flattened, such that the distance between the poles is about 1 part in 300 less than the diameter at the Equator. The ellipsoid also defined by its semi-major axis a, and eccentricity e. Eccentricity measures how much an ellipse deviates from a true circle.

$$e^2 = (1 - (\frac{b^2}{a^2})) = \frac{(a^2 - b^2)}{a^2} = 2f - f^2$$

Eccentricity is measured as the square root of the quantity 1.0 minus the square of the ratio of the semi minor axis to the semi-major axis. It measures how much an ellipse deviates from a true circle. Typical parameter values of an ellipsoid are:

$a = 6378137.0m \quad b = 6356752.31m$

$f = 1/298.26 \quad e = 0.0818187$

Flattening: $f = (a-b)/a$ Eccentricity: $e^2 = (a^2 - b^2)/a^2$

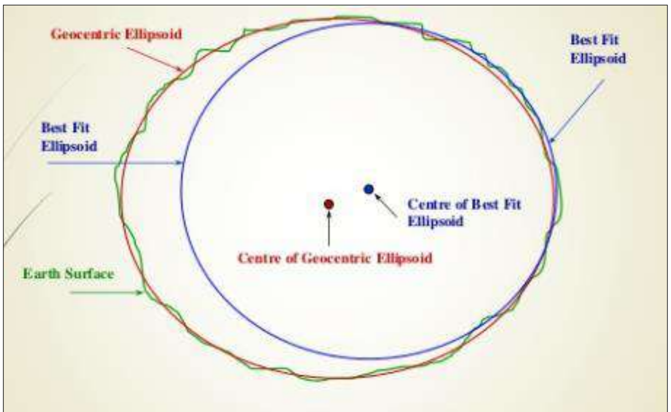
Table: Examples of reference systems and associated ellipsoids

Reference system	Ellipsoid	Semi-Major axis a	Semi-Minor axis b (m)	Flattening (1/f)
WGS 84	WGS 84	6378137.0	6,356,752.30	1/298.26
NAD 83	GRS 80	6378137.0	6,356,752.30	1/298.26
NAD 27	Clarke 1866	6378206.4	6,356,583.80	1/294.98

Types of Ellipsoids

1. Best-Fit Ellipsoid/Local Ellipsoid: based on the measurements within a region, so it best fits that region only. The centre of such reference ellipsoid does not coincide with the centre of gravity of the Earth. Example: Everest Ellipsoid

2. Geocentric Ellipsoid: The centre of geocentric ellipsoid coincides with the centre of the Earth. This type of the ellipsoid can be used worldwide. Example: WGS 84 ellipsoid 44



Best Fit and Geocentric Ellipsoids

Datum

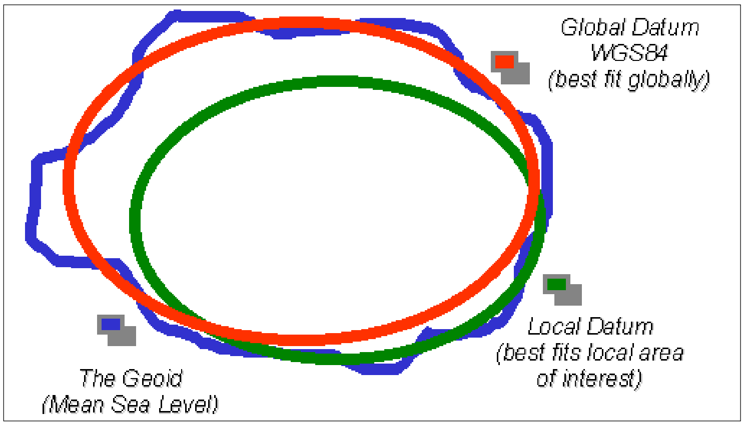
The ellipsoidal figures of the earth or the reference ellipsoids have different origins and orientations with respect to their area of interest. A datum defines the position of the ellipsoid relative to the centre of the earth including the ellipsoid; its origin and orientation; and reference frame (defines axes).

Table: Datums and their principle areas of use

Datum	Area	Origin	Ellipsoid
WGS 1984	Global	Earth center of mass	WGS 84
NAD 1983	North America, Caribbean	Earth center of mass	GRS 80
NAD 1927	North America	Meades Ranch	Clarke 1866
European 1950	Europe, Middle East, North Africa	Potsdam	International

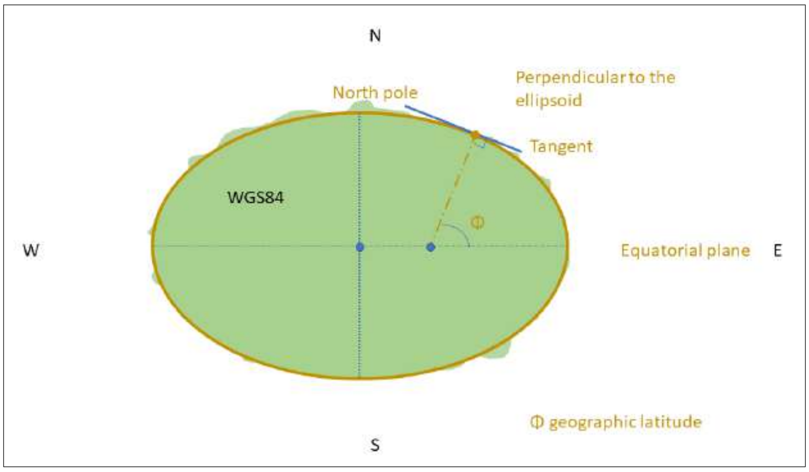
In general, a datum provides a frame of reference for measuring locations on the surface of the earth and it defines the origin and orientation of latitude and longitude lines. A geodetic datum is a set of constants specifying the coordinate system used for geodetic control, i.e. for calculating coordinates of points on the earth‖. These constants include parameters to specify the location of the origin of the coordinate system, the orientation of the coordinate systems and the reference ellipsoid. There are hundreds of locally-developed reference datums around the world. The most widely used datum is WGS 1984. It serves as the framework for worldwide positional measurements. There are two types of datums: local and global datums.

- A **local datum** aligns its spheroid to closely fit the earth's surface in a particular area. A point on the surface of the spheroid is matched to a particular position on the surface of the earth. This point is known as the origin point of the **datum**.
- A global datum is the reference ellipsoid and its center coincides with the center of the earth.



World Geodetic System 1984 (WGS84):

WGS84 ellipsoid datum is assumed to be identical with the GRS80 (Table 1.1). It is the most recently developed and widely used datum. This datum has been refined several times to coincide with the current ITRF2000 within a few centimeters at the global level for all mapping and charting purposes (2002). GIS uses WGS84 as a reference coordinate system. Satellite-based positioning equipment such as GPS helps to determine heights with an accuracy of a few centimeters w.r.t a reference ellipsoid (e.g. WGS84). It serves as the framework for positional measurements worldwide.



The World Geodetic System (WGS) was developed in 1960 and was significantly overhauled in 1984. It is maintained by the US National Geospatial-Intelligence Agency that invests billions of dollars into ensuring that it continues to most accurately depict the Earth geoid. Its calculation of the location of Earth's centre is now accurate to within the width of a postage stamp. WGS-84 is currently used by all GPS applications and is, conclusively, the most accurate measure of the distance between any two points on the surface of the Earth.

Everest Spheroid

India and other countries of the world made measurements in their countries and defined reference surface to serve as Datum for mapping. In India the reference surface was defined by Sir George Everest, who was Surveyor General of India from 1830 to 1843. It has served as reference for all mapping in India. Indian system can be called Indian Geodetic System as all coordinates are referred to it. The reference surface was called Everest Spheroid.

The initial point for mapping on the surface of the Earth was chosen at Kalyanpur in Central India. On realization of the system it was found that our system is in error and the assumptions have not been fully met. It is estimated that center of Everest Spheroid is nearly a kilometer from the center of gravity of the Earth. It is also realized that minor axis is not parallel to polar axis but inclined to it by a few seconds. The system is therefore a local one and needs to be redefined, as it is not suitable for higher defense and scientific applications. The system will not be suitable for launching Inter Continental Ballistic Missiles.

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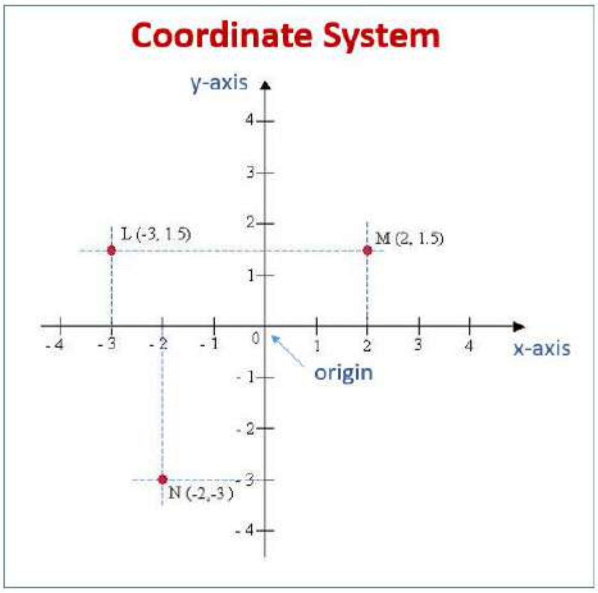
5. Coordinate Systems: Cartesian, Rectangular, Spherical, Curvilinear, Spherical, UTM Grid System.

Coordinate Systems

In geometry, a **coordinate system** is a system that uses one or more numbers, or **coordinates**, to uniquely determine the position of the points or other geometric elements on a manifold such as Euclidean space. The order of the coordinates is significant, and they are sometimes identified by their position in an ordered tuple and sometimes by a letter, as in "the *x*-coordinate". The coordinates are taken to be real numbers in elementary mathematics, but may be complex numbers or elements of a more abstract system such as a commutative ring. The use of a coordinate system allows problems in geometry to be translated into problems about numbers and *vice versa*; this is the basis of analytic geometry.

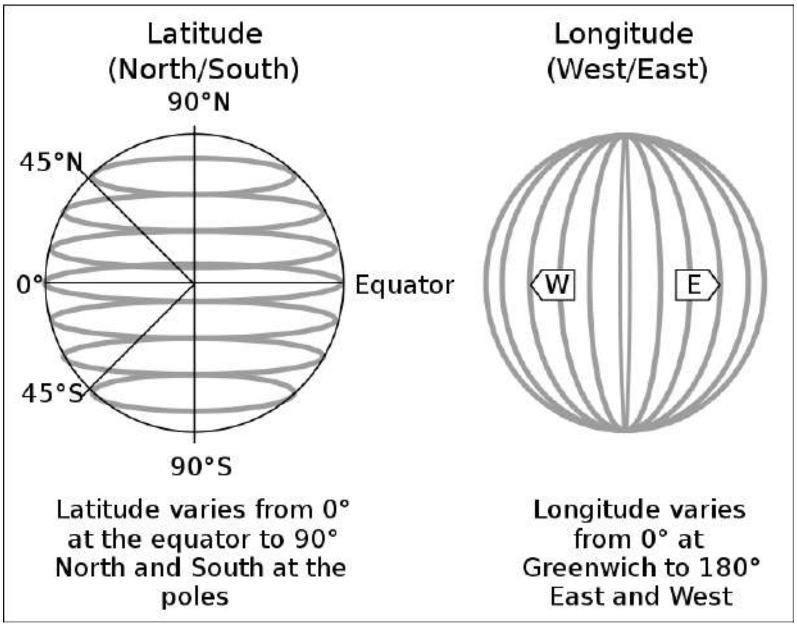


Geographic Coordinate System

A geographic coordinate system (GCS) is a coordinate system associated with positions on Earth (geographic position). A GCS can give positions:

- as spherical coordinate system using latitude, longitude, and elevation;
- as map coordinates projected onto the plane, possibly including elevation;
- as earth-centered, earth-fixed (ECEF) Cartesian coordinates in 3-space;
- as a set of numbers, letters or symbols forming a geocode.

In geodetic coordinates and map coordinates, the coordinate tuple is decomposed such that one of the numbers represents a vertical position and two of the numbers represent a horizontal position.



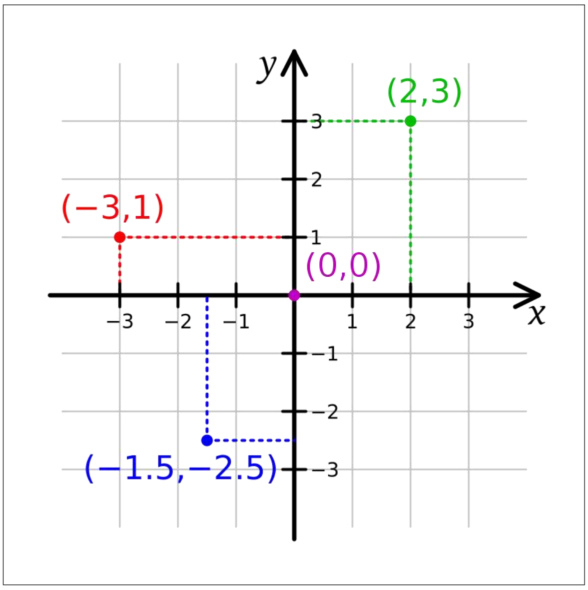
Longitude lines are perpendicular to and latitude lines are parallel to the Equator.

Cartesian Coordinate System

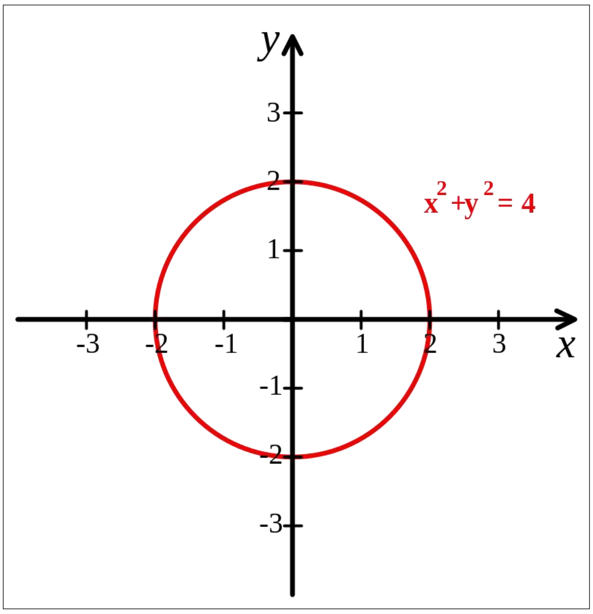
The prototypical example of a coordinate system is the Cartesian coordinate system. In the plane, two perpendicular lines are chosen and the coordinates of a point are taken to be the signed distances to the lines.

In three dimensions, three mutually orthogonal planes are chosen and the three coordinates of a point are the signed distances to each of the planes. This can be generalized to create *n* coordinates for any point in *n*-dimensional Euclidean space.

Depending on the direction and order of the coordinate axes, the three-dimensional system may be a right-handed or a left-handed system. This is one of many coordinate systems.



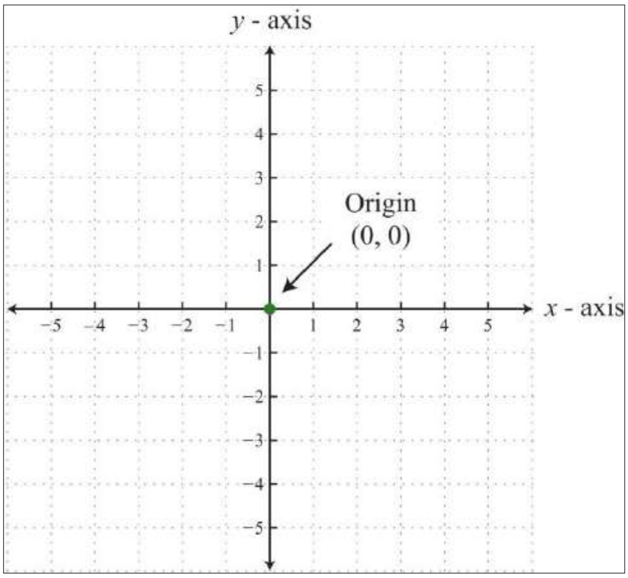
The Cartesian coordinate system in the plane.



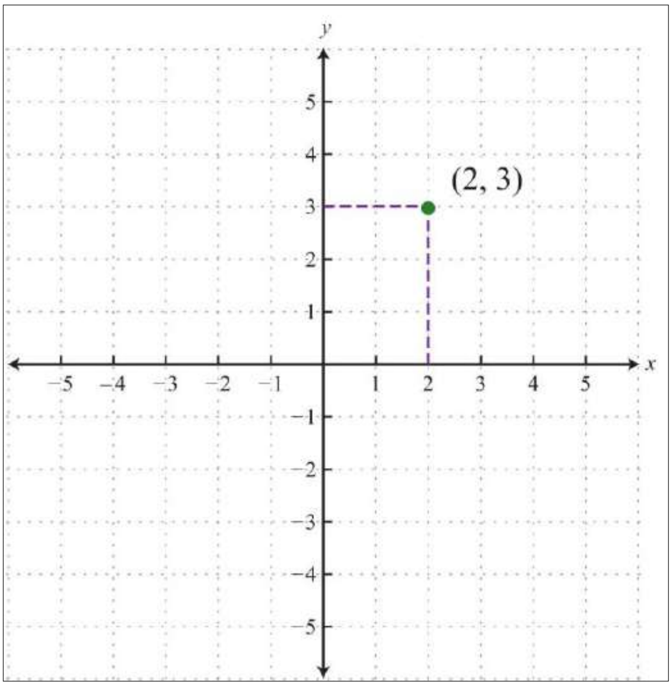
Cartesian coordinate system with a circle of radius 2 centered at the origin marked in red. The equation of a circle is $(x - a)^2 + (y - b)^2 = r^2$ where *a* and *b* are the coordinates of the center (*a*, *b*) and *r* is the radius.

Rectangular Coordinate System

The rectangular coordinate system consists of two real number lines that intersect at a right angle. The horizontal number line is called the x-axis, and the vertical number line is called the y-axis. These two number lines define a flat surface called a plane, and each point on this plane is associated with an ordered pair of real numbers (x, y). The first number is called the ***x*-coordinate**, and the second number is called the ***y*-coordinate**. The intersection of the two axes is known as the origin, which corresponds to the point (0, 0).



An ordered pair (x, y) represents the position of a point relative to the origin. The x-coordinate represents a position to the right of the origin if it is positive and to the left of the origin if it is negative. The y-coordinate represents a position above the origin if it is positive and below the origin if it is negative. Using this system, every position (point) in the plane is uniquely identified. For example, the pair (2, 3) denotes the position relative to the origin as shown:

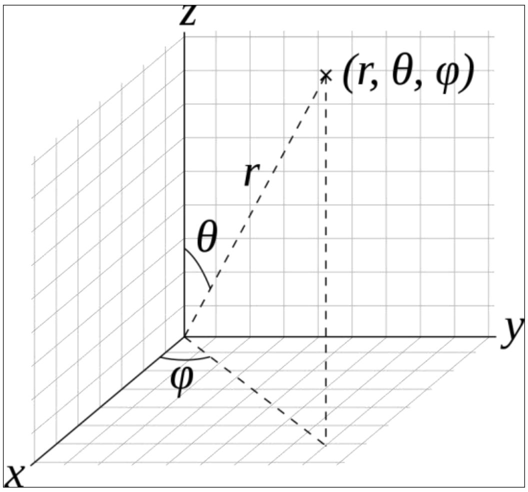


This system is often called the Cartesian coordinate system, named after the French mathematician René Descartes (1596–1650).

The *x*- and *y*-axes break the plane into four regions called quadrants, named using roman numerals I, II, III, and IV, as pictured. In quadrant I, both coordinates are positive. In quadrant II, the *x*-coordinate is negative and the *y*-coordinate is positive. In quadrant III, both coordinates are negative. In quadrant IV, the *x*-coordinate is positive and the *y*-coordinate is negative.

Spherical Coordinate System

In mathematics, a **spherical coordinate system** is a coordinate system for three-dimensional space where the position of a point is specified by three numbers: the *radial distance* of that point from a fixed origin, its *polar angle* measured from a fixed zenith direction, and the *azimuthal angle* of its orthogonal projection on a reference plane that passes through the origin and is orthogonal to the zenith, measured from a fixed reference direction on that plane. It can be seen as the three-dimensional version of the polar coordinate system.



The spherical coordinate system is commonly used in *physics*. It assigns three numbers (known as coordinates) to every point in Euclidean space: radial distance *r*, polar angle *ϑ* (theta), and azimuthal angle *φ* (phi). The symbol *ρ* (rho) is often used instead of *r*.

To define a spherical coordinate system, one must choose two orthogonal directions, the *zenith* and the *azimuth reference*, and an *origin* point in space. These choices determine a reference plane that contains the origin and is perpendicular to the zenith. The spherical coordinates of a point *P* are then defined as follows:

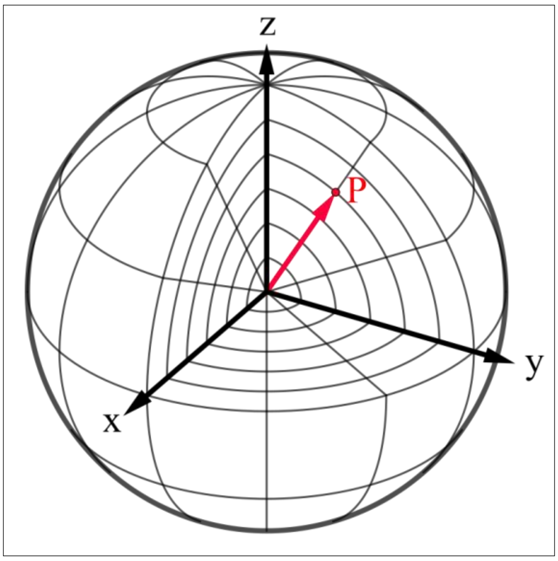
- The *radius* or *radial distance* is the Euclidean distance from the origin *O* to *P*.
- The *inclination* (or *polar angle*) is the angle between the zenith direction and the line segment *OP*.
- The *azimuth* (or *azimuthal angle*) is the signed angle measured from the azimuth reference direction to the orthogonal projection of the line segment *OP* on the reference plane.

The sign of the azimuth is determined by choosing what a positive sense of turning about the zenith is. This choice is arbitrary, and is part of the coordinate system's definition.

The *elevation* angle is 90 degrees ($\pi/2$ radians) minus the inclination angle.

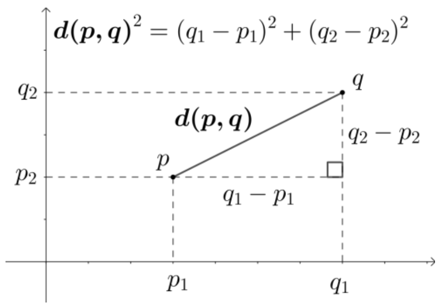
If the inclination is zero or 180 degrees (π radians), the azimuth is arbitrary. If the radius is zero, both azimuth and inclination are arbitrary.

In linear algebra, the vector from the origin O to the point P is often called the position vector of P.



A globe showing the radial distance, polar angle and azimuthal angle of a point *P* with respect to a unit sphere, in the mathematics convention. In this image, *r* equals 4/6, *ϑ* equals 90°, and *φ* equals 30°.

In mathematics, the **Euclidean distance** between two points in Euclidean space is the length of a line segment between the two points. It can be calculated from the Cartesian coordinates of the points using the Pythagorean theorem, therefore occasionally being called the **Pythagorean distance**. These names come from the ancient Greek mathematicians Euclid and Pythagoras, although Euclid did not represent distances as numbers, and the connection from the Pythagorean theorem to distance calculation was not made until the 18th century.

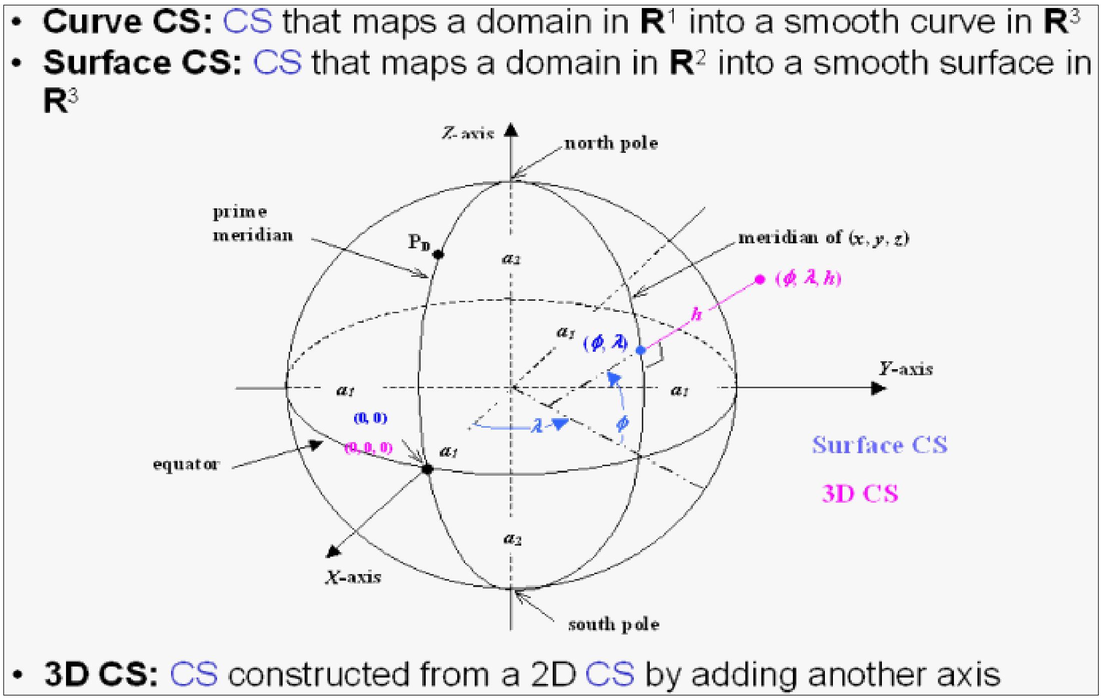


Using the Pythagorean theorem to compute two-dimensional Euclidean distance

Curvilinear Coordinate System

In geometry, **curvilinear coordinates** are a coordinate system for Euclidean space in which the coordinate lines may be curved. These coordinates may be derived from a set of Cartesian coordinates by using a transformation that is locally invertible (a one-to-one map) at each point. This means that one can convert a point given in a Cartesian coordinate system to its curvilinear coordinates and back. The name *curvilinear coordinates*, coined by the French mathematician Lamé, derives from the fact that the coordinate surfaces of the curvilinear systems are curved.

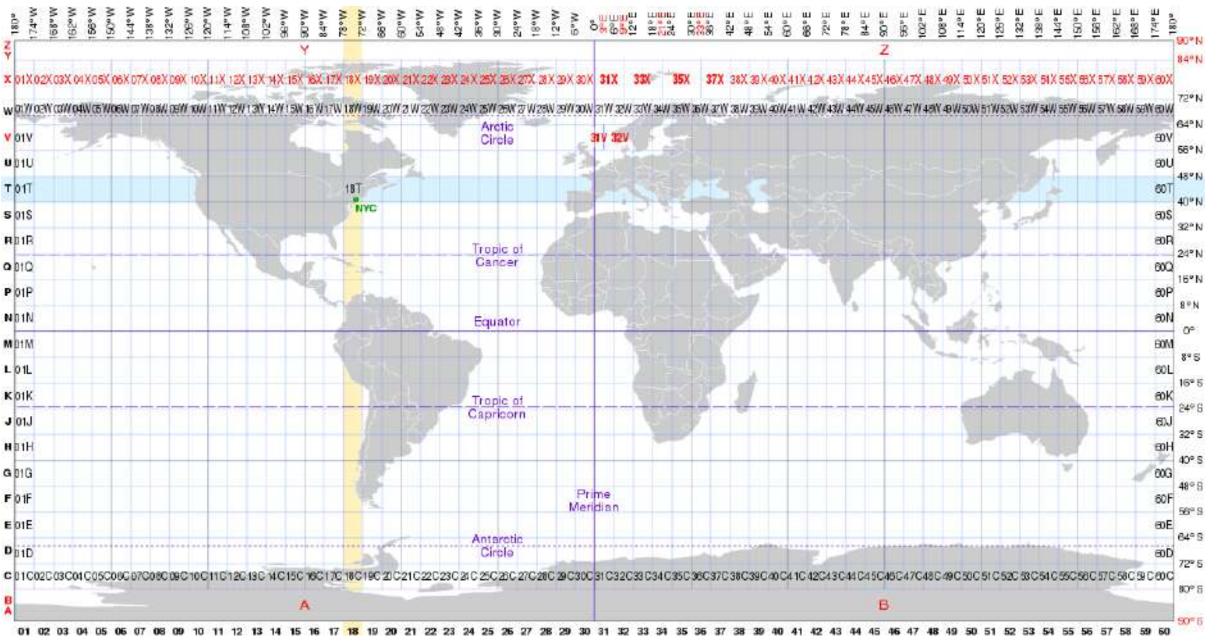
Well-known examples of curvilinear coordinate systems in three-dimensional Euclidean space (**R**^{3}) are cylindrical and spherical coordinates.



UTM Grid System

UTM is the acronym for Universal Transverse Mercator, a plane coordinate grid system named for the map projection on which it is based (Transverse Mercator). The UTM system consists of 60 zones, each 6-degrees of longitude in width. The zones are numbered 1-60, beginning at 180-degrees longitude and increasing to the east. The military uses their own implementation of the UTM system, called the Military Grid Reference System (MGRS).

The National Oceanic and Atmospheric Administration (NOAA) website states that the system was developed by the United States Army Corps of Engineers, starting in the early 1940s.

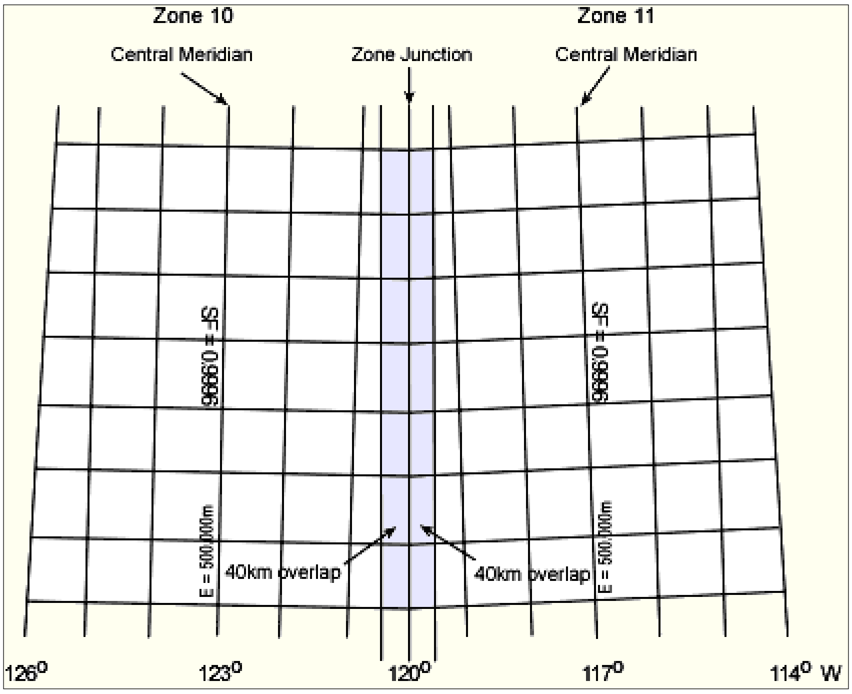


UTM zones on an equirectangular world map with irregular zones in red and New York City's zone highlighted

A mercator projection is a 'pseudo cylindrical' conformal projection (it preserves shape). What you often see on poster-size maps of the world is an equatorial mercator projection that has relatively little distortion along the equator, but quite a bit of distortion toward the poles.

What a transverse mercator projection does, in effect, is orient the 'equator' north-south (through the poles), thus providing a north-south oriented swath of little distortion. By changing slightly the orientation of the cylinder onto which the map is projected, successive swaths of relatively undistorted regions can be created.

This is exactly what the UTM system does. Each of these swaths is called a UTM zone and is six degrees of longitude wide. The first zone begins at the International Date Line (180°, using the geographic coordinate system). The zones are numbered from west to east, so zone 2 begins at 174°W and extends to 168°W. The last zone (zone 60) begins at 174°E and extends to the International Date Line.



The zones are then further subdivided into an eastern and western half by drawing a line, representing a transverse mercator projection, down the middle of the zone. This line is known as the 'central meridian' and is the only line within the zone that can be drawn between the poles and be perpendicular to the equator (in other words, it is the new 'equator' for the projection and suffers the least amount of distortion). For this reason, vertical grid lines in the UTM system are oriented parallel to the central meridian. The central meridian is also used in setting up the origin for the grid system.

GEO 495.2: GEOGRAPHIC INFORMATION SYSTEM

1. Basic Concepts and components in GIS: An overview of the development of the GIS fields, Data Sources; Data acquisition methods.

2. Data structure: Vector and Raster data structures, data storage.

3. Modern trends in GIS: 3D GIS and Web GIS, Real time GIS, Mobile GIS and application of GIS

4. Basics of GPS Surveying: Conceptual Framework, Space Segment, Ground Segment, Control Segment, Satellite Triangulation, Pseudo Random Code. DGPS and GNSS

5. GPS-aided traversing; Manual and Computer plotting for preparation of maps.

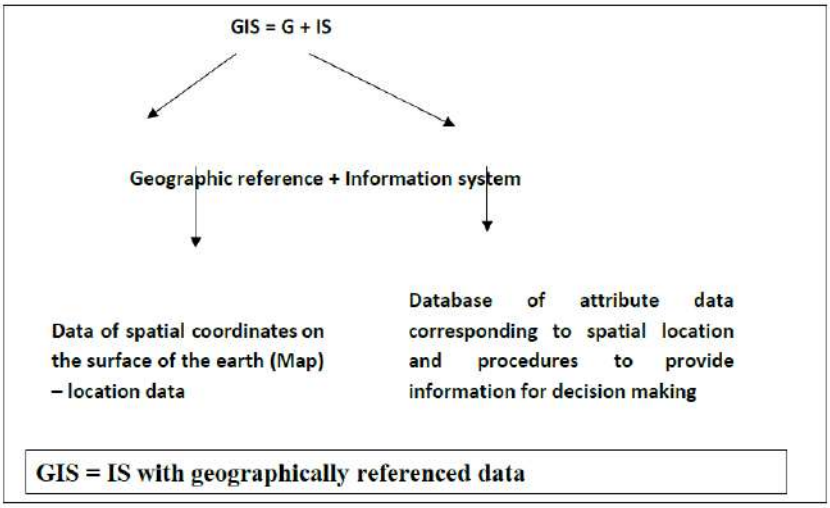
1. Basic Concepts and components in GIS: An overview of the development of the GIS fields, Data Sources; Data acquisition methods.

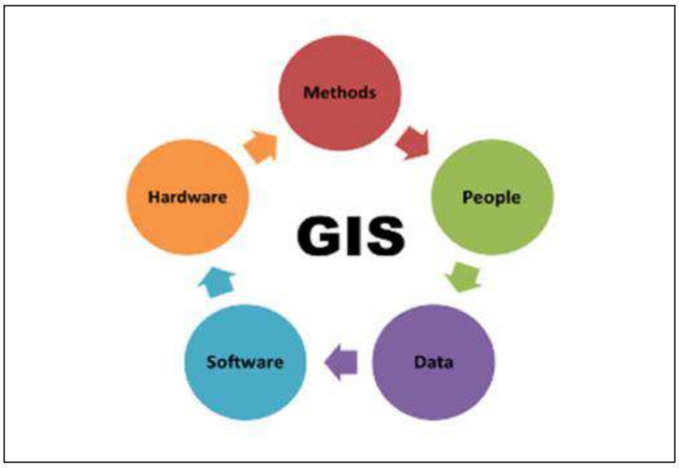
Basic Concepts and Components in GIS

A geographic information system (GIS) is a framework for gathering, managing, and analyzing data. Rooted in the science of geography, GIS integrates many types of data. It analyzes spatial location and organizes layers of information into visualizations using maps and 3D scenes. With this unique capability, GIS reveals deeper insights into data, such as patterns, relationships, and situations—helping users make smarter decisions.

Definition of GIS

A GIS is basically a computerized information system like any other database, but with an important difference: *all information in GIS must be linked to a geographic (spatial) reference* (latitude/longitude, or other spatial coordinates).



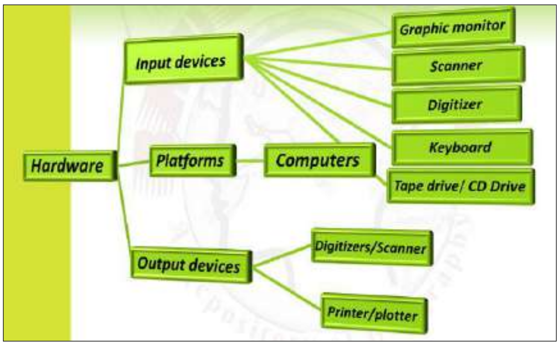


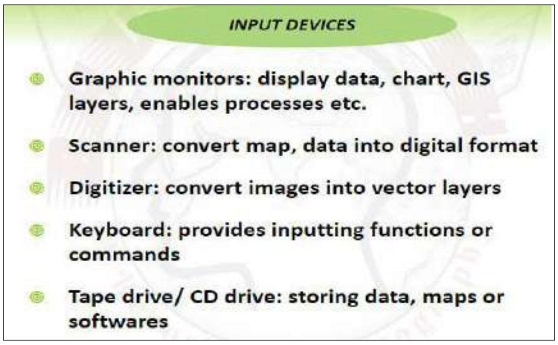
Components in GIS

GIS integrates five key components: hardware, software, data, people, and methods.

1. HARDWARE

Hardware is the computer on which a GIS operates. Today, GIS runs on a wide range of hardware types, from centralized computer servers to desktop computers used in standalone or networked configurations.





2. SOFTWARE

GIS software provides the functions and tools needed to store, analyze, and display geographic information. Key software components are:

- A database management system (DBMS)
- Tools for the input and manipulation of geographic information
- Tools that support geographic query, analysis, and visualization
- A Graphical User Interface (GUI) for easy access to tools

SOFTWARE

- GIS software provides the functions and tools that are necessary to store, process, analyze, modeling and display of Geospatial data.
- Software's are classified by its capability:
  - Input Module
  - Editing Module
  - Modeling Module
  - Analysis Module

GIS SOFTWARES

- ARC INFO
- Arc View 3X
- MapInfo
- MGE
- Geo media
- Geo concept
- Geo mattica
- WINGIS
- Micro station
- AutoCAD
- QGIS

IMAGE PROCESSING

- ERDAS
- ER Mapper
- ILWIS
- ENVI
- PCI
- Arc View image analysis
- TNTMIPS
- Ecognition

GIS SOFTWAREs

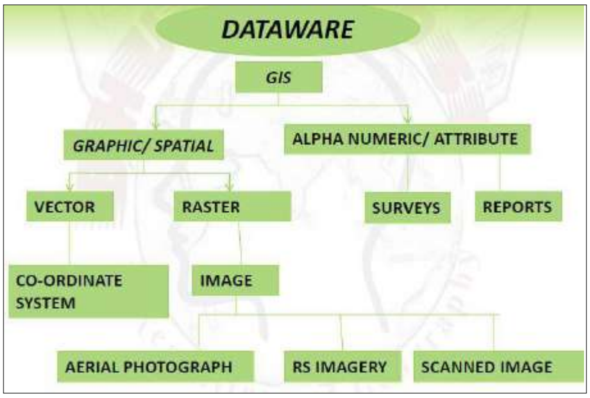
- Autodesk – Products include Map 3D, Topobase, MapGuide and other products that interface with its flagship AutoCAD software package.
- Bentley Systems – Products include Bentley Map, Bentley PowerMap and other products that interface with its flagship MicroStation software package.
- Intergraph – Products include GeoMedia, GeoMedia Professional, GeoMedia WebMap, and add-on products for industry sectors, as well as photogrammetry.
- ESRI – Products include ArcView 3.x, ArcGIS, ArcSDE, ArcIMS, ArcWeb services and ArcGIS Server.
- ENVI. Utilized for image analysis, exploitation, and hyperspectral analysis.
- IDRISI – GIS product developed by Clark Labs, a part of Clark University. Economical but capable, it is used for both operations and education.
- MapInfo by Pitney Bowes – Products include MapInfo Professional and MapXtreme. integrates GIS software, data and services.
- Manifold System – GIS software package.
- Smallworld – developed in Cambridge, England (Smallworld, Inc.) and purchased by General Electric and used primarily by public utilities.
- QGIS (previously known as Quantum GIS) is a free and open-source cross-platform desktop geographic information system (GIS) application that supports viewing, editing, and analysis of geospatial data

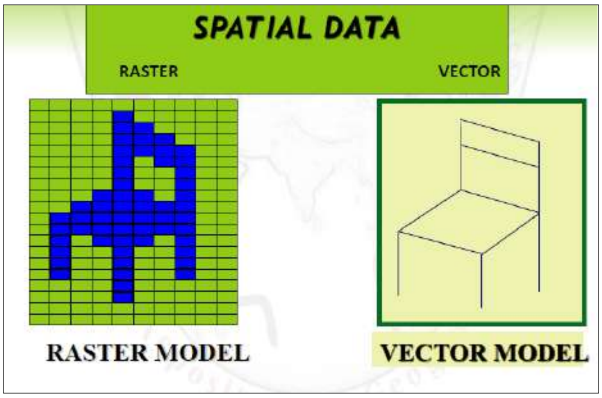
GIS Processes in Different Software's

	AUTOCAD MAP	MAPINFO	ARCVIEW	ARC GIS	ERDAS	GOOGLE EARTH
1	Rubber sheeting	Geo referencing	Geo referencing	Geo referencing	Geo referencig	Geo referencing
2	.dwg	.tab	.shp	.shp	.img, .cov, .shp	.kml, .kmz
3	Feature creation: point, line polygon in one layer	Point, line, polygon feature created in one layer	Feature created in seprate layer	Feature created in separate layer	Feature created in separate layer	Feature created in separate layer
4	Drawing cleanup	–	–	–	Drawing cleanup	–
5	Topology (relation between features)	–	–	Topology	–	–
6	Data management	Data management	Data management	Data management	Data management	Data management
7	Query & Analysis	Query & Analysis	Query & Analysis	Query & Analysis	Query & Analysis	–
8	Layout	Layout	Layout	Layout	Layout	Layout
9	Raster image band change	–	–	Raster image band change	Classification	–
10	–	–	–	–	Mosaic	–
11	–	–	–	–	Subset	–
12	Clipping in overlay	–	–	Clipping	Clipping	–

3. DATA

May be the most important component of a GIS is the data. Geographic data and related tabular data can be collected in-house or bought from a commercial data provider. Most GIS employ a DBMS to create and maintain a database to help organize and manage data. The data that a GIS operates on consists of any data bearing a definable relationship to space, including any data about things and events that occur in nature. At one time this consisted of hard-copy data, like traditional cartographic maps, surveyor's logs, demographic statistics, geographic reports, and descriptions from the field. Advances in spatial data collection, classification, and accuracy have allowed more and more standard digital base-maps to become available at different scales.



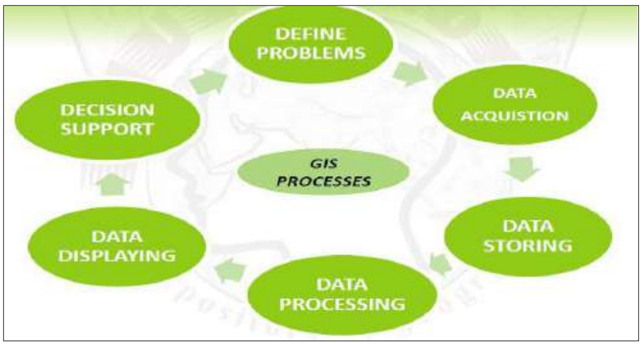


4. PEOPLE

GIS technology is of limited value without the people who manage the system and to develop plans for applying it. GIS users range from technical specialists who design and maintain the system, to those who use it to help them do their everyday work.

5. METHODS

A successful GIS operates according to a well-designed plan and business rules, which are the models and operating practices unique to each organization.



An Overview of the Development of the GIS Fields

Geographic information systems were first formally introduced with the development of the Canada Geographic Information System (CGIS) in the early 1960s. The CGIS both benefitted from earlier conceptualizations and pioneered new software, hardware and algorithms for handling spatial data. From the 1970s to the 1990s there was an emphasis on Geographic Information *Systems*. GIS innovators John Coppock and David Rhind divided this era into:

1. A pioneer period from the late 1950s to the 1970s which emphasized conceptual and software development;

2. A government-funded experimental research period from the mid-1970s to the early 1980s with GIS continuing to be provided on mainframe computers;

3. A commercial period with increased involvement of both industry and government from the early 1980s to the late 1980s dominated by companies such as Esri and Intergraph; and

4. The end of the 1980s to the early 1990s showing ever increasing academic participation together with intense vendor competition that resulted in a reduced number of GIS companies that were now producing GIS with user friendly interfaces on desktop computers.

In 1992 Michael Goodchild introduced the era of Geographic Information Science. This captured the imagination of the community, and journals and academic teaching and research have reflected this change to the present day. Ironically, it also saw the introduction of avowedly non-scientific approaches with the advent of Public Participation GIS and the use of non-authoritative data in the form of Volunteered Geographic Information (VGI).

- Before Geographic Information Systems (GIS) were introduced to the world, and to the world of academic geography, place and the uniqueness of place was considered all-important.
- In the 1950s and early 1960s the uniqueness of place was challenged by the introduction of quantitative and theoretical approaches to geography.
- In the 1960s the rise of geographic information systems gradually led to an ascendancy of a spatial and scientific approach to geography.
- By the late 1980s, GIS were providing jobs for students who were educated and trained to use and develop these new software tools.

- However, throughout the decades since GIS were first introduced there were those in the discipline who continued to celebrate the uniqueness of place and the value of qualitative geography as well as a plethora of non-quantitative and a spatial approach to geography. Recently, many GIS practitioners have attempted to accommodate and assimilate a diversity of approaches to Geography and to respect approaches that emphasize both the uniqueness and similarities of places.

GIS Timelines

A preliminary understanding of the main developments in the history of GIS can be gained from online websites. Two of the most notable are the one maintained at University College London and one maintained by Caitlin Dempsey (2017) at the GIS Lounge website. The former provides detailed information on all of the main developments in the history of GIS between 1959 and 1999. Essentially the website is fossilized although it remains a useful resource for quickly examining the history of GIS. It also provides links to other related timelines available on the web. The link to "A Time Line of Past Events and Forces" in GIS is also broken but that time line can be found in the report of the Mapping Science Committee (1997) on *The future of spatial data and society: Summary of a workshop*, This list of important dates and events in the development of GIS along with other scientific and political forces occurring contemporaneously was "crowd sourced" from attendees at the workshop for the dates 1956-1996. Subsequently a few items were added for the earlier part of the 20th century. The GIS Lounge (2017) timeline notes that the first use of the phrase "geographic information system", but not the acronym GIS.

Antecedents to Geographic Information Systems

Historical accounts of the origins of GIS invariably pay tribute to the intellectual debt owed to those who sought to organize, visualize, and interpret spatial data. Commonly these discussions reach back into the distant past, frequently referencing the map overlays of troop movements created by the French cartographer, Berthier, during the Battle of Yorktown in the American War of Independence. Equally ubiquitous are references to the atlas that Accompanied the Second Report of the Irish Railway Commissioners in 1837 that displayed population, traffic flows, topography and geology all overlain on a base map (see, for example, the equally useful timeline for a study of the history of GIS: *Milestones in the history of thematic cartography, statistical graphics, and data visualization* actively maintained by Friendly and Denis, 2001). Many historical accounts of GIS cite the work of Dr John Snow, the British physician who, in 1854, mapped the incidence of cholera in London, providing convincing evidence that the disease was water- and not air-borne (Waters 1998). Berthier and

Snow sought to map their data so that it might be used both to understand the underlying processes that produced the data and to provide operational insights as to how these data might be exploited.

Despite these promising beginnings it was not until almost a century later that planners and professional geographers once again began to utilize the mapping of combinations of spatial data in the overlay process that was to become one of the most quintessential of GIS operations. The origins of the overlaying of mapped data in planning are described by Steinetz, Parker, and Jordan (1976). Their research shows that in the United States the method of overlay analysis was implicit in the work of Warren Manning in his 1912 study of the town of Billerica, MA, work that was subsequently published in the journal *Landscape Architecture Quarterly* in 1913. Steinetz, Parker, and Jordan also recognized the implied use of overlay analysis in the results of a competition for the design of a new plan for the city of Düsseldorf in Germany that were published in 1912. Steinetz and his colleagues described other studies that used overlay procedures throughout the first half of the twentieth century, but it was not until the work of Jacqueline Tyrwhitt and Jack Whittle appeared in the *Town and Country Planning Textbook; An Indispensable Book for Town Planners, Architects, and Students* (cited and discussed by Steinetz, Parker, and Jordan 1976) that detailed and explicit accounts of the overlay process and ensuing spatial analysis were explained. The technique was quickly popularized by many others including, most famously, Ian McHarg (1969). Because of the popularity of McHarg's book, *Design with Nature* (now cited almost 5000 times in the academic literature), he is regarded as having had a prodigious influence on the development of GIS, but *Design with Nature* did not provide a description of a methodology for computerizing the overlay process, although such a methodology is indeed articulated in the article by Steinetz, Parker, and Jordan (1976) and had been formally described in Roger Tomlinson's (1974) doctoral thesis, a seminal work that has been downloaded almost 2,000 times.

It is important to note that before software and hardware systems were developed that were officially recognized as "geographic information systems" there were numerous developments that occurred within the classified military arena. Clarke and Cloud (2000), for example, have provided a detailed assessment of the importance to the development of the associated field of analytical cartography of the US CORONA program of reconnaissance satellites that was operated by the Central Intelligence Agency from 1959 to 1972 along with the associated SAGE program for processing the imagery.

The Era of Geographic Information Systems

In their account of the early history of GIS, published as part of the first major review of the field, Coppock and Rhind (1991) divided their retrospective into four periods: (i) the pioneer period from the mid-1950s to approximately 1975; (ii) the government-supported, experimental period beginning in the mid-1970s and ending in the early 1980s; (iii) the commercial period from the early 1980s to 1990; and (iv) the user dominance era starting in 1990. For all four periods Coppock and Rhind discuss the significance of conceptual developments, progress and improvements in software and hardware, and the contributions of academia, commercial enterprises, and governments. This discussion follows Coppock and Rhind's schema. For an alternative view of the early days of GIS see Foresman (1998). Foresman's edited book is noteworthy for providing a more operational and raster-oriented coverage of the origins of GIS, and for including many chapters written by the "pioneers" of GIS. His chronology of the evolution of GIS includes several overlapping "ages": the pioneer age, mid-1950s to the early 1970s; the research and development age, the very early 1970s to the mid-1980s; the implementation and vendor age, the early 1980s to the mid-1990s; the client applications age, the early 1990s to the early 2000s; the local and global network age, the late 1990s onwards into the 2000s. These developments are then correlated with developments in academic geography, computing, and environmental awareness.

The Pioneer Period: The Mid-1950s to the Mid-1970s

Conceptual developments during this period included the overlay method (also known as the "layer-cake" model) for the organization of geographical data discussed previously and the popularization of the geographical data matrix by Brian Berry. Originally, the data matrix was organized with the columns representing places and the rows representing their attributes. When Berry's model was incorporated into early GIS software this arrangement was transposed to make the geographical matrix more compatible with standard database technology. Waters (1998) discusses contributions from the field of operations research, where work on decision support systems by IBM researchers was being incorporated into planning-based software.

During the 1960s the first fully functional vector-based GIS, the Canada Geographic Information System (CGIS), were developed. The CGIS, initially collaboration between Roger Tomlinson's company, Spartan Air Services of Ottawa, and the Canadian Government's Canada Land Inventory, produced a series of innovations, including hardware for laser scanning of maps and software for vectorizing the resulting images and for storing raster layers efficiently, with such algorithmic developments as Morton ordering (Waters 1998). Because of Roger Tomlinson's seminal contribution to the origins and development of GIS he has often been credited with being the "father of GIS". In these early years, those working in the field of GIS were not simply taking advantage of developments in the field of computer science, as computer science did not offer all the software, hardware and algorithmic innovations that were needed for the development of GIS. As the field matured, GIS would indeed take advantage of computer hardware developments and the move away from mainframe computing. External developments in database technology also proved beneficial to the development of GIS.

During this seminal period the Harvard Laboratory for Computer Graphics and Spatial Analysis, established in 1965 by Howard Fisher, laid the foundations for many of the subsequent developments in GIS. Thus, the Harvard Laboratory made major algorithmic contributions and produced widely adopted computer mapping packages, such as SYMAP, CALFORM, SYMVU, GRID, POLYVRT, and ODYSSEY. The first three packages for producing line printer maps and 2-D and 3-D plots, respectively, were adopted throughout North American universities. William Warntz became the Director of the Harvard Laboratory in 1969 and made further conceptual contributions, including recognition that the critical features of surfaces such as the "peaks, pits, passes and pales" could be used to produce triangulated irregular network (TIN) models to provide more compact storage of surface features of various types (Warntz and Waters, 1975). Associated with the Harvard Laboratory at various times was Jack Dangermond, founder (in 1969) and co-owner of the world's leading GIS company, Esri, which now produces the industry-dominant ArcGIS and supports numerous annual conferences, including their flagship Users' Conference, as well as prolific press publishing extensive educational resources. For a complete history of the early days of the Harvard Laboratory see Chrisman (2006). In the United Kingdom, the experimental cartography unit (ECU) was founded in 1967 by David Bickmore, head of the cartography unit at the Clarendon Press. Like the Harvard Laboratory, the ECU stimulated and championed the possibilities of computer-based mapping, providing the incentive for the British Ordnance Survey to move into automated, computer-based mapping.

In 1970 the US Census Bureau produced the first geocoded census. The topological structure of street segments was coded by identifying the IDs of right and left blocks and "from" and "to" nodes. Also recorded, using X,Y coordinates, were the address ranges of street segments. These files were known as DIME (dual independent map encoding) files and were the forerunner of the US Census Bureau's more sophisticated TIGER (topologically integrated geographic encoding and referencing) files (Mark *et al*. 1997).

One of the primary ways in which new knowledge about GIS has been disseminated is through the organizations that have catered to academia, government, and industry. The Urban and Regional Information Systems Association (URISA) is one of the oldest such organizations. URISA held its first conference in 1963 and has continued to hold annual conferences up until the present. These are now known as the GIS-Pro Conferences and the 55th annual meeting was held in Jacksonville, FL, in 2017. Over the decades the proceedings of the URISA annual conferences have been a major source of information concerning new developments in the evolution of GIS.

The Government-Funded Experimental Research Period: The Mid-1970s to the Early 1980s

Conceptual and software developments during this period were taking place within academia, government agencies, and industry. For example, algorithms to solve location-allocation problems that had been developed in the mid-1960s were now available in stand-alone programs and were also being integrated into software systems, such as GADS (geodata analysis and software display system) developed by IBM's research division (Waters 1998). In Europe, government-sponsored research led to the development of the Swedish road data bank and other computerized spatial databases.

Developments in GIS reflected advances in the field of computer science. During this period, mainframe systems had given way to minicomputers based on time sharing and, eventually, to desktop microcomputers, laptops and tablets enabling the gradual movement of GIS software to these new computing platforms. One of the most prominent and earliest of the government-supported, mainframe GIS of this period was the Minnesota land management information system (MLMIS). This was a raster-based (as opposed to the vector-based CGIS) resource inventory, where the pixel cells had a resolution of 40 acres. By the end of this period, such mainframe systems were gradually becoming obsolete, due to high maintenance costs, the problem of data currency, access issues, and nonuser-friendly command line interfaces. The introduction of powerful workstations in the early 1980s led to the gradual demise of large mainframe systems.

In 1974 the first Auto-Carto conference was held. These conferences are now held biennially (the most recent in 2016) and sponsored by the Cartography and Geographic Information Society. Similarly, in Europe, a series of fourteen EuroCarto meetings were held from 1981 to 1997 (every year except for 1982, 1988, and 1996). In 2015, these conferences re-emerged under the sponsorship of the International Cartographic Association (ICA) as the 1st ICA European Symposium on Cartography (EuroCarto 2015).

The Commercial Period: The Early 1980s to the Late 1980s

Tomlinson (1987), writing in the first volume of what was to become a flagship journal of GIS, provided a state-of-the-art review of this newly emerging subdiscipline of geography. He noted that significant progress had been made in adopting GIS software in government and commercial organizations, including in the transport and facility planning and management, cadastral systems, agriculture and the environment, and the forestry and civil engineering sectors. He argued that in the future new innovations would come from academia and from government rather than the commercial sector. This was only to be partially true for, in 1982, Esri had released ARC/INFO, the first commercial GIS. ARC/INFO adapted the CGIS model of handling the spatial and attribute data separately. The former used Esri's topological ARC structure while the latter were stored in the INFO relational database. In 1986, Esri released PC ARC/INFO due to the popularity of the IBM PC desktop computer. By 1988, Esri had become a $40 million a year company with clients in forestry applications and other government departments.

Tomlinson (1987) had been correct in arguing that the expansion of commercial GIS was being curtailed by the lack of educational opportunities to produce personnel who could run and maintain GIS facilities, conduct basic research, stimulate new innovations, and staff university departments. In 1988, to motivate fundamental research into the development of GIS, the US National Science Foundation (NSF) made a grant to a consortium of universities that included the departments of geography at the University of Santa Barbara (the lead institution where Mike Goodchild was the Executive Director), the State University of New York at Buffalo, and the surveying engineering department at the University of Maine. This consortium is now funded from a variety of research grants totalling about $5 million annually much of which continues to come from the NSF. In addition to its primary focus on research, which manifested itself in a series of research initiatives, the NCGIA (National Center for Geographic Information and Analysis) also developed a core curriculum in GIS comprised of 75 lectures, grouped into three semesters each of 25 lectures. The lectures were initially written by 35 different authors and contained additional laboratory material. They were remarkably successful and by January 1995 over 1300 copies had been distributed to over 70 countries. Eventually, the original core curriculum was made available in Chinese, French, Hungarian, Japanese, Korean, Polish, Portuguese, and Russian. The core curriculum was intended to provide a core set of knowledge that would allow faculty teaching GIS courses to cover a broad set of topics to students new to the discipline.

In February 1987, the UK's Economic and Social Research Council established four regional research laboratories (RRLs), in London, Edinburgh, Cardiff, and Newcastle. Their mandate involved four primary functions: data management (the provision of a spatial data archive); software development; spatial analysis; and research training together with professional development. Concurrent with the development of the RRLs, the UK's Lord Roger Chorley chaired the Committee of Inquiry into the Handling of Geographic Information. The Committee's Report was made public in 1987 (Waters 1998) and made recommendations (subsequently acted upon) that the British Ordnance Survey, the primary supplier of maps to the British public, should move to a fully digital environment.

The Period of User Dominance: The End of the 1980s to the Early 1990s

Coppock and Rhind (1991) state that during the last of their four periods there was intense competition among GIS software manufacturing companies due to "user dominance" and an associated thinning out of the market to a small number of major vendors. This competition was fostered by the numerous GIS conferences and by the publication of the annual GIS World Sourcebooks (Waters 1998). These volumes were noteworthy for their annual survey of GIS companies and their software, which included detailed tables assessing the capabilities and attributes of the listed GIS software. This ongoing competition resulted in the emergence of a few dominant companies among the GIS software vendors, including Intergraph and Esri. During this period, vendors moved away from the complexity of command line interfaces to graphical user interfaces (GUIs), once again tracking ongoing developments in computer hardware and commercial operating systems and interfaces (including the so-called WIMP interface of windows, icons, menus, and pointers). It was in 1990 that the US Census Bureau introduced its TIGER file system: this, together with the fact that Census Bureau data was freely available, further boosted the US geodemographics industry. Other countries including Canada and the United Kingdom made census data only available on a so-called "cost recovery" basis, arguably imposing a continuing chill on what might have been a more robust market for GIS data. In recent years many countries have permitted more open access to geospatial data under the Aarhus Convention, which became law in October 2001. However, the only states that signed the agreement were from Europe and Asia and, ironically, not the United States. E-government now incorporates an open access philosophy and uses GIS to enable the delivery of spatially referenced data between government and citizens (G2C) and also provides citizens access to government information (C2G).

During this period, a number of companies supplied GIS software that specialized in niche markets. For example, Caliper Corporation produced Trans CAD, a software package focused on transportation planning and transportation GIS (GIS-T). Others, such as Idrisi, developed by Clark University in Worcester, MA, successfully catered to the academic market, providing detailed tutorials and accompanying datasets. In 2017 Clark Labs celebrated their 30th anniversary. It was during this period that the movement to introduce GIS instruction into the K-12 curriculum in the United States gathered momentum. These efforts were summarized and resource materials and advice for teaching GIS in primary and secondary schools were provided at the first national conference on the educational application of geographic information systems held in 1995 and sponsored by Technical Educational Research Centers (TERC). TERC has continued to provide educational resources to schools for all grade levels (and for university GIS courses as well) and now maintains an active website.

By the end of the 1990s Mike Phoenix, former higher education specialist for Esri, was able to claim that Esri's GIS software products were used in more than 60 different kinds of university academic and administrative departments (Waters 1998). By this date, GIS had influenced the teaching of many of the subdisciplines of geography and would, in the following decade, go on to influence the operations of many other disciplines that used spatial data.

The Era of Geographic Information Science (GI Science)

The mid-1990s saw a sea-change in the development of the academic discipline of GIS. In 1992, Goodchild published a major theoretical contribution when he argued that the discipline should move from a concern with the technology of geographic information *systems* to developing answers to questions that might more properly be considered part of a geographic information *science* (Goodchild 1992). In the opening arguments of his paper, Goodchild stated that much of the early history of GIS was technology driven. It was concerned with how to get geographical data into an information system and with new technologies that were developed largely within government agencies, such as the CGIS and the US Census Bureau, and by remote sensing companies that were developing new technologies to acquire satellite imagery. Now, he argued, it was more appropriate to concentrate on the task of how to "handle" and exploit the data held in these GIS databases. The way forward was prepared by research that was being reported at two newly developed biennial conference series. The first of these was the International Geographical Union's Spatial Data Handling symposia (the earliest held in Zurich in 1984 and the 17th, and most recent, in Beijing in 2016). The second were the Conferences on Spatial Information Theory (COSIT) which began in 1992 with the 13th, and most recent of these, held in L'Aquila, Italy, in 2017.

Goodchild presented a review of the nascent discipline of GIScience, including a synopsis of three decades of algorithmic research, into a series of topics: spatial data handling; data collection and management; data capture; spatial statistics; data modelling and theories of spatial data; data structures, algorithms and processes; data display (visualization); analytical tools; and, finally, institutional, managerial, and ethical issues. While some of these developments were to benefit from progress in computing (e.g., data display profited from a new emphasis on scientific visualization, often referred to as the second revolution in computer science), most launched new sub disciplines in geography (e.g., spatial statistics, which now produced new stand-alone software packages such as GeoDa, and new functionality in commercial software, such as Esri's ArcGIS ToolBox, Spatial Analysis and Geo-Statistical Analysis modules). Some of these new fields were located in other academic departments such as information science and geomatics engineering, mirroring developments that had occurred decades before when fields such as geomorphology and climatology moved out of academic geography.

Within a few years a number of journals had changed their names to reflect this new emphasis on science as opposed to systems. For example, in 1997 the *International Journal of Geographic Information Systems* had replaced the word *Systems* in its name with *Science*. The new name was explained in the introduction to that volume by then editor, Peter Fisher, who acknowledged the debt to Goodchild's seminal article in providing a rationale for the new focus to the journal and the discipline. The *American Cartographer*, which had been launched in 1974, had changed its name in 1990 to *Cartography and Geographic Information Systems*. This lasted until 1999, when it also changed the *Systems* in its title to *Science*. Other journals, such as *Transactions in GIS*, circumvented the problem by leaving the acronym in their title undefined. When the 2nd edition of *Geographical Information Systems: Principles, Techniques, Applications and Management* appeared in 1999, the word *Systems* was retained, but when the same four authors published the first edition of a textbook two years later, they included both terms, *Geographic Information Systems and Science* (Longley *et al*. 2001). The *Annals of the Association of American Geographers* requests submissions in four broad areas, one of which is *Methods, Models and Geographic Information Sciences* but its Table of Contents retains the now more ambiguous acronym, *GIS*, and its specialty group in the field prevaricates, as well, with the title *Geographic Information Science and Systems*. The new NCGIA core curriculum, which gathered lectures for its website until 2000, also used geographic information science in its title. The lectures and associated material were now all online and no print copies were created. A note posted on the website in August 2000 stated that there would be no further updates due to new educational resources becoming available, including the digital library of Earth system education, the NCGIA's own center for spatially integrated social science, and Esri's virtual campus (Waters 2013). A review of progress in the field of GIScience, twenty years after the initial discussions of the concept, has been given by Goodchild (2010).

New educational initiatives also characterized this period. In 1990, the NCGIA board of directors recommended that a new organization be developed to assist researchers in GIScience. The UCGIS (University Consortium for Geographic Information Science) website, in its brief history of the organization, states that an ad hoc steering committee was formed by the NCGIA in 1991 containing 16 members from seven different disciplines. Unfortunately, this brief historical note does not list either the members of the committee nor the seven disciplines represented. In 1994, a founding meeting was held in Boulder, CO, and in 1995 the UCGIS was formally incorporated. The UCGIS had two primary objectives listed on its website: "Advance research in the field of geographic information science" and to "Build scholarly communities and networks to foster multidisciplinary GIS research and education." The membership of UCGIS has fluctuated over the years, reaching a high of perhaps 70 US universities in about 2005 but declining to 58 US universities at the time of writing. In addition, Esri and the United States Geological Survey are Affiliate Members. In the initial meeting it was made quite clear that this was a US organization and non-US universities would only be granted affiliate status. This has now changed but the University of Salzburg's Department of Geoinformatics remains the only non-US member.

The UCGIS has promoted annual meetings and symposia and, in partnership with the Association of American Geographers, the development of a body of knowledge (BoK) for teaching GIS. This was seen as a natural successor to the core curricula developed by the NCGIA. However, in conceptualization the BoK was vastly different. Waters (2013) provides a critical review of the development process that led to the publication of the BoK in 2006. The BoK was structured into ten knowledge areas that were then divided into 73 units that, in turn, were further subdivided into 329 topics. Contributors to the BoK had suggested that one of the primary weaknesses of the core curricula had been the lack of an explicit structure for continuous updating. In the field of computer science there is a process for updating the curriculum approximately every six years (Waters, 2013). In 2016 the UCGIS placed the original BoK online and implemented a process for adding content. Under the guidance of an editorial board new topics were added, existing topics were revised and expanded and the BoK became a "living document" that would be kept current of all that was new in GIScience (Sinton, 2017). The UCGIS has also expressed concern over the US Geospatial Data Act that was reintroduced into the US Senate of May 2017 that proposes to limit US Government work to licensed architects and engineers.

Reactions to a Formal Geographic Information Science Approach to GIS

Some academic geographers reacted with dismay to the new emphasis on geographic information science, seeing it as a reassertion of the aridity of the spatial paradigm of the so-called "quantitative revolution," which had been disavowed by various members of the discipline in the 1970s. The most widely cited critique of the spatial paradigm within GIS came in the form of John Pickles' edited volume, *Ground Truth* (Pickles 1995). Although a few of the leading proponents of GIScience contributed essays to the book, most of the papers were written by academics unsympathetic to the achievements of those working in GIS.

Shortly after the publication of *Ground Truth*, the public participation in GIS (PPGIS) movement was launched at an NCGIA sponsored workshop held at the University of Maine. Moreover, one of the papers in *Ground Truth* (Harris et al., 1995) had also focused on "participatory GIS". PPGIS may be defined as an approach to community planning that privileges the traditionally marginalized segments of society (the poor, the old, the young, the physically challenged, and members of ethnic minorities, among many others). It leverages GIS software to allow these individuals to participate in the planning of their communities and their environments. To achieve these goals PPGIS broadened traditional approaches to GIS by including a wide range of social science methodologies and theories. It is closely aligned with participatory GIS (PGIS), a cognate set of methodologies and approaches and low-tech solutions, such as sketch maps, to the acquisition of geographic information. Typically, PPGIS and PGIS involve the interaction and collaboration of academics with GIS expertise with members of the community wishing to participate in the planning of their communities. These approaches had antecedents, paradoxically in the later work of Bill Bunge, one of the pioneers of the quantitative revolution (Miller and Goodchild 2015). PPGIS has also produced new lines of research, such as the current concern with the design of age-friendly communities.

In the twenty-first century, stimulated by the popularity of PPGIS, which had spawned a series of conferences in conjunction with the annual URISA meetings, GIS began to embrace various traditionally non scientific approaches to geography, including qualitative, feminist, and critical GIS to name a few. PPGIS itself had rarely spelled out whether it was concerned with geographic information systems or science, the latter being somewhat of an anathema to those practicing PPGIS. The more important of these innovative approaches to GIS included formal adoptions of critical GIS and feminist focused methods to the use of the technology. The possibility of the former was introduced in an article by Nadine Schuurman (2000) who identified three waves of criticism of the GIS community. She argued that the first wave had lasted from 1990 to 1994 and the debate had cantered on the merits of the positivist approach adopted by GIS practitioners. The second wave occurred in the mid-1990s and represented the beginning of a dialogue between GIS specialists and those concerned with both the social effects and implications of GIS technology. The catalyst for this discourse was the NCGIA's "Research Initiative 19, GIS and Society: The Social Implications of How People, Space, and Environment Are Represented in GIS." According to Schuurman, in the third wave, at the end of the 1990s, there was a greater commitment to the technology of GIS. This led to the rise of PPGIS in that decade and ever since. Quite separately, there was a call for a "critical GIS" or "GIS2" that would incorporate the various perspectives of social theorists (see Sheppard *et al*. (1999) for a discussion of the societal implications of the NCGIA's Varenius Project, and also the papers in the special issue of *Cartographica*, 2009, 44(1)).

GIS Developments since 2005: The Worlds Of Volunteered GIS, Web-Based Mapping, Mobile GIS, Cloud Computing and Big Data

Since 2005, developments in GIS have again mirrored the importance of progress in computing technology. Crowdsourcing and social networks have been hugely influential developments in the social application and individual use of computing technology, but these changes have been reflected in the move away from the use of authoritative data in GIS and the rise in influence and use of volunteered geographic information (VGI). The attractions of VGI are well described in Goodchild's (2007) seminal paper on the topic: VGI is inexpensive, timely and available to all on both sides of the digital divide. Goodchild (2010), in reviewing progress in the field of GIScience, notes that the breaking down of the barriers between expert and nonexpert is also referred to as neo-geography and that VGI itself has been called crowd sourced geographic information and community mapping, and thus has strong links to PPGIS. VGI has been aided by the move to web-based mapping and the availability of online GIS technology such as ArcGIS Online and the almost universal availability of map-based apps on smart phones and in-car GPS navigation systems (see Miller (2007) for a review of these technologies that have produced a time–space convergence and aided the processes of globalization). GIS and computing hardware are becoming invisible technologies whose benefits can be leveraged and enjoyed seamlessly by wide sectors of the population in industrialized and developing countries.

Other software developments that have led to the almost universal use of geographic information and related technologies include Google Earth, OpenStreetMap, and software for finding directions, such as MapQuest. The familiarity of large sections of affluent populations with this type of software has led to the rise of location-based services and to new developments such as OpenImageMap and web mapping services.

Advances in computer technology, including cyber infrastructure (leading to Cyber GIS), cloud computing, and the rise in importance of "big data," are almost immediately integrated into GIS software, with leading GIS companies such as Esri providing online guides as to how big data may be used in such GIS applications as predictive modelling and social media. A review of the implications for the discipline of geography in general, and GIS in particular, involving a move to a "data driven" geography, is provided by Miller and Goodchild (2015). Traditionally, big data was concerned with the three "Vs": volume, velocity, and variety. The terms are self-explanatory and geographic data often qualify on all three counts. More recently, computer scientists have added additional "Vs" to the list, including veracity (relating to the provenance of the data: thus, for example, VGI might have lower veracity than authoritative data), value, validation (whether the data conforms to a priori model expectations), and voracity (the rate of ingestion, which is important in the use of virtual reality simulations with a GIS framework). Vagueness (or uncertainty) might also be added to the list as it is endemic to much GIS data, both VGI and authoritative. Finally, vicinity adds many challenges to the analysis of big, *spatial* data in a GIS environment (Hultquist et al., 2017).

GIS Returns to Its Roots in Geography and GIS

It can be argued that GIS has returned to its origins, from earlier concerns common to many geographers, at least on the human geography side of the discipline. Miller and Goodchild (2015) summarize the history of geography's concerns with idiographic (description-seeking) and nomothetic (law-seeking) approaches. At various times over the centuries one approach has been dominant and the other subordinate, disparaged, or overlooked. Miller and Goodchild argue that Strabo and Ptolemy were concerned with both approaches, for they provided detailed descriptions of specific places as well as generalizations that applied to the Earth or large regions. However, Miller and Goodchild also state that such an integration has rarely been adopted by researchers in the two millennia since Strabo and Ptolemy wrote. GIS, with its emphasis on software and algorithms and its concern with creating spatial databases, is seen by these authors as an intellectual activity that permits a dialogue between the idiographic and nomothetic world views. Perhaps this is best demonstrated in the various spatial interpolation algorithms, some of which produce global models (trend surface analysis, for example) while others emphasize local differences such as geographically weighted regression and discriminant analysis (Nicholas et al. 2016). Miller's (2007) call for a people-based approach to GIS also emphasizes individual differences.

A recent trend in GIS has been the recognition of the importance of geo-design. This is now the focus of a new series of conferences being held annually in Redlands and in Europe and China. It has led to new undergraduate and graduate degree programs and has been championed by Esri cofounder, Jack Dangermond, reflecting his graduate education in landscape architecture. Dangermond (2014) has defined geo-design as taking geographic information and linking "it to the design, decision-making, and planning process using collaboration … by building the power of GIS into the process, allowing alternative plans to be visualized, compared, and evaluated." He credits his former Harvard University professor Carl Steinitz as introducing him to "this methodology" and so the history of GIS returns to its roots.

The Future History of GIS

In 2007, the NSF began supporting research into "transformative science" and in 2015 the National Academies Press pre-published *Fostering Transformative Research in the Geographical Sciences* (National Academies of Sciences, Engineering, and Medicine, 2015). This publication recognized GIS as one of the five areas of geographical research that could be considered "transformative" over the previous five decades. Indeed, there is little doubt that over the past fifty years GIS has been a transformative science for both the academic discipline of geography and the world we inhabit. The impact of GIS on the discipline of geography has been compared often to the impact of the telescope on astronomy but, as with the telescope, people choose what they want to see through the GIS lens. The NSF is interested in how transformative science has changed the world. It would behoove the discipline of geography to do as Sheppard *et al*. (1999) suggested and study how GIS has transformed the world and recommend how it *should* transform the world. Perhaps that will be the Future History of GIS.

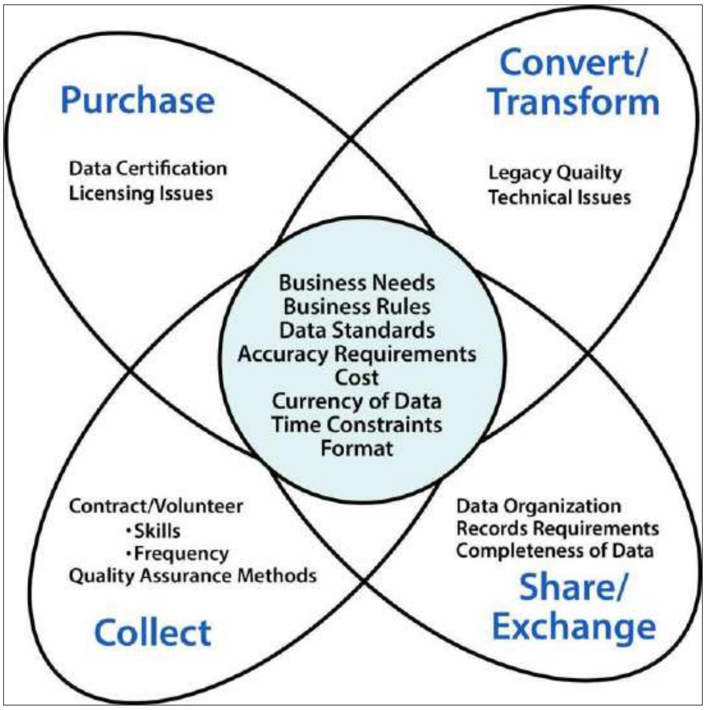
Data Sources; Data Acquisition Methods of GIS

There are four methods of acquiring data: collecting new data; converting/transforming legacy data; sharing/exchanging data; and purchasing data. This includes automated collection (e.g., of sensor-derived data), the manual recording of empirical observations, and obtaining existing data from other sources.

Common Data Acquisition Considerations are:

1. **Business Needs:** The first thing to always consider is the business need - why are these data required? What will be done with them?
2. **Business Rules:** A business rule identifies the constraints under which the business operates. For instance, where applicable, all geospatial data must have Federal Geographic Data Committee (FGDC) compliant metadata. These rules will affect your data acquisition decisions.
3. **Data Standards:** Any Government, USGS, or industry standards that apply will need consideration.
4. **Accuracy Requirements:** Among the most familiar accuracy requirements is the locational accuracy for spatial data; but there are other accuracy requirements that you may need to consider as well.
5. **Cost:** Cost is always a consideration. Sometimes it's cheaper to buy than to collect.

6. **Currency of Data:** For many types of work, the data need to be fairly current. For others, data may need to cover a specified time period. For others, data need to be in a specific season. If you are trying to determine vegetation coverage, for example, you may want photographs from the summer, when vegetation is at the highest. If you are trying to look for land forms, you may want winter photos.
7. **Time Constraints:** You should determine how soon you need the data.
8. **Format:** Do you need the data as spatial data, photos, flat files, Excel files, XML files? This may not apply, but you need to determine that for each project.



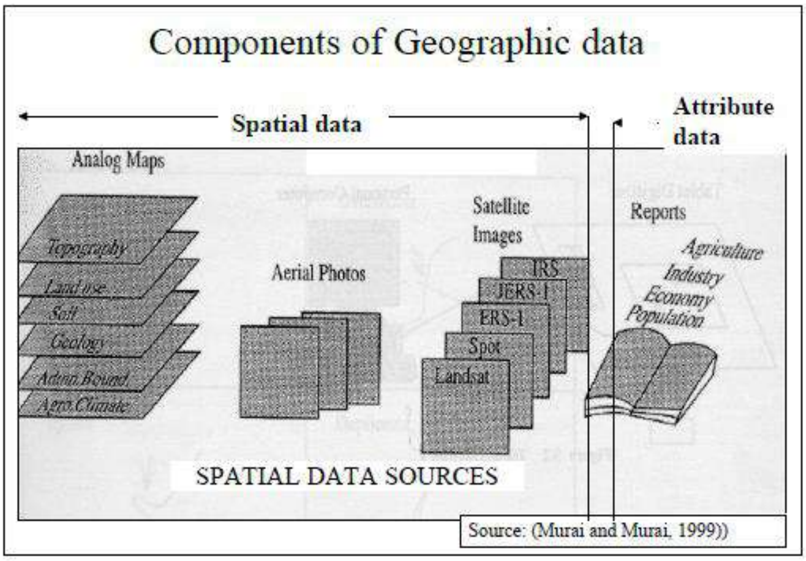
Like for any other Information System, creating a GIS involves 4 stages:

i. Data input
ii. Data Storage
iii. Data Analysis and modelling, and
iv. Data Output and presentation

The distinction from other Information Systems is that for a GIS the data inputs are of two types:

(i) Spatial data (latitude/longitude for georeferencing, the features on a map, e.g. soil units, administrative districts), and

(ii) Attribute data (descriptive data about the features, e.g. soil properties, population of districts, etc.)



Spatial data sources for creating a GIS are analogue maps (soil map, land use map, administrative districts, map, agro-ecological zone map, etc.) or aerial photographs and satellite imageries. Data input is the process of encoding analogue data in the form of maps, imageries or photographs into computer readable digitized form and writing data into the GIS database.

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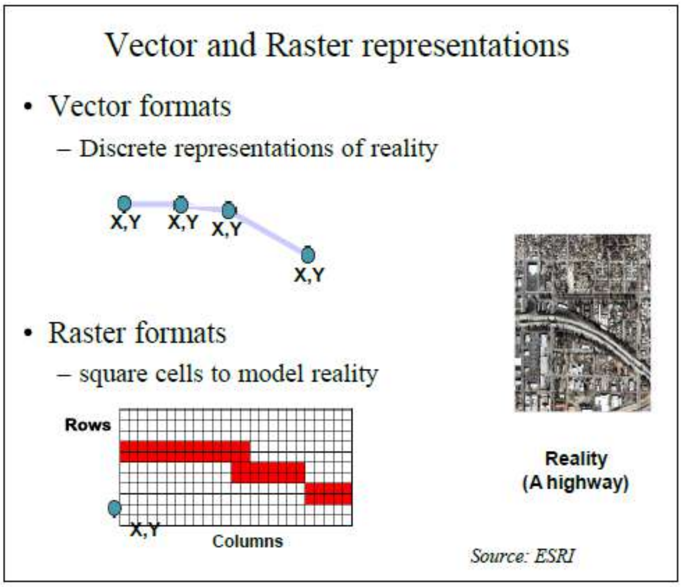
2. Data Structure: Vector and Raster Data Structures, Data Storage.

Spatial Data capture (representing locations in a database) can be in two basic formats:

(1) Vector format

(2) Raster format

In the Vector format reality is represented as points lines and areas and in the raster format reality is represented as grid of cells/pixels. The Vector format is based on discrete objects view of reality (analogue maps) and the raster format is based on continuous fields view of reality (photographs, imageries, etc. In principle, any real world situation can be represented in digital form in both raster and vector formats. The choice is up to the user. Each format has its advantages and disadvantages.



1. <u>Vector Data Capture</u>

This is generally used for capturing data fro analogue maps. It is based on th observation that any map consists of 3 basic kinds of features –

(i) Point features,
(ii) line features, and
(iii) Polygon or area features.

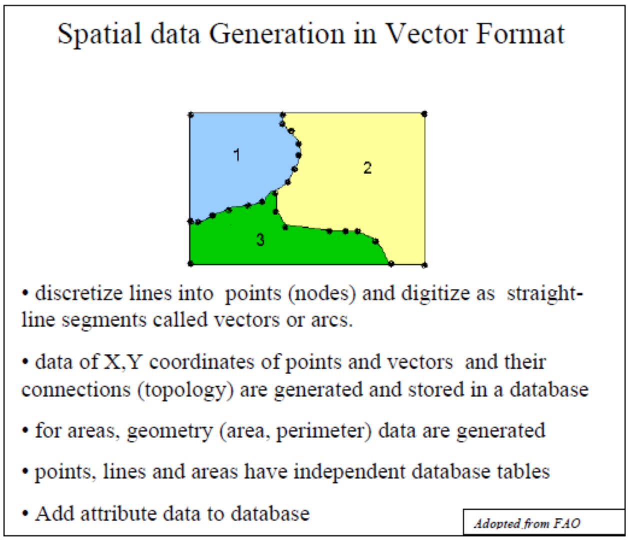
- **Points** do not have length, width or area. They are described completely by their coordinates and are used to represent discrete locational information on the map to identify locations of features such as, cities, towns, well locations, rain gauge stations, soil sampling points, etc.
- **A line** consists of a set of ordered points. It has length, but no width or area. Therefore it is used to represent features such as roads, streams or canals which have too narrow a width to be displayed on the map at its specified scale.
- **A polygon** or area is formed when a set of ordered lines form closed figure whose boundary is represented by the lines. Polygons are used to represent area features such as land parcels, lakes, districts, agro-ecological zones, etc. A polygon usually encloses an area that may be considered homogeneous with respect to some attribute. For example, in a soil map, each polygon will represent an area with a homogeneous soil type.

A vector based system displays graphical data as points, lines or curves, or areas with attributes. Cartesian coordinates (x, y) or geographical coordinates (latitude, longitude) define points in a vector system.

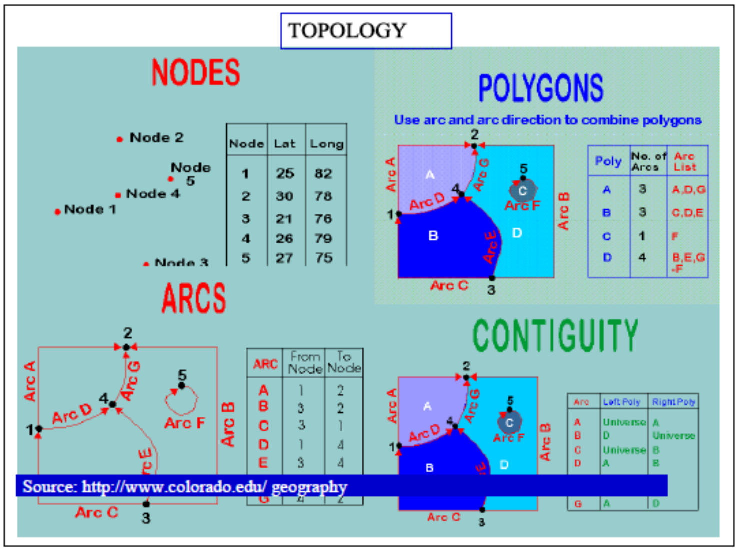
Data is captured from a map in the form of known x-y coordinates or latitude- longitude by first discretizing the features on the map into a series of nodes (dots) and digitizing the points one by one directly after placing the map on a digitizer. The digitizer can be considered to be an electronic graph paper with a very fine grid. The map is placed on the digitizer and the lines and areas are discretized into a series of points. The digitizer's cursor is used to systematically trace over the points.

- The points on the map are captured directly as point coordinates.
- Line features are captured as a series of ordered points.
- Area features are also captured as an ordered list of points.

By making the beginning and end points/nodes of the digitization the same for the area, the shape or area is closed and defined. The process of digitizing from a digitizer is both time consuming and painstaking. Alternately, the map can be scanned and the scanned image digitized on-screen with appropriate software tools. The latter process is relatively simpler, more accurate and is Digitization is usually done feature by feature. For example, all point features are on a map (say cities, towns, etc.) are digitized in one layer. Similarly all line features (e.g. Roads, rivers, drainage network, canal network, etc.) are digitized as a separate layer. So are the polygon features (soils, districts, agro-ecological zones, etc.) For the points feature, the digitization process builds up a database of the points' identification number (ID) and their coordinates. For the lines it builds up a database of their ID, the starting and end nodes for the line and its length. In addition the GIS also create a database of the topology, that is, the spatial relationships between the lines. For the polygons also it develops the database of their ID, lines or arcs which comprise it, its topology and its area and perimeter.



The identification number (ID) is the key field in each data base (points, lines, areas databases) as it can be used to relate the spatial data with the attribute data. The data resolution depends on the discretization of the digitized points on the initial map. Vector systems are capable of very high resolution (<.001 in) and graphical output is similar to hand drawn maps.



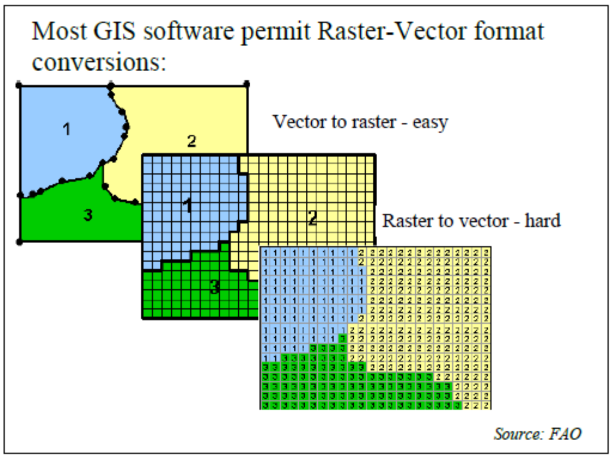
Map projections and Scale

Note that all standard maps which are to be digitized are drawn to specific *projection* and *scale*. But, the digitizer which facilitated the computerized map has its own scale and units and the digitized maps are in these units and scale. Translating information from the digitized map into the real world information of locations, lengths and areas requires information about the mathematical equations used for the projection as well as the scale in which the original analogue map is prepared. In case several map layers are to be digitized (topography, soils, districts, etc), it is necessary to ensure that they are all assembled in the same projection and scale before any spatial analysis is done using them. Most standard GIS have the facility to convert from one map projection to the other and to transform scales from the digitizer scale to map scale to ensure that all map layers have the same locational reference.

2. <u>Raster Data Capture</u>

A raster based GIS locates and stores map data by using a matrix of grid cells or pixels. Each cell or pixel is represented either at its corner or centroid by a unique reference coordinate (cell address). Each cell also has discrete attribute data assigned to it.

The raster data resolution is dependent on the pixel or grid cell size. Data can be conveniently captured from remote sensing imageries, aerial photographs, and other such imageries of the earth's surface in a raster data format. In this format, the various features are identified by superposing the imageries over a fine rectangular grid of the earth's surface which they represent. Raster data capture does not build topography, which is deriving spatial relationships between the identified features. But it facilitates simple scalar operations on the spatial data which a vector format does not permit. Raster data requires to be converted to vector format before topology can be built and spatial operations can be carried out. The raster format also requires more storage space on the computer than the vector format. Most standard GIS software has the facility to transform maps from raster formats and vice versa.

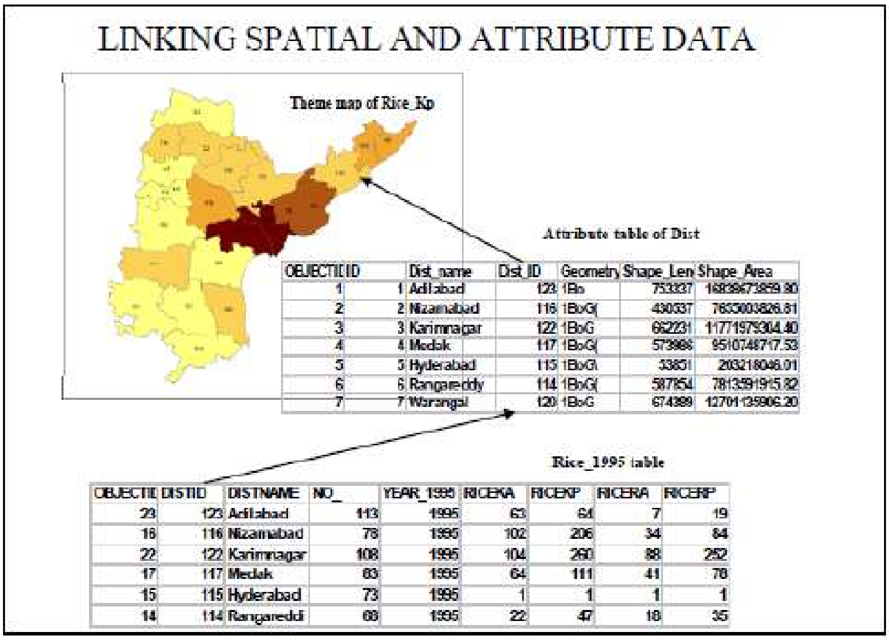


Attribute Data

Attribute data are descriptive data of point, line and area features. For points, this may be the name of the location, its elevation, etc. For lines attribute data could be the name of a road, or canal and other descriptions associated with them. For polygons, the attribute data may relate to name of a district and its population, area, area under specific crops in the district, etc.

Attribute data about points/lines/areas features can be entered into different database files. The files can be linked to the default spatial database generated after digitizing by creating an identification key in each data file which is also common to the spatial database generated by the GIS after digitization.

Maps representing several layers of spatial and thematic or attribute information (soil map, rainfall map, agro-eco zone map, district map, States map, etc.) can be digitized in this fashion independently.



Data Storage and Retrieval

A GIS does not store maps. It stores data organized into a database. The locational data of different features (coordinates, topology) are generated during the digitization process. The attribute data of locations are created separately. The GIS must provide the link between the locational and attribute data. The relational database model is most suitable to ensure such linkage and the database query language can be used to retrieve data. Relational database concepts are therefore central to organizing and managing data in GIS.

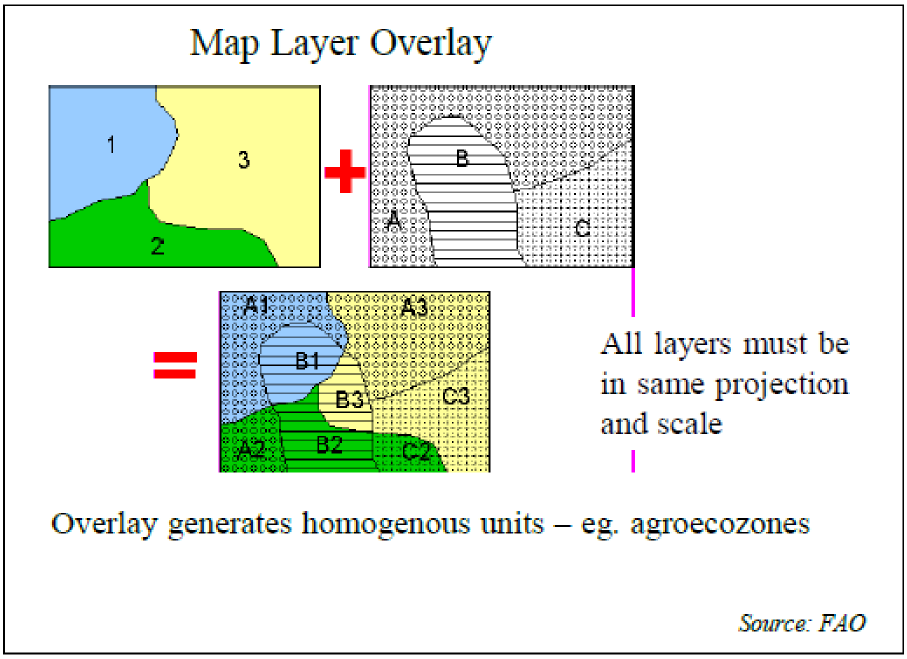
The specific format of data storage varies with the GIS software. For example, Geomedia GIS stores the spatial and attribute data in a Microsoft Access databases. The feature attribute database created during digitization is created in a specific folder called the Warehouse. The map connections are stored in file created in the Geoworksapces folder Retrieval of data is possible by employing the appropriate query language for the database model. Other attribute databases can be stores as MS Access files anywhere in the system and connections to them can be established if the share a common ID with the feature attribute table.

Geographic Analysis

What distinguishes GIS from other databases or information systems are its spatial analysis functions. These functions use spatial and non-spatial data to answer questions about the real world. The answers could relate to a presentation of the current data (first level use), some patterns in the current data (second level use) and predictions of what the data could be at a different place or time (third level use). Geographic analysis is carried out using the layers of map information created in vector or raster data formats and associated attribute data to find solutions to specific problems. In each case the problem needs to be defined clearly before the relevant map layers and analysis procedures can be identified.

For instance, if the problem is to find optimal locations for siting of wells for conjunctive use in an irrigation project area, information about the geographical features influencing the groundwater recharge will be required. These will include maps of existing well locations, rainfall; land use, soils and command area of the project, all of which influence recharge. Regions with recharge above a selected threshold value may be considered suitable for additional wells. Further, if the area happens to be near the coast, a buffer zone may be required within which no wells can be sited to prevent sea water intrusion. Similarly buffer zones may be required on either side of canals to prevent drawl of canal water by the wells. What could happen to the ground water levels and quality in the area if the present use is persisted with or changed could be the subject of another study where the GIS can help to provide more realistic answers.

Most standard GIS software come with basic analytical tools that permit overlays of thematic maps, creation of buffers, etc., in addition to calculations of lengths and areas. Overlay operations permit overlaying one polygon over the other to generate a new map of their intersections which are new polygon combinations with desired homogenous properties with respect to specified polygon attributes.



3. Modern Trends in GIS: 3D GIS and Web GIS, Real time GIS, Mobile GIS and application of GIS

People working in many different fields use GIS technology. GIS technology can be used for scientific investigations, resource management, and development planning. GIS technology is used predominantly for storage, management and analysis of data referenced spatially to the Earth. It is essentially a geographic method of spatial data analysis, designed to connect data with comprehensive information and enable enterprises to study maps and unveil hidden geographical patterns more easily.

3D GIS

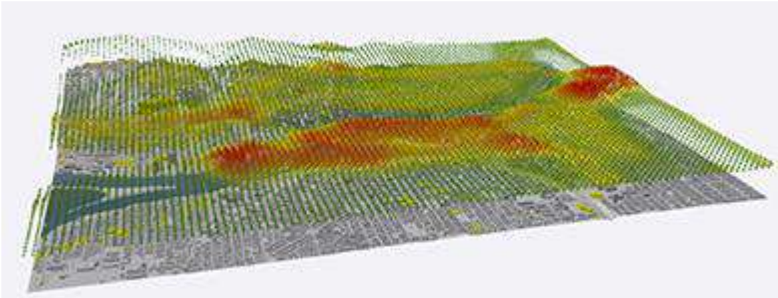
3D GIS is a three-dimensional Geographic Information System which spatially encapsulates the 3rd dimension into spatial data. Thus, instead of just x and y there is now a z component to spatial objects. These 3 dimensions can have their own attributes – thereby making it possible to 3d visualisation or volumetric analysis.

3D GIS is most commonly applied in urban landscapes that creates a sense of realism of urban objects. Cities are not yet making wide use of 3D GIS and bring the tools of Spatial Analytics to XYZ data of urban objects – detailed floor plans and realistic three-dimensional rendering found in architectural practice.

Some critical applications of 3D GIS are:

1. 3D GIS, coupled with road information models, could have a major impact on the way transportation businesses carry out their activities.
2. 3D GIS — again, along with building information models — could help with facility and asset management, public safety concerns, and interoperability.
3. 3D GIS technology could help with planning for noise issues that may affect a building from variables such as nearby roads and industrial facilities.

4. 3D GIS technology goes beyond application within urban environments and shows that users can create models of the interiors of buildings, or they can up the scale and create region-wide or even global models.



3D GIS Technology Based Spatial Data Analysis

3D GIS Software Based Urban Planning

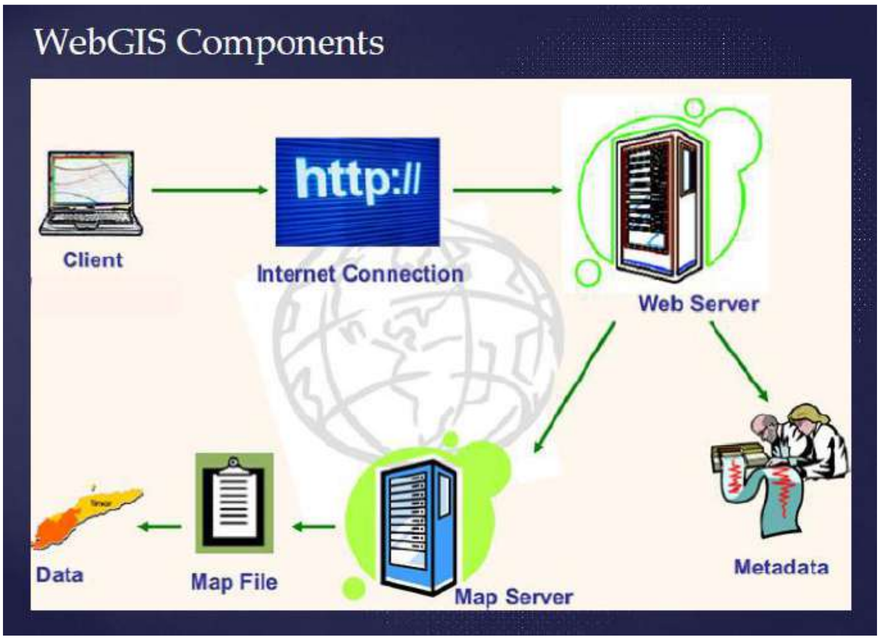
3D GIS Software Based Project

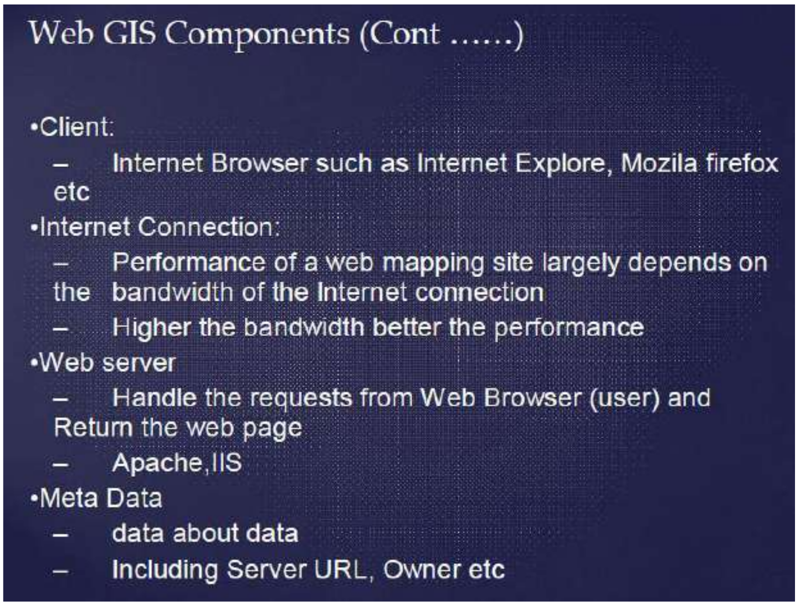
Web GIS

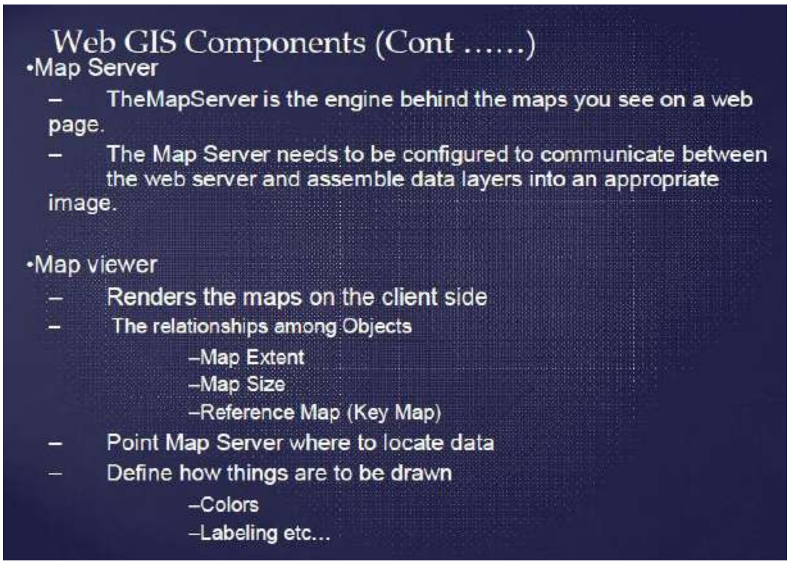
In its simplest form, web GIS can be defined as any GIS that use web technology to communicate between a server and a client. The client relies on HTTP specifications to send requests to the server. The server performs the requested GIS operations and sends responses to the client via HTTP.

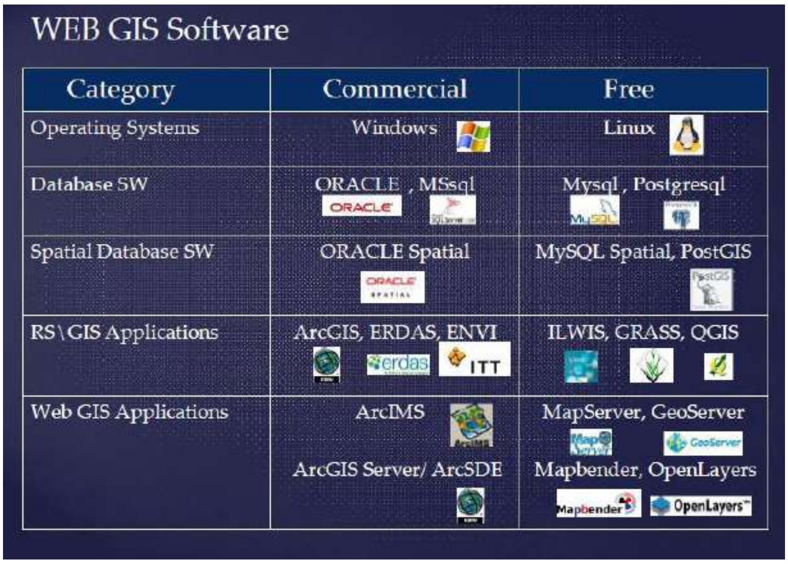
Web GIS provides many more opportunities to provide broader access to your authoritative GIS data, enabling you to move your system of record to a system of engagement that facilitates everything from self-service mapping to making better decisions.

GIS application is an engaging and powerful tool for designing and planning government projects like flood management, forest mapping, and natural disaster. Web GIS technology is used in geosciences research collaboration.





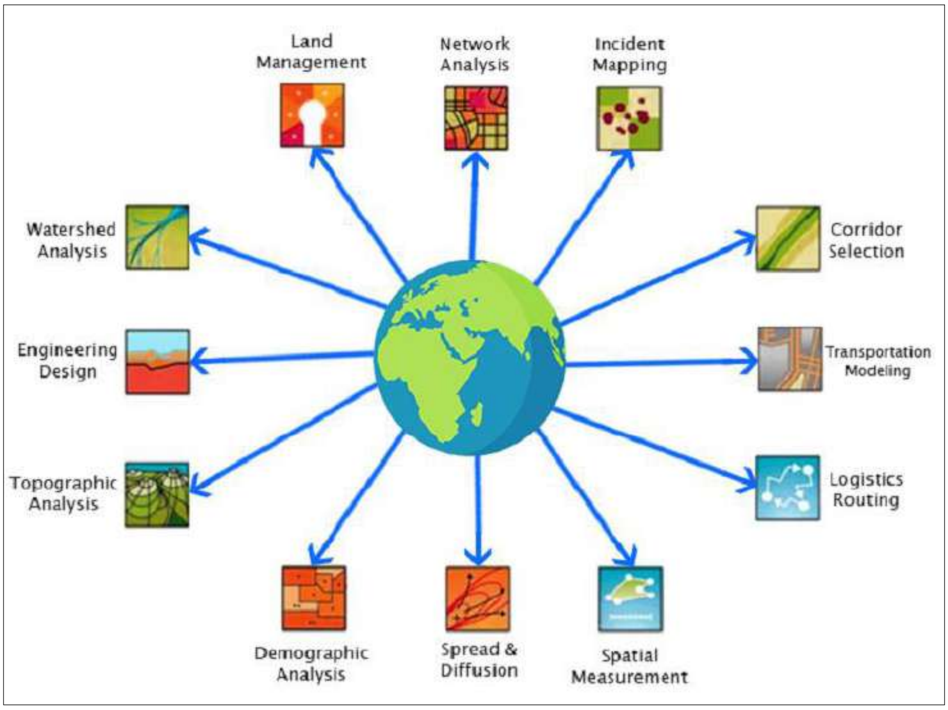


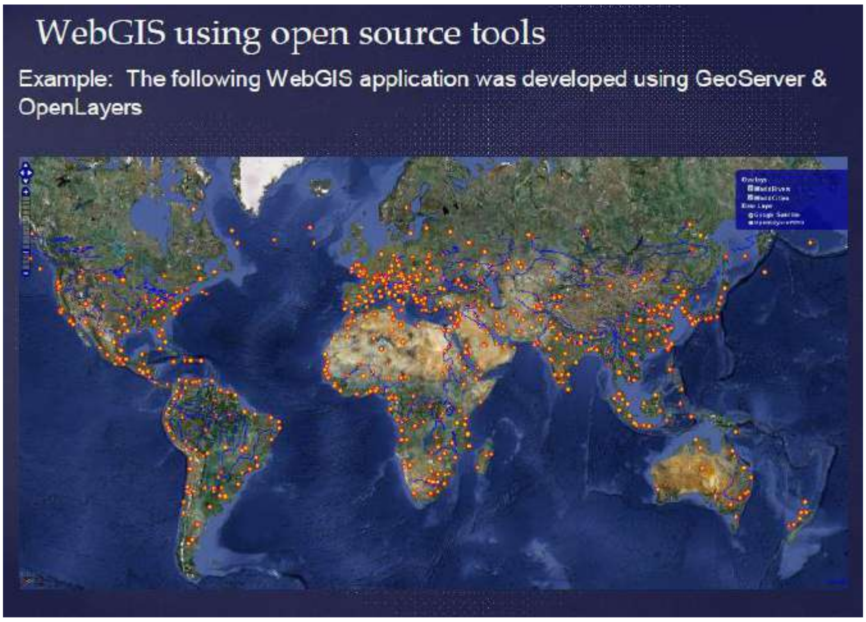


WEB GIS Software

Category	Commercial	Free
Operating Systems	Windows	Linux
Database SW	ORACLE , MSsql	Mysql , Postgresql
Spatial Database SW	ORACLE Spatial	MySQL Spatial, PostGIS
RS\GIS Applications	ArcGIS, ERDAS, ENVI	ILWIS, GRASS, QGIS
Web GIS Applications	ArcIMS ArcGIS Server/ ArcSDE	MapServer, GeoServer Mapbender, OpenLayers

Tools and Technologies for Wed GIS





Real-time GIS

Real-Time GIS gives you the ability to simultaneously tap into, analyze, and display streaming data from many sensors, devices, and social media feeds. You can define filters and location-based analytics that automatically refine and focus real-time data on events that matter most to you.

Real-Time GIS continuously updates maps and databases and sends alerts to key personnel the moment a critical threshold or event happens for faster decisions and response.

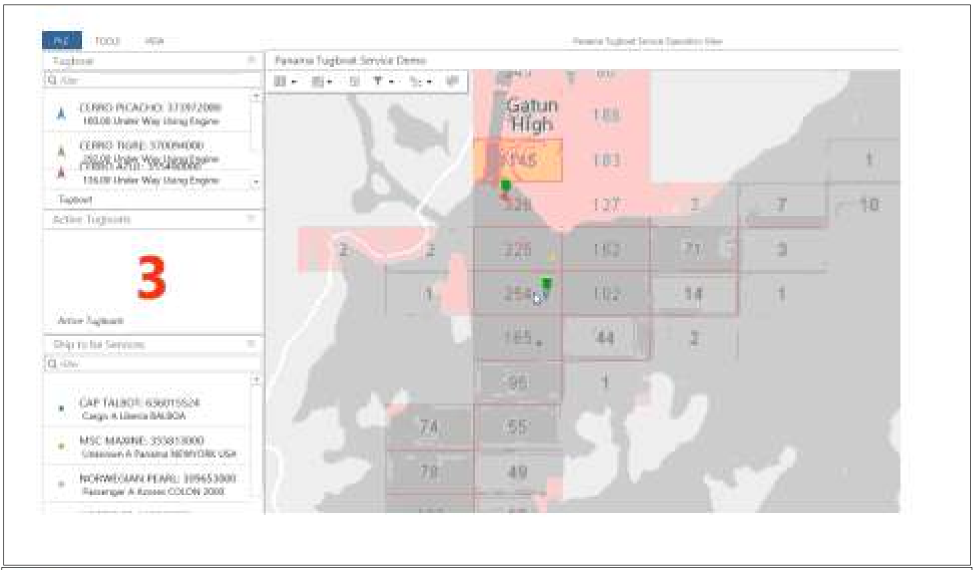
Application of Real time GIS:

i. Improve situational awareness during events:

When disasters strike every second counts, real-time situational awareness saves lives and helps protect people, property and critical resources. That's why police, fire and emergency management organisations at all levels of government utilise Esri's Real-Time GIS capabilities in their operations and dispatching centres.

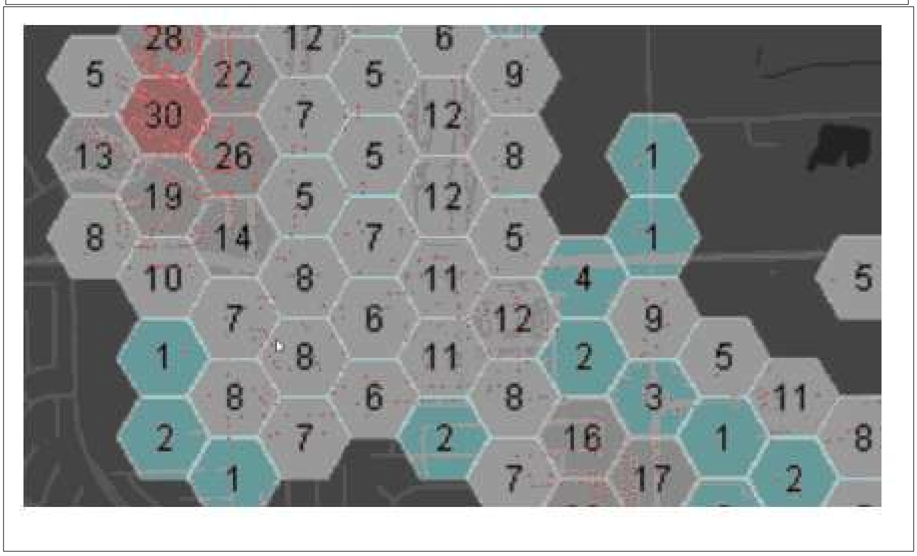
ii. Track tens of thousands of assets in motion:

Getting the location of a moving object is one thing but tracking entire fleets of vehicles, vessels or aircraft in real time allows moment-by-moment decision-making for improved operational awareness. Ports, airports, transportation companies and government agencies all use Esri's Real-Time GIS technology to monitor moving assets.



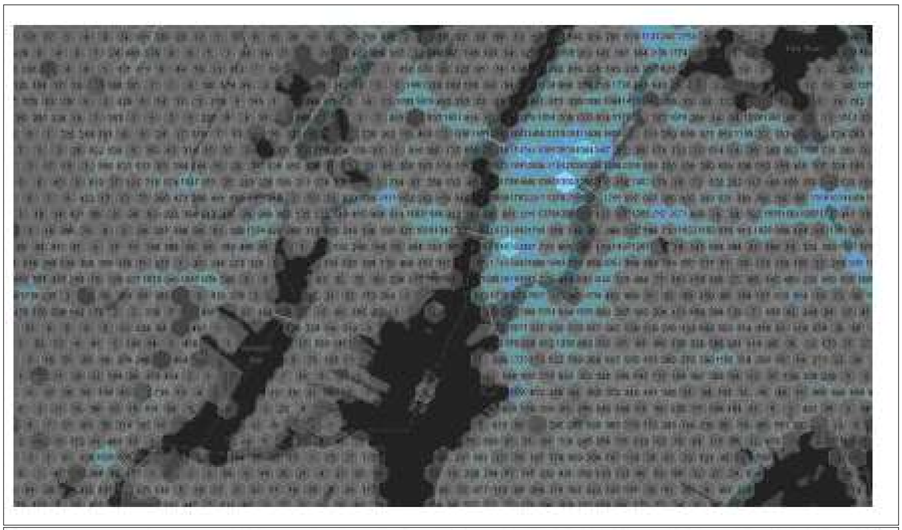
iii. Monitor an unlimited number of stationary sensors:

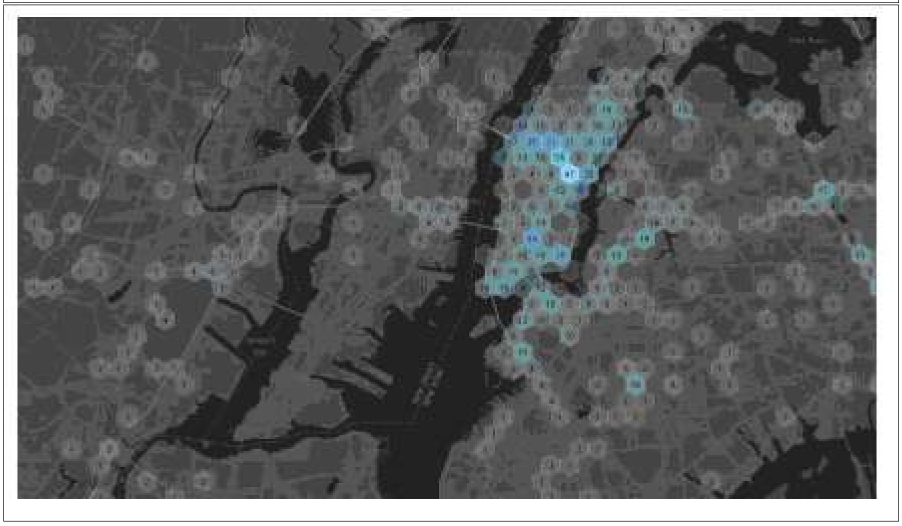
Delivering products at optimal freshness or guaranteeing the most reliable service can be a differentiator for businesses. Companies that store and transport perishable commodities or deliver safe energy to consumers rely on Esri's Real-Time GIS to monitor data feeds from distributed sensors for better customer service.



iv. Make sense of millions of social media feeds easily:

Monitoring social media is just good business. Analysing locations and connections to social activities in real time? Well, that's a formula for beating the competition to the punch by seeing who, what and where people are talking about your products and services. Companies, like Waze, give their partners access to Esri's real-time analytics.





v. Open your gateway to the Internet of Things (IoT):

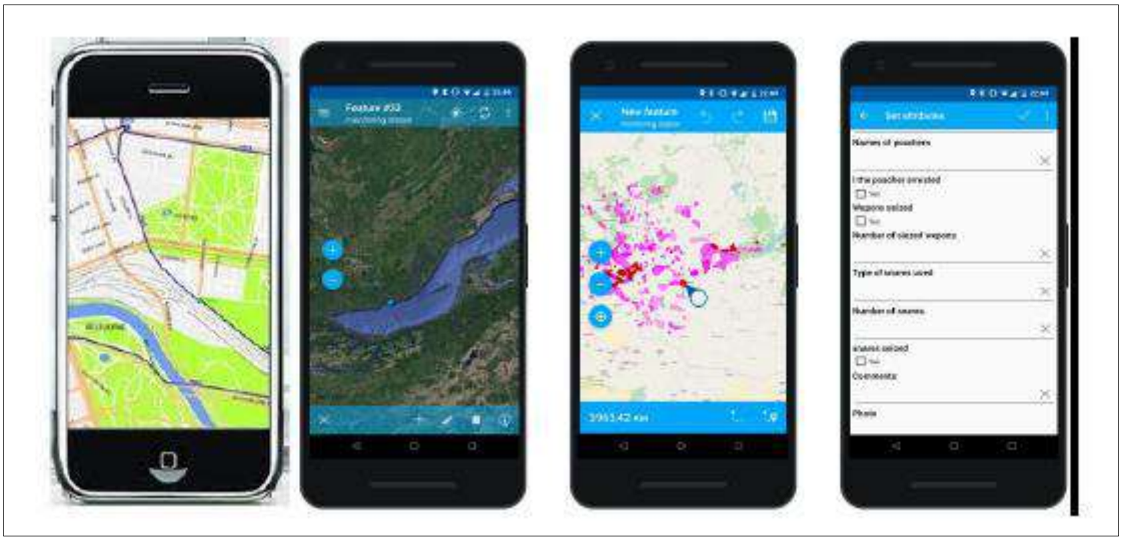
Making sense of Big Data produced by the Internet of Things (IoT) can be challenging for organisations. But what if that huge volume, relentless velocity and staggering variability of data flowing into your systems could be filtered, analysed in real time and then stored for future Big Data analysis? Esri's Real-Time scales big when you need to.

<u>Mobile GIS</u>

Mobile GIS is taking Geographic Information Systems (GIS) out of the office and into the field. A mobile GIS allows folks out in the field to capture, store, update, manipulate, analyze, and display geospatial data and information.

Mobile GIS integrates one or more of the following technologies:

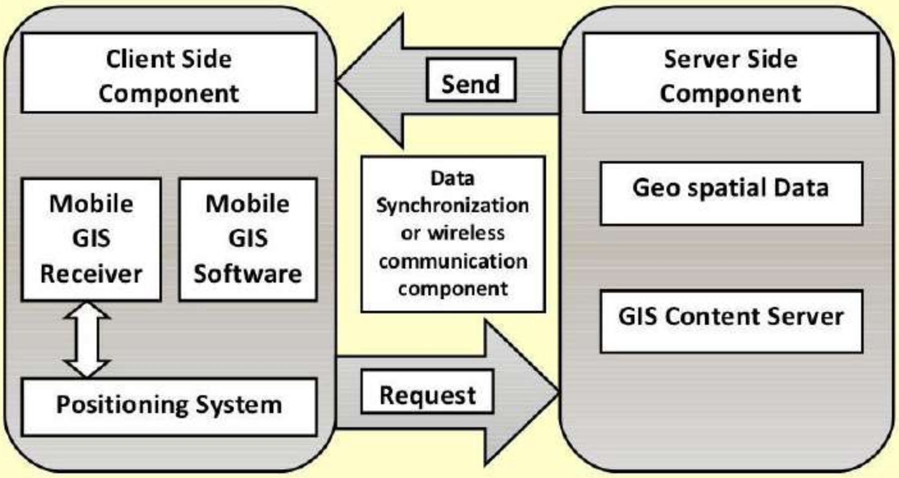
- Mobile devices (such as a PDA, tablet, or laptop computer, and in some countries mobile phones)
- Geographic Information System (GIS) software
- The Global Positioning System (GPS)
- Wireless communications for Internet-based GIS access



Benefits of Mobile GIS

- Improves efficiency and accuracy of field operations
- Improves completeness and accuracy of GIS data
- Improves quality of geographic analysis and decisions
- Easy access of GIS Data
- Replace paper-based workflows

Mobile GIS Architecture



Application of GIS

GIS have been developed independently for a wide variety of purposes and the future of GIS will depend to a large extent on the degree to which these various needs can be integrated and met by one type of product. The growth of GIS in recent years has been led by developments in a number of areas and there have been distinct differences in the forms that development has taken and in the meaning attached to GIS.

i. Forestry:

Forestry has been responsible for a significant growth in the use of GIS in the past five years. Ideally, GIS technology would be used for the updating and maintenance of a current forest inventory and for modelling and planning forest management activities such as cutting and silviculture, road construction, and watershed conservation. In other words, the true advantages of GIS accrue oily when emphasis is placed on the manipulation, analysis, and modeling of spatial data in an information system. In practice GIS have often been used for little more than automation of the cartography of forest inventories, because of limitations in the functionality of software or resistance to GIS approaches on the part of forest managers.

ii. Property and Land Data

The acronyms LIS and LRIS (Land Information System and Land Related Information System) are often used in this sector, reflecting the relative importance of survey data and the emphasis on retrieval rather than on analysis.

iii. Utilities for Various Aspects

Telephone, electric and gas utilities operate in both private and public sectors in North America, and it is useful to distinguish between applications at large and small scales. Large-scale applications include monitoring the layouts of pipelines and cables and locations of poles and transformers, and as in the case of land parcel systems, combining needs for cartography and spatial retrieval. Small scale applications include planning of facilities and transmission lines to minimize economic, social and environmental costs, and demand forecasting. Some utilities have built large databases for such purposes, and also make use of digital topographic data. In the long term as GIS software stabilizes and develops, it is likely that the advantages of better capabilities for easy exchange of data formats will make such systems an attractive option for these applications. Developments in this arena have not yet reached the beginning of the growth curve, but a significant proportion of this market will probably move away from existing automated cartography systems in GIS in the next 10 years, and several vendors appear to have anticipated this trend (Tomlinson, 1987).

iv. Transport, Facility, and Distribution Planning

In addition to both public and private sector transport agencies, much of the work in this sector is carried out by contractors, such as market research firms and university staff. Although market research frequently calls for sophisticated forms of spatial analysis, such as site selection and modelling, vendors of GIS have not made any significant penetration of the market. Instead, most companies rely on a combination of standard statistical packages. There is every indication that this sector will be a major growth area for applications of GIS in the next 10 years Software for these forms of analysis is at present rudimentary but developing rapidly. There is a pressing need for the ability to handle multiple formats of geographical data, scales and types of features, and hierarchical aggregation of features in processing socio-economic data, and in combination with advanced forms of spatial analysis and map display. The potential market includes retailers, school systems, transport and distribution companies and other agencies that need to solve problems of routing and rescheduling on networks, and the direct mail industry (Tomlinson, 1987).

v. Civil Engineering

A major use of digital topographic data is in hirge-scale civil engineering design, such as cut and fills operations for highway construction. The first digital developments in this field derived from the photogrammetric operations, which are the primary source of data. There are multiple systems installed in civil engineering firms and government agencies. Rapid growth is occurring in both Canada and the U. S. in the significance of digital topographic data for defense, because of its role in a number of new weapons systems, including Cruise, and because of the general increase of defense budgets in the industrialized world. This work has drawn attention to the importance of data quality, and the need for sophisticated capabilities for editing topographic data as well as for acquiring them. These needs are presently being met by enhancements to automatic cartography systems (e.g., Intergraph) and it is not yet clear whether they will lead to any significant convergence with GIS (Tomlinson, 1987).

vi. Agriculture and Environment

The use of GIS approaches can be traced to the; need to measure the area of land resources, to reclassify and dissolve prior to display, and to overlay data sets and to compare them spatially. These remain among the most basic justifications for GIS technology. GIS technology is of considerable interest in land management, particularly of national parks and other federal, state and provincial lands, and has been adopted in both the U. S.and Canada. In agriculture, the main issue arises from the critical importance in farming of changes over time and season. Although much research has been conducted on the interpretation of agricultural data from remotely-sensed imagery, there remain the conceptual problems of classification and interpretation. Marine environmental monitoring and climatology are good examples (Tomlinson, 1987).

vii. Military history of use:

Problems of maintaining military lands in support of the training mission, while dealing with environmental compliance and land stewardship issues, have become increasingly complex for military and civilian personnel. Many of the environmental laws and regulations that have been passed in the past two decades affect our military training lands. To achieve compliance, protect valuable natural and cultural resources, prevent incompatible land uses and support the training mission, military installations need a program that integrates training mission requirements with effective land management practices (Severinghaus & Goran, 1991). This program is called Integrated Training Area Management (ITAM). One of the primary tools to display and analyze data is its GIS system. As discussed earlier, the military developed GRASS for this purpose. Currently the military is converting its systems over from a GRASS UNIX system in most cases to a DOS ARC/INFO system. These systems are more users friendly and compatible with systems and are utilized by various federal and state agencies. GIS systems are used extensively by the military to assist decision makers in numerous natural resources and environmental compliance issues. GIS has become so ingrained into the NEPA process it would be deficit to analysis and display data without this tool.

GIS and automated geographic information systems are rapidly expanding. The following areas are a summation:

- Engineering mapping (all disciplines)
- Automated photogrammetry
- Land planning
- Tax mapping
- Highway mapping
- Utility mapping and management
- Geodetic mapping
- Event mapping (accidents, crime, fire, facility failures, etc.)
- Census mapping

- Statistical mapping
- Environmental impact studies and assessments
- Natural resource mapping and management
- Transportation mapping and management
- Urban planning and management

4. Basics of GPS Surveying: Conceptual Framework, Space Segment, Ground Segment, Control Segment, Satellite Triangulation, Pseudo Random Code. DGPS and GNSS

GPS Surveying

To understand the GPS surveying process, you need to understand what GPS is. In short, GPS, or the global positioning system, is a satellite-based navigation system. GPS was first developed for military use starting in the 1970s and became fully operational in 1993. Since then, it has expanded its use to consumer and commercial applications.

GPS uses a network of satellites, which communicate with receivers on the ground. When a receiver requests data to calculate its location, four or more GPS satellites will communicate with the receiver, sending the position of the satellite, the time the data was transmitted and the distance between the satellite and the receiver. The information collected from these satellites then calculates the latitude, longitude and height of the receiver. If the receiver is moving, continuous data collection can be used to calculate the changing position of the receiver over time, which can be used to calculate speed. No matter the weather conditions or time, GPS can triangulate the signal and provide a location.

While most people are familiar with GPS and have used it to some degree on their smartphones or car navigation systems, GPS is a powerful tool for commercial applications. It's particularly useful for the surveying industry. Surveying was one of the first commercial adaptations for GPS for its ability to obtain latitudes and longitudes without the need for measuring distances and angles between points. In combination with other surveying equipment, like the Total Station, GPS technology provides valuable information for surveyors to help develop plans and models for client projects.

GPS Surveying Process

GPS surveying uses similar technology to nearly any other GPS application — however, how surveyors use GPS differs significantly. The primary differences are in two areas — technology and usage.

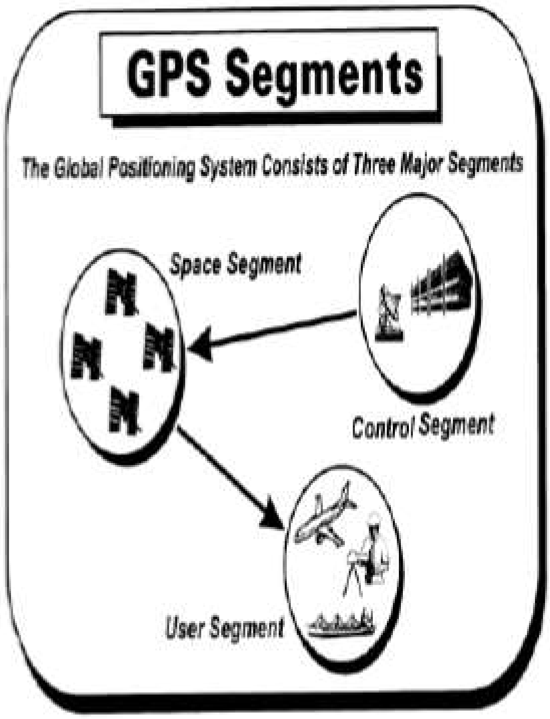
Technology: Surveyors use more sophisticated technology than typical GPS applications to increase the accuracy of the data they collect. The receivers used for surveying are significantly more complex and expensive than those you would find in a typical car navigation system, with high-quality antennas and more sophisticated calculation technology.

Data Usage: The data surveyors collect from the GPS technology is used differently than in a typical navigation system — instead of using location data for navigation, the data is used for measuring between two points. These measurements are collected then stored, manipulated and displayed in a geographic information system, or GIS, for use in a survey model.

The Global Positioning System (GPS) employs trilateration to calculate the coordinates of positions at or near the Earth's surface. Trilateration refers to the trigonometric law by which the interior angles of a triangle can be determined if the lengths of all three triangle sides are known. GPS extends this principle to three dimensions.

GPS Segments/ Components of GPS/ Principles of GPS

The Global Positioning System consists of three major segments: the Space Segment, the Control Segment, and the User Segment. The space and control segments are operated by the United States Military and administered by the U.S. Space Command of the U.S. Air Force. Basically, the control segment maintains the integrity of both the satellites and the data that they transmit. The space segment is composed of the constellation of satellites as a whole that are currently in orbit, including operational, backup and inoperable units. The user segment is simply all of the end users who have purchased any one of a variety of commercially available receivers. While the user segment obviously includes military users, this book will concentrate on the civilian uses only.



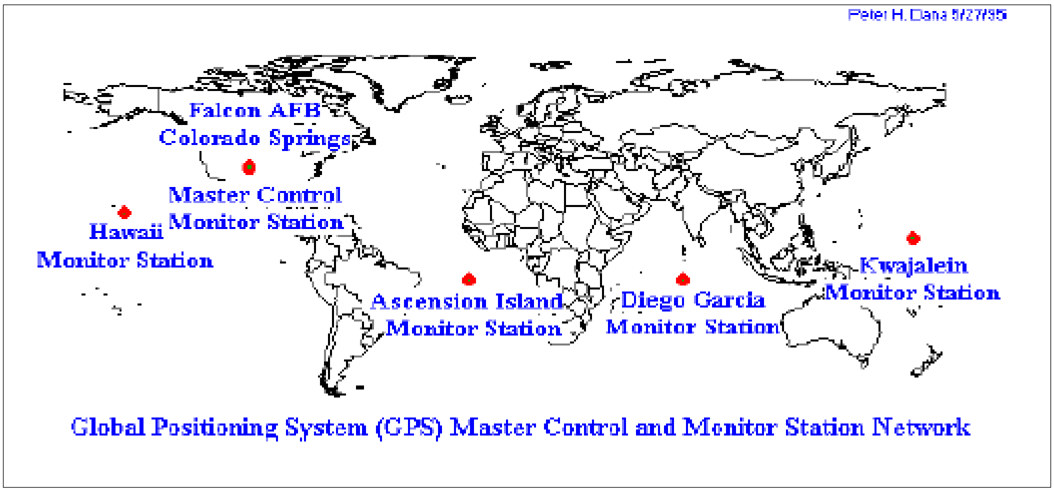
The Control Segment

The control segment of the Global Positioning System consists of one Master Control Station (MCS) located at Falcon Air Force Base in Colorado Springs, Colorado, and four unmanned monitor stations located strategically around the world e.g. Hawaii Monitor Station, Ascension Monitor Station, Diego Garcia Monitor Station, and Kwajalein Monitor Station.

- In addition, the Air Force maintains three primary ground antennas, located more or less equidistant around the equator.
- Observation and controlling the satellite system regularly.
- To check the satellite functions and it's accurate position in the space.
- To determine the time of GPS.
- Update periodically navigation messages for each satellite.
- In the event of some catastrophic failure, there are also two backup Master Control Stations, one located in Sunnyvale, California, and the other in Rockville, Maryland.
- The unmanned monitor stations passively track all GPS satellites visible to them at any given moment, collecting signal (ranging) data from each. This information is then passed on to the Master Control Station at Colorado Springs via the secure DSCS (Defence Satellite Communication System) where the satellite position ("ephemeris") and clock-timing data (more about these later) are estimated and predicted.

- The Master Control Station then periodically sends the corrected position and clock-timing data to the appropriate ground antennas which then upload those data to each of the satellites.
- Finally, the satellites use that corrected information in their data transmissions down to the end user.
- This sequence of events occurs every few hours for each of the satellites to help insure that any possibility of error creeping into the satellite positions or their clocks is minimized.
- The CS is responsible for maintaining the satellites and their proper functioning. This includes maintaining the satellites in their proper orbital positions (called station keeping) and monitoring satellite subsystem health and status.
- The CS also monitors the satellite solar arrays, battery power levels, and propellant levels used for manoeuvres. Furthermore, the CS activates spare satellites (if available) to maintain system availability.
- The CS updates each satellite's clock, ephemeris, and almanac and other indicators in the navigation message at least once per day. Updates are more frequently scheduled when improved navigation accuracies are required. (Frequent clock and ephemeris updates result in reducing the space and control contributions to range measurement error.
- Depending on the satellite block, the navigation message data can be stored for a minimum of 14 days to a maximum of a 210-day duration in intervals of 4 hours or 6 hours for uploads as infrequent as once per two weeks and intervals of greater than 6 hours in the event that an upload cannot be provided for over 2 weeks.
- Furthermore, the CS resolves satellite anomalies, controls SA and AS, and collects pseudo range and carrier phase measurements at the remote monitor stations to determine satellite clock corrections, almanac, and ephemeris. To accomplish these functions, the CS is comprised of three different physical components: the master control station (MCS), monitor stations, and the ground antennas.
- Newly added control stations after 2005 are Washington DC England, Ecuador, Argentina, Bahrain and Australia.
- These Monitor stations measure signals from the SVs, which are incorporated into orbital models for each satellites.

Master stations collect the data about the satellites of this system continuously from the other tracking stations. MCS process the tracking data for computation of satellite ephemerides (or co-ordinate) & satellite clock parameters. The Master control station uploads ephemeris and clock data to the SVs. The SVs then send subsets of the orbital ephemeris data to GPS receivers over radio signals. The MCS also monitor the position of satellites at any instant of time, the functional capacity of the satellites & variation of the navigation data. The computation of satellite's Ephemeris & Clock errors are most important tasks of control stations, as both variables are important to get high accuracy.



The Space Segment

The space segment consists of the complete constellation of orbiting NAVSTAR GPS satellites. The current satellites are manufactured by Rockwell International and cost approximately $40 million each.

- To each satellite must be added the cost of the launch vehicle itself which may be as much as $100 million. To date, the complete system has cost approximately $10 billion. Each satellite weights approximately 900 kilograms and is about five meters wide with the solar panels fully extended. There were 11 Block I prototype satellites launched (10 successfully), followed by 24 Block II production units. Currently, only one of the Blocks I satellites is still operational, while four Block II backups remain in ground storage size of the constellation includes 21 operational satellites with three orbiting backups, for a total of 24. They are located in six orbits at approximately 20,200 kilometers altitude.
- Each of the six orbits is inclined 55 degrees up from the equator, and is spaced 60 degrees apart, with four satellites located in each orbit. The orbital period is 12 hours, meaning that each satellite completes two full orbits each 24-hour day.
- The space segment is the constellation of satellites from which users make ranging measurements. The SVs (i.e., satellites) transmit a PRN-coded signal from which the ranging measurements are made. This concept makes GPS a passive system for the user with signals only being transmitted and the user passively receiving the signals.

- The Space Segment of the system consists of the GPS satellites. These Space Vehicles (SVs) send radio signals from space. The Space Segments - consists of the group of minimum 24 Satellites & the signals -that are broadcast by them, which allow user to determine position velocity & time. The basic functions of satellites are - To receive & store data uploaded by Control Segment. Maintain accurate time by means of on board ATOMIC CLOCKS & Transmit information & signals to users on TWO L- band frequencies. Out of 52 constellations of GPS Satellites, the 11 were launched as an experimental satellite in Feb 1978 under so-called Block 1 Phase, Block 2 & Block 2 A were launched from 1989 onwards. Full operational capability was declared on 17 July in 1995.
- Currently 12 of these satellites are re-designed as the part of GPS Modernisation Programme.

GPS Satellite Details

- **Name:** NAVSTAR (The Navigation Satellite Timing and Ranging-USA)
- **Galaxy:** consist of 24 satellites.
- **Manufacture:** Rockwell International
- **Altitude:** 20200 km
- **Weight:** 845 kg
- **Number of path or orbit:** 6
- **Number of satellite per path:** 4

- **Orbital inclination:** 55 degree to equatorial plane
- **Orbital spacing:** 60 degree (360/6)
- **Orbital period:** 12 hours
- **Planned life span:** 7.5 years

The User Segment

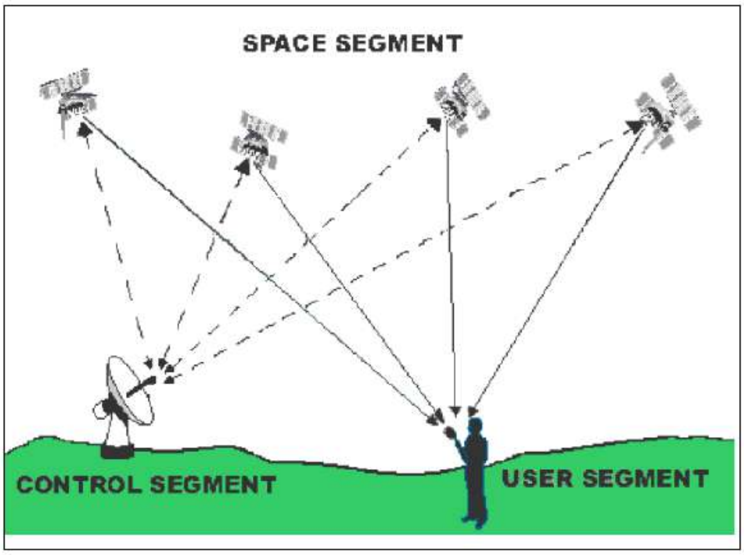
Information that comes from space and sends to satellites is the most important part of GPS. The part that does this work is User Segment. It has the GPS receiver section. GPS collect and stored the all information that has come from space. For this, 4 satellites are required.

The GPS user segment consists of the GPS receivers and the user community. GPS receivers convert SV signals into position, velocity and time estimates. Four satellites are required to compute the four dimensions of X (latitude), Y (longitude), Z (altitude) and T (time). GPS receivers are used for navigation, positioning, time dissemination and other research

The user receiving equipment comprises the user segment. Each set of equipment is typically referred to as a GPS receiver, which processes the L-band signals transmitted from the satellites to determine user PVT (Position, Velocity and Time). While PVT determination is the most common use, receivers are designed for other applications, such as computing user platform attitude (i.e., heading, pitch, and roll) or as a timing source.

Navigation in three dimensions is the primary function of GPS. Navigation receivers are made for aircraft, ships, and ground vehicles and for hand carrying by individuals. Precise positioning is possible using GPS receivers at reference locations providing corrections and relative positioning, geodetic control and plate tectonic studies are example.

Time and frequency dissemination, based on the precise clocks on board the SVs and controlled by the monitor stations, is another use for GPS, Astronomical observatories, telecommunications facilities, and laboratory standards can be set to precise time signals or controlled to accurate frequencies by special purpose GPS receivers. Research projects have used GPS signals to measure atmospheric parameters.



Working Functions of GPS

Generally the functions of a GPS are completed with 5 steps.

Step -1: Triangulating from Satellites

GPS operation is based on the concept of ranging and Trilateration from a group of satellites, which act as precise reference points. Each satellite broadcasts a Navigation Message that contains the following information;

- A pseudo-random code called a Course Acquisition (CA) code, which contains orbital information about the entire satellite constellation (Almanac).
- Detail of the individual satellite's position (Ephemeris) that includes information used to correct the orbital data of satellites caused by small disturbances.
- The GPS system time, derived from an atomic clock installed on the satellite, with clock correction parameters for the correction of satellite time due to differences between UTC and GPS time (the occasional 'leap' second added to a year) and delays (predicted by a mathematical ionosphere model) caused by the signal travelling through the ionosphere. A GPS health message that is used to exclude unhealthy satellites from the position solution.

The GPS receiver in the aircraft takes 12.5 minutes to receive all of the data frames in the navigational message. Once obtained, the receiver starts to match each satellite's CA code with an identical copy of the code contained in the receiver's database. By shifting its copy of the satellite's code, in a matching process, and by comparing this shift with its internal clock, the receiver can calculate how long it took the signal to travel from the satellite to the receiver. The distance derived from this method of computing distance is called a Pseudo-range because it is not a direct measure of distance, but a measurement based on time. Pseudo-range is subject to several error sources, including atmospheric delays and multipath errors, but also due to the initial differences between the GPS receiver and satellite time references.

Using a process called Trilateration, the GPS receiver then mathematically determines its position by using the calculated pseudo-ranges and the satellite position information that has been supplied by the satellites.

<u>GPS_3D-Trilateration</u>

- If only one satellite is visible, position location is impossible as the receiver location can be anywhere on the surface of a sphere with the satellite at its centre.
- If two satellites are visible the receiver location can be anywhere on a circle where the surfaces of the two spheres intercept. So position location is also impossible.
- When a third satellite becomes visible, the GPS receiver can establish its position as being at one of two points on the previously derived circle where the third satellite sphere intercepts it. So, whilst position fixing is possible, it is unreliable unless it is assumed that the receiver is at sea level on the surface of the Earth, because it is almost certain that only one of the two derived points would be near the surface of the Earth. So fixing is possible, but only in two dimensions (2D fixing): in latitude and longitude.
- With at least four satellites visible, and their alignment good, the four spheres will intersect at only one point in space, so receiver position can be accurately fixed in three dimensions (3D fixing): in latitude, longitude and altitude.
- With five satellites visible, it is possible for the system to automatically detect an erroneous signal.
- With six satellites visible, it is possible for the system to automatically detect an erroneous signal, identify which satellite is responsible and exclude it from consideration.
- Altitudes derived from GPS positions are known as Geodetic altitudes and were not initially used for aircraft navigation; PBN requires that they, and the navigational information presented by the system, are based on the World Geodetic System established in 1984, the WGS 84 coordinate system.
- As the GPS satellites provide a very accurate time reference as well as precise 3D position fixes, they can also calculate and provide accurate speed data.

Step-2: Measuring distance from a Satellite

Normally distances are calculated on GPS is based on signals of a Satellite ranging. The easy formula to calculate the distance is:

Distance (d) = Speed of satellite ranging (3 x 108 m/second) x time

Time (Δ t) = t2 – t1 where, t1 = sending time, t2 = receiving time

Step- 3: Getting Perfect Timing

If travel time measures through the radio signal are the basics of GPS, then stopwatch are very working instrument in this case. If their time is stopped for one thousandths of a second, then it will wrong at 200 miles. In terms of Satellites, timing is perfect because the Atomic clock is the compulsory element of Satellite systems. The key to accurate scheduling is to measure the distance to an extra satellite. If the three exact measurements can identify the three-dimensional position, then the fourth incorrect measure does the same thing.

Step-4: Knowing where a Satellite is in Space

We assume that we know the exact position of Satellites, for which we can used that satellites as a reference point. But how can we know that exactly where they are? After all, they float in the space of 11,000 miles.

Step-5: Correcting Errors

So far, the calculation we are pointing to a GPS, that is sporadically. As if the whole thing was happening in a vacuum. But in reality, there are a lot of things which can be disrupt the GPS signals. To get the accurate results, this error likely to be corrected. For example, the ionosphere and atmosphere may be a reason for delay the whole function. Some error can be factored out by using arithmetic calculation and model. The relative position of the satellites in the sky can give rise to other errors.

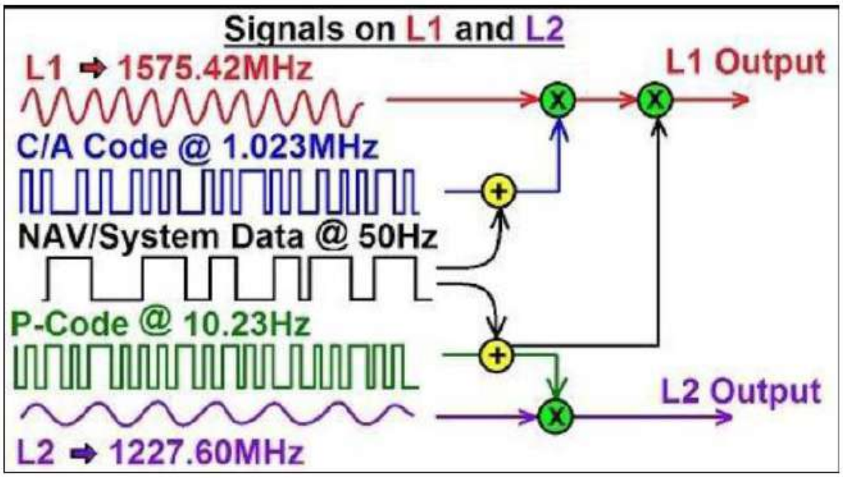
Pseudo Random Code (PRC): Pseudo Random Code is the prime part of GPS. It physically complicated digital number or complicated sequence of ‘on’ and ‘off’ pulse. There are 2 types of PRC signals generally found.

Coarse Acquisition Code (C/A): (a) This contains L1 signals. (b) It repeats every 1023 bits & modulates at a 1 MHz rate. (c) C/A code is the basis for civilian GPS uses.

Precise Code (P): (a) Modulate both L1 & L2 carries at a 10 MHz rate. (b) Used for Military purpose. (c) It is more complicated than C/A code.

There are 2 types of Signals: L1 & L2

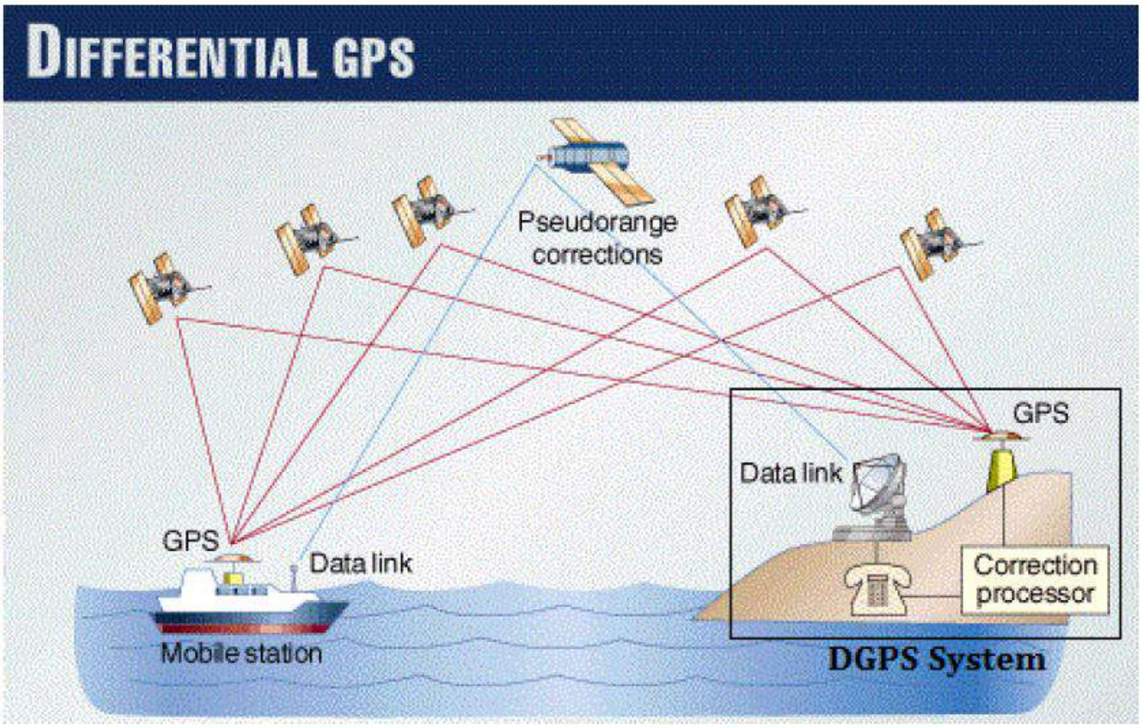
1. **L1 carries:** (a) L1 carries 1575.42 MHz. (b) L1 carries both the status message and a pseudo random code for timing.
2. **L2 carries:** (a) L2 carries 1227.60 MHz. (b) Use for the more precise military pseudo random code.



Differential Global Positioning System (DGPS)

A Differential Global Positioning System (DGPS) is an enhancement to the Global Positioning System (GPS) which provides improved location accuracy, in the range of operations of each system, from the 15-meter nominal GPS accuracy to about 1-3 cm in case of the best implementations. The United States Coast Guard (USCG) and the Canadian Coast Guard (CCG) each run DGPSs in the United States and Canada on long wave radio frequencies between 285 kHz and 325 kHz near major waterways and harbors. The USCG's DGPS was named NDGPS (Nationwide DGPS) and was jointly administered by the Coast Guard and the U.S. Department of Defense's Army Corps of Engineers (USACE). It consisted of broadcast sites located throughout the inland and coastal portions of the United States including Alaska, Hawaii and Puerto Rico. Other countries have their own DGPS. A similar system which transmits corrections from orbiting satellites instead of ground-based transmitters is called a Wide-Area DGPS (WADGPS) or Satellite Based Augmentation System.

Differential Global Positioning Systems (DGPS) are GPS systems that use fixed reference locations on Earth to calculate positioning errors transmitted by the satellites in view. Since the location of these reference points in already knows, they can easily calculate any positioning errors that are being transmitted by the GPS constellation. This error information is then transmitted out to GPS devices, which use this information to calculate their accurate position.



Applications of DGPS

➢**Air Navigation:** One of its more popular applications is in air navigation. By using it a pilot can receive constant information about where the plane is in 3 dimensions.

➢**Farming:** It is also becoming a hot topic in precision farming. Farmers can use DGPS to map out their crops, map crop yields, and control chemical applications and seeding.

➢**Hydrographic Survey:** It is also proving to be useful in ground and hydrographic surveying.

➢**Weather forecast:** Another application is in weather forecasting, where atmospheric information can be gained from its effects on the satellite signals.

➢**Coastal Monitoring:** There has also been at least one experiment where it was used for beach morphology and monitoring.

➢**Transport:** DGPS can also be used for train control for such things as avoiding collisions and routing.

➢**City Administrative:** There is even been research into using it to help the visually impaired in getting around in cities.

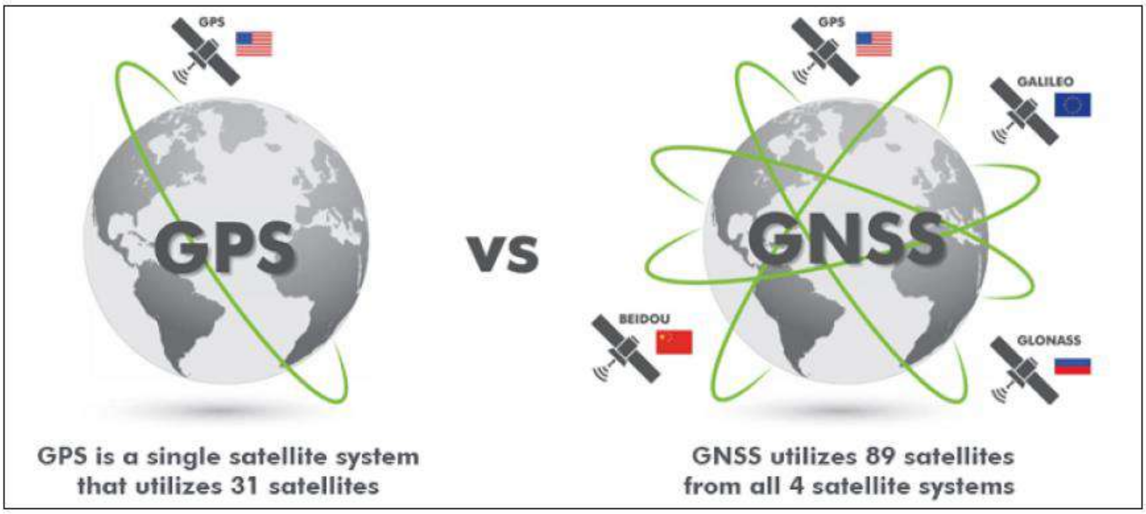
➢**Car Navigation:** There is also at least one project that is working on using DGPS for car navigation.

➢**Sports field:** In the sports world it is finding a place in balloon and boat racing. It will eventually become an integral part of much of our technology.

GNSS

GNSS stands for Global Navigation Satellite System, and is the standard generic term for satellite navigation systems that provide autonomous geo-spatial positioning with global coverage. This term includes e.g. the GPS, GLONASS, Galileo, Beidou and other regional systems.

Global Navigation Satellite System (GNSS) refers to a constellation of satellites providing signals from space that transmit positioning and timing data to GNSS receivers. The receivers then use this data to determine location. By definition, GNSS provides global coverage. 27 satellites At present, there are total 27 satellites in orbit and all are operational. In open sky conditions, standard accuracy GNSS receivers are accurate to within about two meters. High precision GNSS systems dramatically improve precision using GNSS correction data to cancel out GNSS errors. One way to obtain this data involves monitoring GNSS signals from a base station at a known location. So, for the time being, GNSS receivers work by receiving signals sent from the relevant satellites in orbit. The signals that are used depend on the type of receiver. A GPS receiver can only make use of signals from the GPS satellites, while a GLONASS receiver can only use signals from GLONASS satellites.



5. GPS-aided traversing; Manual and Computer plotting for preparation of maps.

Today, GPS is a vital part of surveying and mapping activities around the world. When used by skilled professionals, GPS provides surveying and mapping data of the highest accuracy. GPS is especially useful in surveying coasts and waterways, where there are few land-based reference points.

GPS-Aided Traversing: Manual Plotting for Preparation of Maps

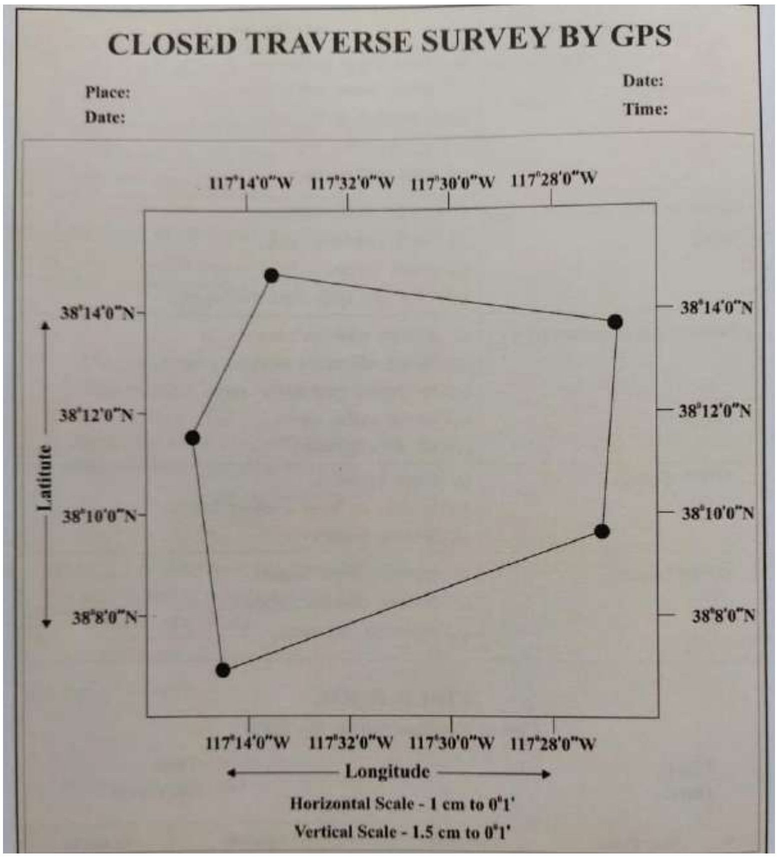
FIELD BOOK

Closed Traverse Survey By G.P.S

Place: Time:

Date: Surveyor:

Sl No.	Way Point	Latitude	Longitude	Remarks
1	30	39°13′41.92″N	117°33′18.54″W	Light Post
2	31	39°12′56.82″N	117°27′01.99″W	Light Post
3	32	38°9′56.68″N	117°27′19.29″W	Tree
4	33	38°7′57.07″N	117°34′17.54″W	Tree
5	34	38°11′20.35″N	117°34′48.74″W	Light Post



GPS-Aided Traversing: Computer Plotting for Preparation of Maps by Using Mobile and Computer

I. Get a smart phone and install a GPS app:

You don't need a GPS device to do GPS. Almost any good quality smart phone will do. Find a smart phone and install a free GPS app on it. The best (and easiest) GPS app I've found for my Android phone is GPS-Simple for Android, and you can also check this list of apps for Apple iOS devices. To use GPS-Simple, you may need to change some of the settings on your phone, such as enabling GPS.

II. Go to each location and write down the latitude and longitude from the app:

Once you've got your phone you should go to each location you want to map and use the GPS app to get the latitude and longitude. If the location is very remote you might need to move around a bit until your phone can get a lock on it. The GPS-Simple app will even tell you how accurate the result is (for me it is normally 10-20 meters, but it varies).

A GPS app interface

Once you've got the latitude and longitude write them down on a record sheet, along with the name of the location and what it is (village, health centre, school, borehole, etc). An example of a record sheet is shown below:

Latitude and longitude come from the GPS app on your phone

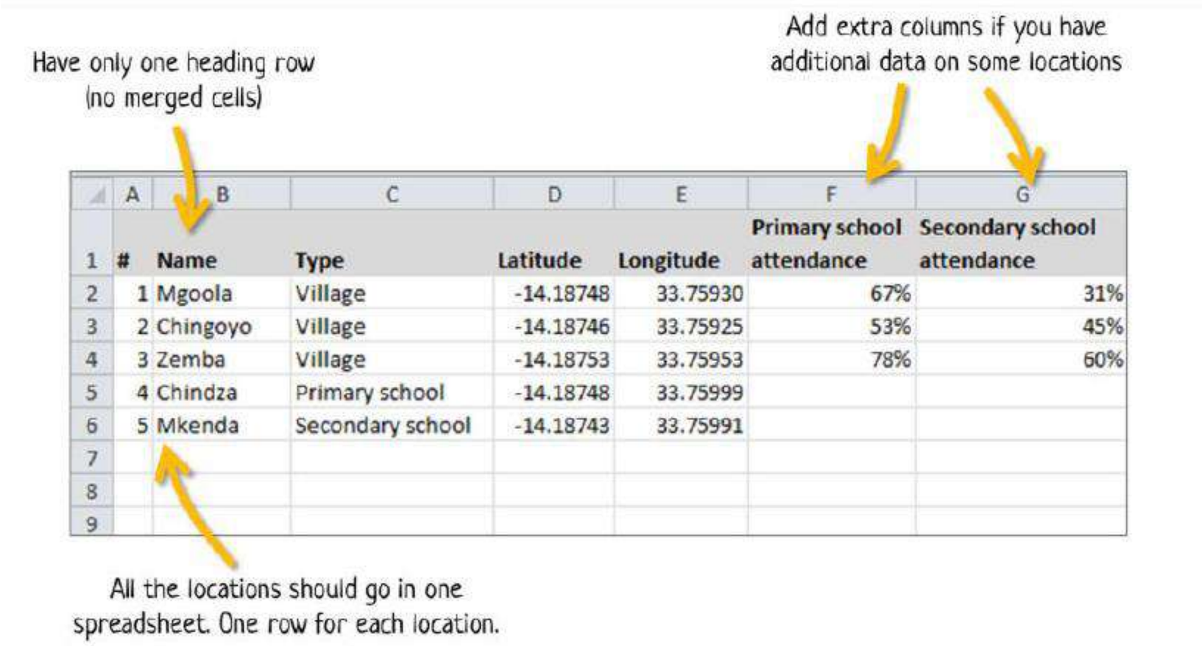
#	Location Name	Type	Latitude	Longitude
1	Mgoola	Village	-14.18748	33.75930
2	Chingoyo	Village	-14.18746	33.75925
3	Zemba	Village	-14.18753	33.75953
4	Chindza	Primary school	-14.18748	33.75999
5	Mkenda	Secondary school	-14.18743	33.75991
6				
7				
8				

Include all the locations that are relevant for your project. (villages, schools, health centres, boreholes, government offices, etc)

If you want to do this all on your phone (without having to write on a record sheet) then check out Device Magic. Device Magic allows you to create data collection forms for your mobile phones that include GPS locations.

III. Enter the data into a spreadsheet:

If you decided to write down everything on a paper form then you'll need to enter that data into a spreadsheet. The spreadsheet should have one heading row, with each row after that being used for only one location.



	A	B	C	D	E	F	G
1	#	Name	Type	Latitude	Longitude	Primary school attendance	Secondary school attendance
2	1	Mgoola	Village	-14.18748	33.75930	67%	31%
3	2	Chingoyo	Village	-14.18746	33.75925	53%	45%
4	3	Zemba	Village	-14.18753	33.75953	78%	60%
5	4	Chindza	Primary school	-14.18748	33.75999		
6	5	Mkenda	Secondary school	-14.18743	33.75991		
7							
8							
9							

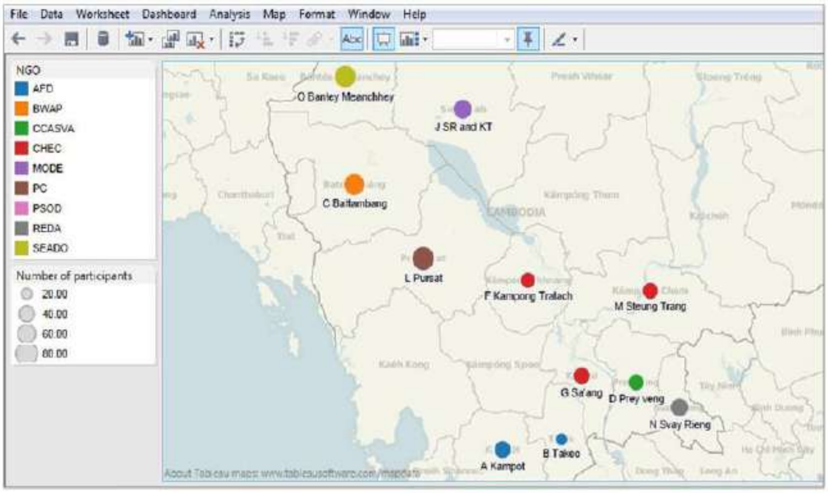
At this point you can also add extra information on each location. For example, if you are mapping villages for a school program you could add the percentage of children attending school in each village. If you are mapping boreholes you could add whether the borehole is functioning or not. When you make your map, this information can be shown using the colour or size of the dots.

IV. Upload the data onto a map:

There are several different mapping providers that will allow you to upload your data onto their publicly available maps, including Google Earth and Bing Maps.

They all work in a similar way, but personally my favourite is Tableau Public because it allows you to combine charts and maps together. To make a map on Tableau Public you first have to download and install the software on your computer. Then open the data from the spread sheet in Tableau Public.

Once the data is open you just drag and drop things onto the map. Have a look at this step-by-step guide from Tableau Public to see how it's done. Here is an example of a simple map I created:



I recently created another map for a new project I'm working on. Getting the GPS coordinates for around 100 villages took 3 days, entering it into a spreadsheet took 1 day and making the map (playing around with all the settings and colouring) took 1 day.

Summary

A GIS is a computer based tool for geographical analysis of information. It is not simply a digitized map, nor does it hold maps. It holds a database of spatial data and attribute or descriptive information about features on a map which can be used to create desired maps. The crucial concept of GIS is the separation of spatial or geographic reference information and attribute or descriptive information of map features for data entry and database development, and their linkage during analysis. Central to both spatial and attribute information is the database management concept. The separation of the two types of information facilitates entering the spatial information (map) into computers in a digitized form and establishing connectivity (topology) between different stored map features (points, lines and polygons). The feature attribute data is entered independently taking care to introduce an identification variable which is in common with the identification variable for each feature that is common with the spatial database. For geographic analysis, the spatial and attribute data are linked through this unique identifier variable common to the two types of data bases.

Initially, spatial data capture is in spatial units and coordinates of the data capture tool. To translate the map information into real world information of locations, distances and areas these need to be translated to real world units through appropriate transformations of scale and map projections.

The digitized maps and their associated feature attributes are the building blocks of the GIS. The maps can be created and stored in different layers, with each layer containing information about one feature. They can be overlaid over each other to obtain new maps (coverages) with new polygons that are homogeneous with respect to specified feature attributes of maps that were used in the overlays. The overlay operations must be between maps with exact boundary fits. Exact fits are obtained between maps only if they are created in the same projection and scale. To make exact fits, appropriate map projection and scale transformation operations will be needed before geographic analysis can be performed using overlay operations.

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PAPER - GEO 496: SPATIAL ANALYSIS AND PROTOTYPE RESEARCH

GEO 496.1: SPATIAL ANALYSIS IN GEOGRAPHY

1. Transport network analysis: Centrality Indices, Shortest path analysis(Transport and allocation problems), Detour and spread.

2. Distance Matrix (Aggregate Travel Distance).

3. Point spatial distribution analysis: Uniformity, randomness and compactness.

4. Analysis of Directional Data; Rose diagram, Dominant Direction, Mean direction.

5. Analysis of Shape: Measures based on axial ratios, perimeters to areas, areas to axial length.

1. Transport Network Analysis: Centrality Indices, Shortest Path Analysis (Transport and Allocation Problems), Detour and Spread.

Network analysis is an important aspect of spatial organization of socio-economic activities. Groups, organizations and circuits of network which are associated with graph theory, are part of network analysis. Such aspects are useful for study of diffusion of innovations, spread of diseases, political movements, traffic analysis, drainage network and computer networking. Graph theory is mostly based of two elements of space:

1. **Vertex** of network (that is called **nodes),** and
2. **Edge** (or **arcs**) which connect two vertexes in the network. Network problems that involve finding an optimal way of doing something are analysed through graph theory.

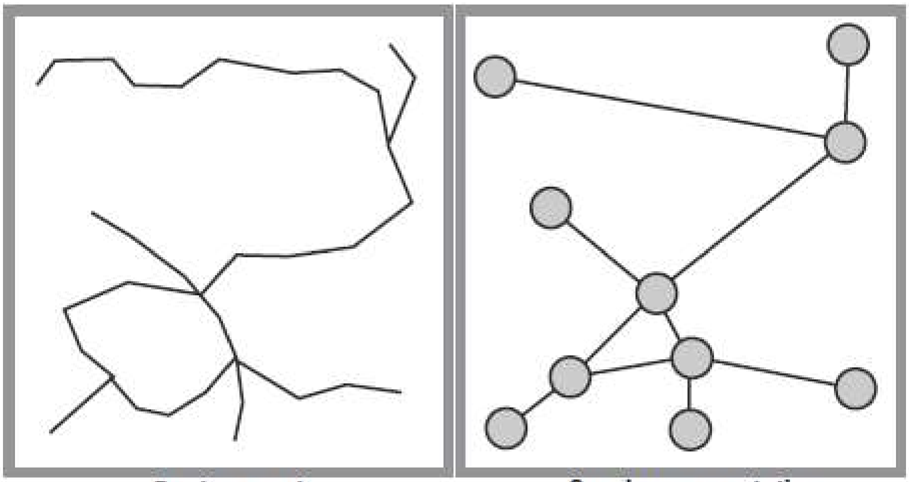
Basic Graph Definition

A graph is a symbolic representation of a network and of its connectivity. It implies an abstraction of the reality so it can be simplified as a set of linked nodes. **Graph theory** is a branch of mathematics concerned with how networks can been coded and their properties measured. The goal of a graph is to represent the structure, not the appearance of a network.

The conversion of a real network into a planar graph is a straightforward process which follows some basic rules:

1. The most important rule is that every terminal and intersection point becomes a node.
2. Each connected node is then linked by a straight segment.

The outcome of this abstraction, as portrayed on is the actual structure of the network. The real network, depending on its complexity, may be confusing in terms of revealing its connectivity (what is linked with what).



Real network Graph representation

A graph representation reveals the connectivity of a network in the best possible way. Other rules can also be applied, depending on the circumstances:

1. A node that is not a terminal or an intersection point can be added to the graph if along that segment an attribute changes. For instance, it would be recommended to represent as a node the shift from two lanes to four lanes along a continuous road segment, even if that shift does not occur at an intersection or terminal point.
2. A “dummy node” can be added for esthetical purposes, especially when it is required that the graph representation remains comparable to the real network. 5) Although the relative location of each node can remain similar to its real world counterpart (as in Figure 2.15), this is not required.

In transport geography most networks have an obvious spatial foundation, namely road, transit and rail networks, which tend to be, defined more by their links than by their nodes. This is not necessarily the case for all transportation network s. For instance, maritime and air networks tend to be defined more by their nodes than by their links since the links are often not clearly defined. A telecommunication system can also be represented as a network, while its spatial expression can have limited importance and would actually be difficult to represent. Mobile telephone networks or the Internet, possibly the most complex graphs to be considered, are relevant cases of networks having a structure that can be difficult to symbolize. However, cellular phones and antennas can be represented as nodes while the links could be individual phone calls. Servers, the core of the Internet, can also be represented as nodes within a graph while the physical infrastructure between them, namely fibres-optic cables, can act as links. Consequently, all transport networks can be represented by graph theory in one way or another.

The following elements are fundamental in understanding graph theory:

• **Graph**. A graph *G* is a set of vertexes (nodes) *v* connected by edges (links) *e*. Thus

$$G = (v, e).$$

• **Vertex (Node)**. A node *v* is a terminal point or an intersection point of a graph. It is the abstraction of a location such as a city, an administrative division, a road intersection or a transport terminal (stations, terminuses, harbours and airports).

• **Edge (Link)**. An edge *e* is a link between two nodes. The link (*i*, *j*) is between initial extremity *i* and terminal extremity *j*. A link is the abstraction of a transport infrastructure supporting movements between nodes. It has a direction that is commonly represented as an arrow. When an arrow is not used, it is assumed the link.

The graph on Figure 2.16 has the following definition = (*v*, *e*); *v* = (1, 2, 3, 4, 5);

$$e = (1, 2), (1, 3), (2, 2), (2, 5), (4, 2), (4, 3), (4, 5).$$

Sub-graph. A subset of a graph *G* where *p* is the number of sub-graphs. For instance $G' = (v', e')$ can be a distinct sub-graph of *G*. Unless the global transport system is considered as a whole, every transport network is in theory a sub-graph of another.

For instance, the road transportation network of a city is a sub-graph of a regional transportation network, which is itself a sub-graph of a national transportation network.

Buckle. A link that makes a node corresponds to itself.

Planar graph. A graph where every intersection of two edges is a vertex. Since this graph is located within a plane; its topology is two-dimensional.

Non-planar graph. A graph where there are no vertexes at the intersection of at least two edges. This implies a third dimension in the topology of the graph since there is the possibility of having a movement “passing over” another movement, such as for air transport. A non-planar graph has potentially many more links than a planar graph.

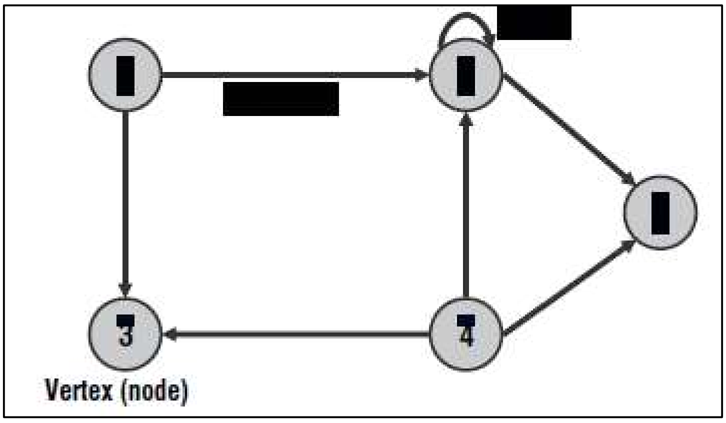
Links and Their Structures

A transportation network enables flows of people, freight or information, which occur along links. Graph theory must thus offer the possibility of representing movements as linkages, which can be considered over several aspects:

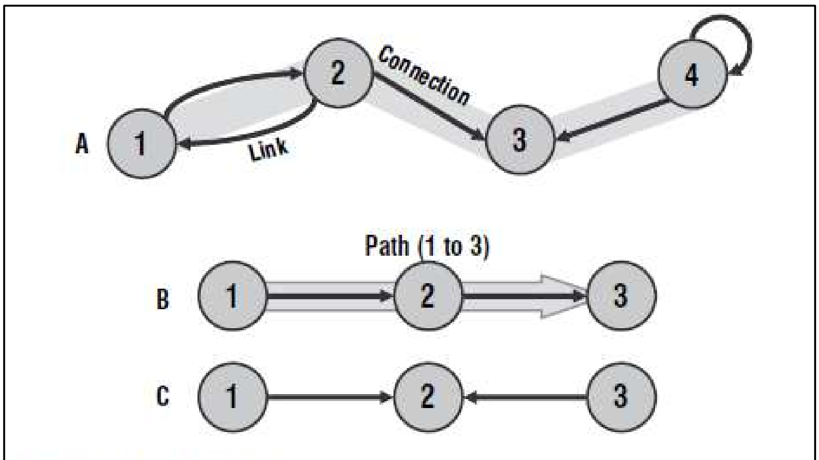
• **Connection**. A set of two nodes. Considers if a movement between two nodes is possible, whatever its direction. Knowledge of the connections within a graph means it is possible to find whether a node can be reached from another node.

• **Path**. A sequence of links that are travelled in the same direction. For a path to exist between two nodes, it must be possible to travel along an uninterrupted sequence of links. Finding all the possible paths in a graph is a fundamental attribute in measuring accessibility and traffic flows.

On graph A of Figure 2.17 there are five links [(1, 2), (2, 1), (2, 3), (4, 3), (4, 4)] and three connections [(1–2), (2–3), (3–4)]. On graph B, there is a path between 1 and 3, but on graph C there is no path between 1 and 3.



Basic Graph Representation of a Transport Network



Connections and paths

Chain. A sequence of links having a connection in common with each other. Direction does not matter.

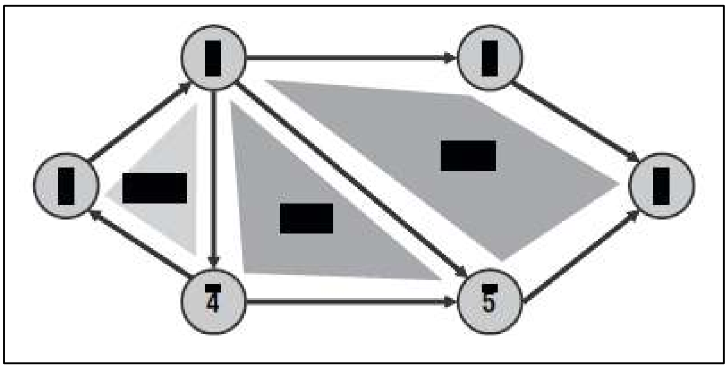
Length of a link, connection or path. Refers to the label associated with a link, a connection or a path. This label can be distance, the amount of traffic, the capacity or any attribute of that link. The length of a path is the number of links (or connections) in this path.

Cycle. A chain where the initial and terminal node is the same and which does not use the same link more than once.

Circuit. A path where the initial and terminal node corresponds. It is a cycle where all the links are travelled in the same direction. Circuits are very important in transportation because several distribution systems use circuits to cover as much territory as possible in one direction (delivery route). On the graph of Figure, 2–3–6–5–2 is a cycle but not a circuit. 1–2–4–1 is a cycle and a circuit.

Basic structural properties

The organization of nodes and links in a graph convey a structure that can be labelled. The basic structural properties of a graph are:



Symmetry and asymmetry. A graph is symmetrical if each pair of nodes linked in one direction is also linked in the other. By convention, a line without an arrow represents a link where it is possible to move in both directions. However, both directions have to be defined in the graph. Most transport systems are symmetrical but asymmetry can often occur as is the case for maritime (pendulum) and air services. Asymmetry is rare on road transportation network s, unless one-way streets are considered.

• **Completeness**. A graph is complete if two nodes are linked in at least one direction. A complete graph has no sub-graph.

• **Connectivity**. A complete graph is described as connected if for all its distinct pairs of nodes there is a linking chain. Direction is not important for a graph to be connected, but may be a factor for the level of connectivity. If $p > 1$, the graph is not connected because it has more than one sub-graph. There are various levels of connectivity, depending on the degree to which each pair of nodes is connected.

Centrality Indices

The degree of centrality of any node on a network may be described in terms of its Konig number, an index developed in 1936 by D. Konig. The Konig number of each node is calculated by adding up the number of arcs from each other node using the shortest path available. For example, in the following figure (Figure 1) point E has the lowest number and is, therefore, the most central node in the network.

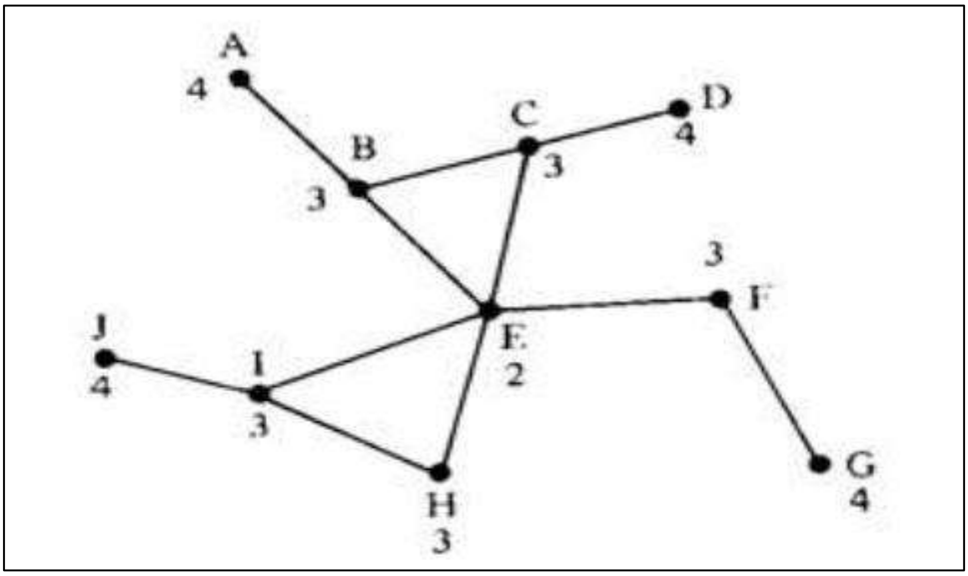


Figure 1

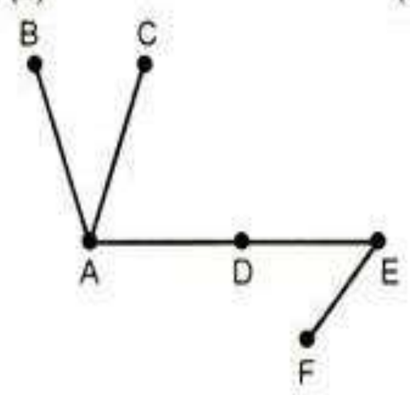
Shortest Path Analysis

Any network may be represented as a matrix with rows as set of origins and the columns as the set of destinations. The number of rows and columns would correspond to the number of nodes in the network. By convention, the horizontal rows of a matrix are identified as a set of origin nodes and the vertical columns of the matrix are defined as a set of destination nodes. Each cell entry in the matrix may be used to record some information on the relationship between a pair of nodes.

Any node which is well connected to other nodes in a network is said to be accessible. Figure 2 shows five nodes linked together by a series of arcs and it can be seen at a glance that node A is the most accessible. But such assessment is not possible in more complex network involving larger number of nodes and alternative routes.

In such cases, accessibility can be found out by compiling a matrix commonly known as shortest path matrix as demonstrated in the following figure. In this matrix, A count is made of the number of arcs separating the various nodes and inserting the appropriate number in appropriate box: for instance, the number of arcs separating A from B, C, D and E, respectively is 1, 1, 1 and 2 and E from A, B, C and D respectively 2, 3, 3 and 1. The totals of each row can beaded up and the lowest total indicates the node, which is most accessible. In this case, 'A' is having a total of 5 (lowest) thus most accessible while 'E' is the least accessible with highest total of 9.

(a)



(b)

	To					Total
	A	B	C	D	E	
A	0	1	1	1	2	5
B	1	0	2	2	3	8
C	1	2	0	2	3	8
D	1	2	2	0	1	6
E	2	3	3	1	0	9

Figure 2

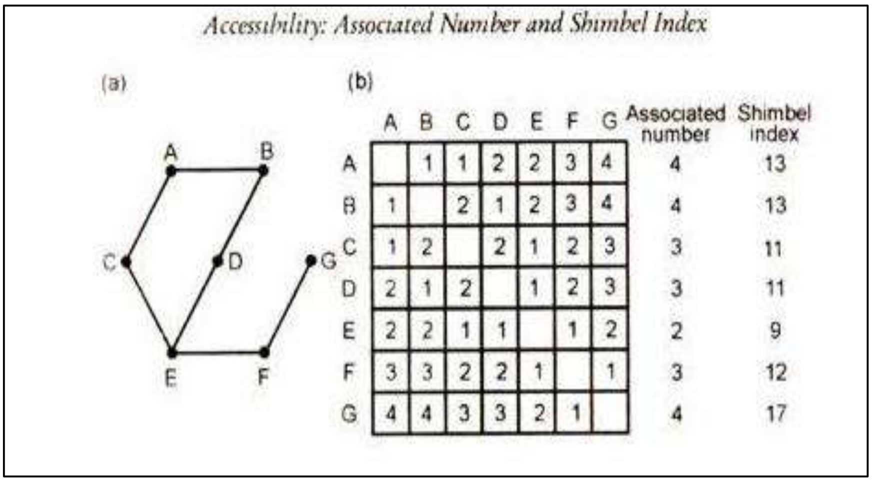
Topologically, accessibility can be measured in three ways:

(i) By shortest path matrix – the number of arcs used in the shortest path between all possible pairs (as shown in Figure 2)

(ii) By the associated number – the number of arcs needed to connect a node to the most distant node from it; and

(iii) By the Shimbel Index, derived from the shortest path matrix, which indicates the number of arcs needed to connect any node with all the other nodes in the network by the shortest path.

Figure 3: Indicates the accessibility, as measured by associated number and Shimbel Index.



	A	B	C	D	E	F	G	Associated number	Shimbel index
A		1	1	2	2	3	4	4	13
B	1		2	1	2	3	4	4	13
C	1	2		2	1	2	3	3	11
D	2	1	2		1	2	3	3	11
E	2	2	1	1		1	2	2	9
F	3	3	2	2	1		1	3	12
G	4	4	3	3	2	1		4	17

From the graph in Figure 3, a shortest path matrix has been prepared in the appropriate squares the number of arcs in taking the shortest path between all the paired nodes. The top row of figures in the matrix gives the number of arcs in the shortest paths from node A to all the other nodes; the second row from node B to all the others; and so on.

Since the associated number is the number of arcs needed to connect a node to the most distant node from it, the associated number is the highest number in each row, e.g., in row A, 4 and in row F, 3. Thus E, with an associated number 2, is the most accessible of all nodes. If we add up all the associated numbers and divide the total by the number of nodes, we get the mean associated number and a low mean figure (in this case 23/7 = 3.3).

While Shimbel Index can be derived from the shortest path matrix – the total of each row gives the Shimbel Index. In Figure 3, A and B are having Shimbel Index of 13, C and D 11, E-9, F-12 and G-17. Since E is having lowest value of all the rows, it is most accessible of all the nodes by the Shimbel Index.

The Spread and Diameter of the Network

The diameter of network was examined by Kansky who developed two useful indices to measure the spread of network. The description of a network in terms of its diameter involves the counting of the number of arcs on the shortest possible path between the two nodes lying farthest apart on the network. In general terms, the diameter increases with increasing size of the network, although any addition of connecting areas may result in the diameter being decreased.

These two indices are:

a. Pi Index, and

b. Eta Index.

a. **Pi Index**: It shows the relationship between the total length of the graph *(c)* and the distance along its diameter *(d)*. It is labelled as Pi because of its similarity with the real Pi value (3.14), which is expressing the ratio between the circumference and the diameter of a circle. A high index shows a developed network. It is a measure of distance per units of diameter and an indicator of the shape of a network. It is expressed as:

$$\pi = \frac{c}{d}$$

Where, *c* is the total length of the network and *d* is the distance along its diameter.

b. **Eta Index**: The Eta Index a similar index to the index of Kansky, which also gives some idea of the spread of the network. Average length per link. Adding new nodes will cause a decrease of Eta as the average length per link declines. The eta index is given by the formulae:

$$\eta = \frac{c}{a},$$

Where, c is total distance of the network and a is the number of arcs.

Detour Index

In the opinion of Robinson and Bamford (1978), owing to topography and other obstacles the direct paths are deflected or deviated. Such deviations can be measured with the help of the Detour Index.

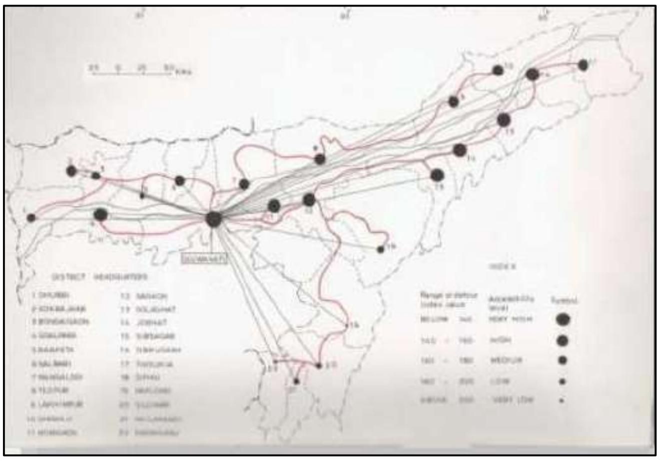
Thus, we can use route distances and straight-line distances to determine the efficiency of a specific route as compared with another. The formula is:

$$\textbf{Detour Index} = \frac{\textbf{Actual Route Distance}}{\textbf{Straight Line Distance}} \times \frac{\textbf{100}}{\textbf{1}}$$

Such a detour index may be compared with various aspects of physical geography, such as the degree of dissection or drainage density of an area over which the routes run. The detour index may also be used to give some comparison between routes before and after improvement has taken place. For example, let us calculate the relative road transport accessibility from the district headquarters of Assam to Guwahati City using the detour index.

Table: Actual and Straight road distances of the district headquarters of Assam from Guwahati to Different District Headquarters

District headquarters	Actual road distance (km)	Straight line distance (km)	Detour index
Dhubri	290	180	161
Kokrajhar	236	147.5	160
Bongaigaon	210	122.5	171.4
Barpeta	140	75	186.6
Goalpara	150	112.5	133.3
Nalbari	71	47.5	149.4
Mangaldoi	68	42.5	160
Tezpur	181	117.5	147.7
Lakhimpur	396	260	152.3
Dhemaji	462	312.5	148
Morigaon	78	62.5	124.8
Nagaon	123	95	129.4
Golaghat	288	222.5	129.4
Jorhat	304	247.5	122.8
Sibsagar	363	297.5	122.01
Dibrugarh	443	340	130.3
Tinsukia	591	390	151.5
Diphu	271	165	164.2
Haflong	368	165	223.0
Silchar	343	177.5	193.2
Hailakandi	336	180	186.6
Karimganj	338	152.5	221.6



Guwahati City Using Detour Index

Interpretation

Detour between Guwahati and Haflong districts is the highest as 223 percent. It is due to undulating topography and higher density of drainage network between them which enhances the actual road distance. On the other hand, in the upper plains of Brahmaputra especially between Guwahati and Jorhat and between Guwahati and Sibsagar towns, the detour is very low as 122and 123 percent respectively. It means that the curve-linearity in the road length is only the 22percent due to gentle slope topography. Thus, topography and relief features of landscape are major factors for detour of road transport network in Assam.

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2. Distance Matrix (Aggregate Travel Distance).

Point of Minimum Aggregate Travel (PMAT)

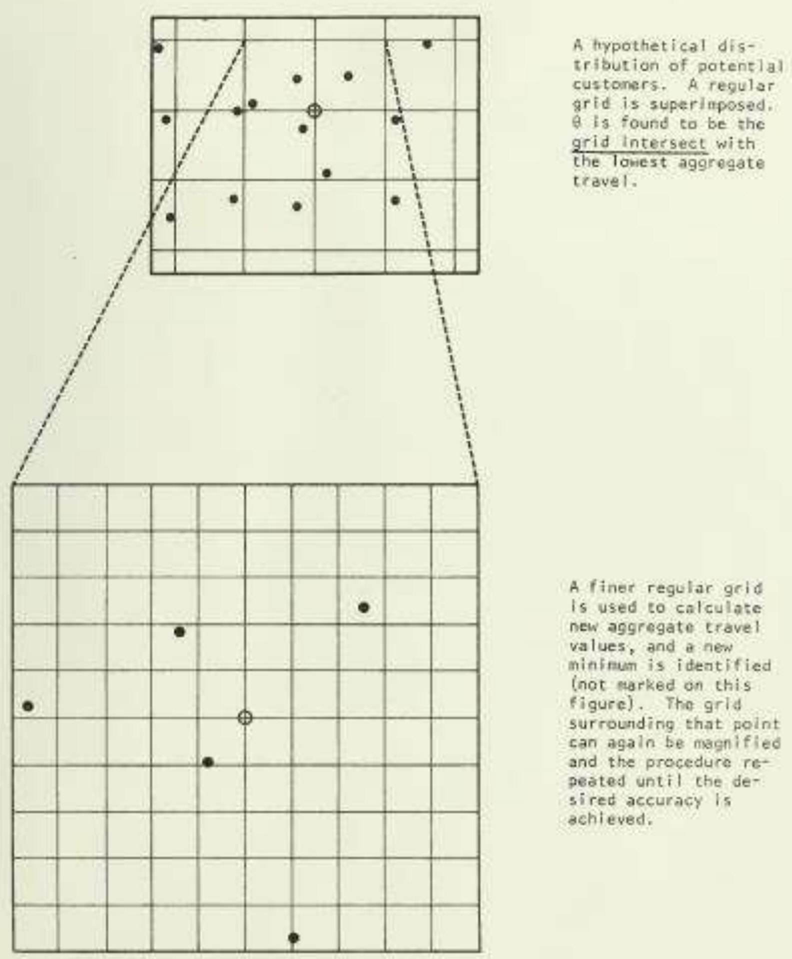
The PMAT has significant practical value as it designates the point to which the total travel by all in the study area is minimized. For example, in locating a state capital, if the objective is to minimize total travel time, it should be located at that point.

The precise determination of this point had perplexed mathematicians for centuries, but it is now accepted as having no mathematical solution. To date, the best methods remain interatlon techniques. Seymour (1965) suggests placing a uniform lattice of points (intersections of a regularly spaced grid system) over the study area and identifying the point with the smallest aggregate travel (Figure 7). This point becomes the center of a finer gride of points, extending to a perimeter delimited by the closest points in the original lattice. Successive reapplications of this technique produce a close approximation of the PMAT.

Despite the lack of a mathematical formula, computer programs can easily provide iterative solutions, and rather accurate estimates can be computed. In practical applications, only approximations are necessary since the solution (location) is often not suited for the point in question.

For example, if a supermarket can estimate the scope of its trade area and frequency of business, the PMAT can be determined for a unit time period. That point may be located in a park, cemetery, or any of a list of areas not zoned for commercial activity or merely not desirable for large scale retail trade. Moreover, judgment is necessary in estimating future shifts in the trade area. All this negates the necessity of precise computations.

Figure 7. One Iterative Step in the Derivation of the PMAT.



3. Point Spatial Distribution Analysis: Uniformity, Randomness and Compactness.

The existence of pattern in the spatial arrangement of phenomena on the earth's surface provides a fundamental stimulus to the research mind of a geographer. Pattern implies some sort of spatial regularity which confirms the operations of a regular causative geographical process. Therefore, identification and measurement of spatial pattern and its trend form the essential task of the geographer who wishes to identify and distinguish homogeneity vs. heterogeneity, isotropy versus anisotropy and randomness.

Randomness means that the process controlling the position of a point operates independently of the positions of other points and there is equal probability of occurrence of a point in each equal subdivisions of the total area. Thus, there is always a probability that the resulting distribution would appear highly nonrandom. Random distributions are isotropic having no directional relationships twin points. In nonrandom distributions the degree of homogeneity can be greater or less than that of a random distribution. Distribution that tends towards more homogeneity is described as uniform and in extreme cases regular. With more heterogeneity they become clustered. Distributions may be anisotropic by virtue of points forming lineation or tending to be closer in some direction than others.

Test of Uniformity

Uniform distribution has points distributed with fairly constant density over an area i.e. homogeneity. Random distribution has uniformity only in terms of probability of occurrence of points. Paradoxically, random distributions are often highly heterogeneous. Uniformity is only obvious when the pattern is geometrically regular. It suggests lack of independence of points from each other. In clustered distribution, obviously density of points varies significantly over the area.

The Chi Square Test (χ^2 – test)

In one sample situation this is the most commonly recommended test for uniformity model. It is a non-parametric test and is restricted to nominal frequency data. It is also highly intuitive and quite straightforward. Let us take the example of e geographer studying the pattern of rural settlements in an area. Settlements are first transformed into point in the area of interest on a map so that a spatial point pattern is formed. The map is then divided into no. of grids of equal dimension. No of points in each grid is then counted.

1. Let the number of points in each grid = O_i
2. No. of grids = K
3. Total no of points (N) = $\sum O_i$
4. For uniform distribution, it is expected that each grid contains identical no. of points. Hence, expected frequency in each grid (E) is defined as the mean no. of points per grid so that, E = N/K

5. The value of Chi-Square is then evaluated from the equation, $\chi^2 = \sum(0_i - E)^2/E$
6. It is then tested with (k - 1) degree of freedom.

$H_{0:}$ point distribution is uniform

H_1: point distribution is heterogeneous

Worksheet for Computation of Chi Square

Grid No	**No. of Settlements (O_i)**	**$(O_i - E)^2 / E$**
1	2	0.78526
2	3	0.129808
3	1	0.847756
4	1	0.847756
5	1	0.847756
6	2	0.078526
7	4	1.001603
8	4	1.001603
9	3	0.129808
10	5	2.693910
11	1	0.847756
12	4	1.001603
13	3	0.129808
14	0	2.437500
15	4	1.001603
16	1	0.847756
-	**∑39**	**∑=13.92308**

With (k - 1) degree of freedom at 0.01 level of significance if χ^2 computed > χ^2 tabulated reject the null hypothesis in favor of the alternate hypothesis and vice versa. This means that the difference between the observed and expected frequencies is highly significant and the spatial pattern of settlement is far from uniform. The observed difference is not due to chance factor alone, but there is definitely a set of controls influencing the spatial pattern of points (settlements) i.e. to be explored further with geographical mind.

Therefore, χ^2 computed < χ^2

Test of Randomness:

In quadrat analysis the area is first divided into a large number of quadrats of identical dimension (T= total number of quadrats). The number of points in each quadrat is counted and totaled. A table is drawn with these showing the observed frequency distribution of quadrats (O_i) corresponding to the number of points. The expected frequencies for each level of points (E_i) are then computed from the Poisson model, as follows

$$E_i = \frac{T \cdot e^{-\frac{N}{T}} \cdot \left(\frac{N}{T}\right)^i}{i!}$$

Where, N = total number of points, and T = number of quadrats. For I = 0

A χ^2 test is then performed to find whether the difference between the observed and the expected frequencies is significant or not with the following hypothesis:

$H_{0:}$ point distribution is random

H_1: point distribution tending towards uniformity or clustering

$$\chi^2 = \sum (0_i - E_i)^2 / E$$

Computation of E_i and χ^2

No. of Points	No. of Quadrats	$Ei = T.e^{-N/T} (N/T)^I / i!$	$(Oi - Ei)^2 / E_i$
0	9	8.033	0.116
1	13	12.049	0.075
2	7	9.037	0.459
3	4	4.518	
4	2	1.694	
5	1	0.508	
6	0	0.161	0.752
-	**∑ = 36**	**∑ = 36**	**∑ = 1.402**

The critical value of χ^2 with two degrees of freedom at the 0.01 significance level is 4.60. this means a value of χ^2 as large as or larger than 4.60 could be obtained by chance under the null hypothesis with a probability of 0.01, as χ^2 computed < χ^2tabulated the null hypothesis can't be rejected at the 0.01 probability level. According to the χ^2- test therefore the points are randomly distributed.

Test of Compactness:

The Nearest Neighbour Analysis technique was devised by a botanist who wished to describe and provide a quantitative description of the patterns of plant distribution especially the distribution of trees. The early beginnings of nearest neighbour analysis can be attributed to the pioneering works of P.J. Clark and F.C Evans in 1954 is their attempt to describe and analyse the pattern and distribution of trees and other plants in the forest. However, since geographers are interested in the study of the pattern of distribution of phenomenon over space the techniques of the nearest neighbour have since been adapted for geographical studies. As such the nearest neighbour analysis has since evolved to it been used to identify a tendency towards or calculate the degree of nucleation (clustering) or dispersion of phenomena in space. The nearest neighbour analysis can be used to analyse the distribution of schools, hospitals, buildings, settlement and a myriad of physical features such as wells, springs mountains, hills etc on the earth surface

Since geography is described as science of spatial relationships of phenomena, the location of human activities (socio- economic as well as cultural) and their distribution pattern have great importance in geographical studies. Distribution of any human activity over space is un-ubiquitous in nature. So the question of location choice of activities is answered by studying their distribution pattern.

Nearest Neighbour Analysis (NNA) provides basis of measuring point pattern of an area/region which would help in understanding the spatial processes of the distribution of human activities. Spatial association and distribution of settlements on the surface of the earth is uneven because the evolution processes of each of them are different from one another and are controlled by the different geographical factors like physiography, climate, soil, natural vegetation and socio-cultural factors also. If settlements are considered as points over space, then the distribution of points is one of main dimensions of studies related to activity distribution. The present analysis provides basis of measuring various arrangements of points or location of settlements.

A set of points of an area can be arranged in a number of ways. But three basic patterns are recognized, namely, regular or uniform, clustered and random. The study of points/settlements distribution in order to discern any regularity in spacing by comparing them with a theoretical random pattern is called Nearest Neighbour Analysis. It is a method of exploring pattern of locational data by comparing graphically the observed distribution with the Nearest Neighbour Distance (NND). It describes the distribution of points according to their spacing. This analysis is done with the help of an index called Nearest Neighbour Index (NNI) which was originally devised by the plant ecologists Clark and Evans in the year 1954. It was originally developed to measure the pattern of incidence of different tree species and was later subsequently applied to the study of understanding the distribution of settlements. However, much of the pioneering work of this kind has been done by King and Dacey in geography. In the study of spatial distribution of settlement, NNA measures the distances between each nearest point and then compares these with the expected values for a random sample of points with a complete spatial randomness. In simple words, it may be said that it measures the ratio of mean of the observed nearest distance with the average expected distance over space to get a Randomness index of point distribution called Rn. However, it depends upon two assumptions:

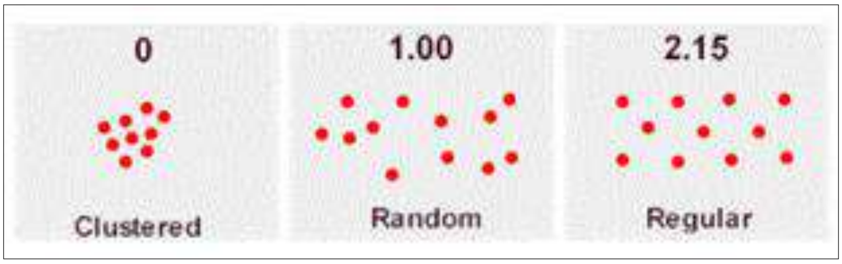
1) All places/ locations of an area are equally likely to be the recipient of an event, and

2) All events are independent at each location.

In measuring the distribution of points over an area, the distance between a pair of nears t points is measured and then mean distance of all the point pairs (i.e., n - 1 where n = number of points) is calculated. In clustered distribution when points are closed to each other, such mean distance will obviously be low, while on the other hand, higher value of mean distance will exhibit relatively high spacing between points and obviously it shows randomness of distribution. To allow comparison between different point patterns and to standardize the results the overall density of points in the area, the Rn value shows results of point distribution.

Figure given below shows three imaginary situations in which points are distributed over an area. One pattern shows loose clusters the other shows a regular spacing and the third one is random distribution of points. 'Random' in this context means the outcome of the processes of location in which any point has the same chance like other points occurring at a particular place on the map or each and every place/point has the same chance of receiving occurrence of an event. However, location of each point does not have influence of the other points. Points are fixed over space.

The nearest neighbour index will produce a result ranging from a minimum as 0 to 2.15, where the following distribution patterns form a continuum:



Three imaginary location patterns measured as clustered, regular and random

Procedure for Calculation

The procedure is as follows:

Step 1: Locate the points/settlements on a map which are to be analysed. For example, Figure-3 illustrates the distribution of 27 villages located in a part of Udaipur district of Rajasthan. The point's data are collected from SOI Toposheet No------------- at R.F. 1: 50,000 having an extent from 24° – 24°5' N latitudes and 73°35' – 73°40' E longitudes with a total area of about 79.55 km^2.

Step 2: Connect all the villages with their nearest neighbour points/villages and measure their crow-fly distances to calculate the average NND for the area under consideration (Table-1).

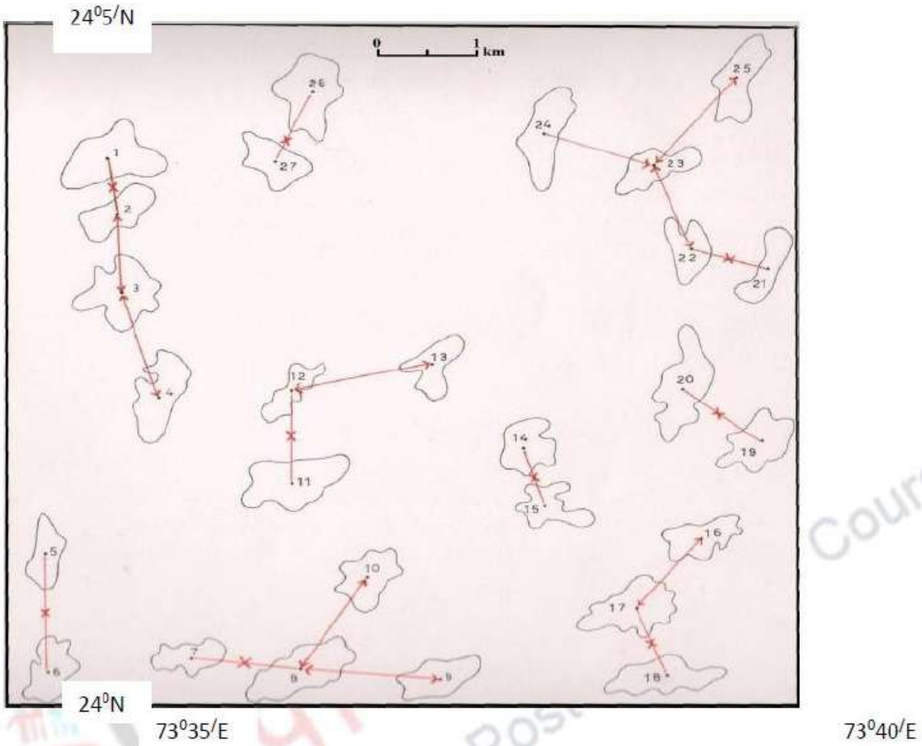


Table 1: Location of the Villages of a part of Udaipur district and their distances with the nearest neighbour villages

Sl No	Village Name	Nearest Neighbour village	Distance (km)	Sl No	Village Name	Nearest Neighbour village	Distance (km)	Sl No	Village Name	Nearest Neighbour village	Distance (km)
1	Larathi	2	0.75	10	Munarara	8	1.45	19	Meghra	20	1.10
2	Samrum	1	0.75	11	Dharpur	12	1.25	20	Kagdoor	19	1.10
3	Sarere	2	1.00	12	Amarpur	11	1.25	21	Bilkhai	22	0.85
4	Bandela	3	1.45	13	Jalpankar	12	1.50	22	Mendela	21	0.85
5	Oro	6	1.60	14	Pana	15	0.8	23	Mokha	22	1.20
6	Madhura	5	1.60	15	Kajdar Bhaliya	14	0.8	24	Darabar	23	1.25
7	Padiyakar	8	1.20	16	Chorai	17	1.15	25	Mandaw	23	1.50
8	Khakhadara	7	1.20	17	Khaindoro	18	1.00	26	Sandar	27	1.00
9	Khandi	8	1.50	18	Odwas	17	1.00	27	Padliza	26	1.00

Total area = 79.55 km^2

Step 3: Measure the distance between each village/town and its nearest neighbour village location. Frequently, only settlements which are close to each other are considered as nearest neighbour and population may be used as an alternate to functional content in establishing those which qualify. If any settlement of the study area has location of nearest neighbour village outside it, these can be included, provided that the necessary information is available for them. In this case, the villages outside the study area are to be ignored.

Step 4: Calculate the mean of the distance recorded in the previous step, to give the observed mean distance between villages and their nearest neighbours ($\bar{D}O$). In the present case ($\bar{D}O$) = 1.15 km per point when total length of all pairs of villages is 31.10 km for 27 number of villages (31.1 / 27).

Step 5: Calculate the density of points in the area (*p)*:

Density (*p*) = number of points (*n*)

Total area (*A*)
= 2779.55
= 0.339 points / villages per sq. km.

Step 6: Calculate the expected mean distance between the villages and their nearest neighbour in a random distribution ($\bar{D}E$). It is shown that:

Expected mean distance ($\bar{D}E$) = 1√p^2
= 1√0.3392
= 0.86 km per point

Note that the density of villages is converted into the linear distance by using concept of circle geometry. So resulted value is shown in km per point / village.

Step 7: Calculate Rn value to determine the distribution pattern, which is the ratio between the observed and expected means of calculated distances as has been represented by the following Formula:

Nearest Neighbour Ratio (Rn) =$\bar{D}o/\bar{D}E$

= 1.15/0.86

= 1.337

Where, $\bar{D}O$= mean of the nearest observed distance, $\bar{D}E$= expected distance

Where, $\bar{D}E$ = 1√p^2 and

p = density of points in an area nA

Any calculated value for *Rn* will fall somewhere between 0 – 2.15. The smaller is the value the more clustered will be the pattern and the higher the value the more regular will be the pattern. This indicates that an *Rn* value of 0 will indicate a complete clustering which means that there is maximum aggregation of all the points at one location. 1 indicates a random distribution while 2.15 indicates a regular pattern. In case of village study *Rn* = 0 will indicate a compact distribution of buildings while *Rn* = 2.15 will indicate a complete dispersed situation. In the above example a value of 1.337 indicates a near random situation. But the term random describes only the appearance and not the factors which produced it. Nearest Neighbour Analysis is useful for simple objective comparison. The distribution of villages in Udaipur district of Rajasthan may be directly compared with similar patterns with other parts of the country. In practice Rn are unlikely to approach very closely to either end of the scale of possible values and it is as well to avoid labelling distribution as uniform or clustered.

The value of Rn may fall between 0 and 1 or from 1 to 2.15 which may indicate either approaching cluster or approaching uniform distribution if the value of $\bar{D}E$ is significantly different from $\bar{D}O$. Otherwise, the distribution should be considered as random as the difference between observed and expected is attributed to the chance factor only. This situation can be answered by inferential statistical methods. If the sets of observations are a sample or treated as such, the probability that the pattern could have arisen by chance can be established by a statistical test.

Z - Statistics

The deviation between observed and expected nearest neighbour mean distances is tested to use a *z*-statistics derived such that:

z = $\bar{D}E - \bar{D}O / SdE$,

Where, *SdE* denotes the term standard error of the expected mean nearest neighbour distance that has been found to be:

$SdE = 0.26136/\sqrt{n}\ (nA)$,

Where, n = number of observations and A = the area.

Greater the difference between the observed and expected average distances, the larger are the values of the z test which shows greater the probability of non-randomness of observed pattern and vice versa. However, this test requires a large number of points, not less than 100 to test the probability of randomness in understanding point distribution.

4. Analysis of Directional Data: Rose Diagram, Dominant Direction, Mean Direction.

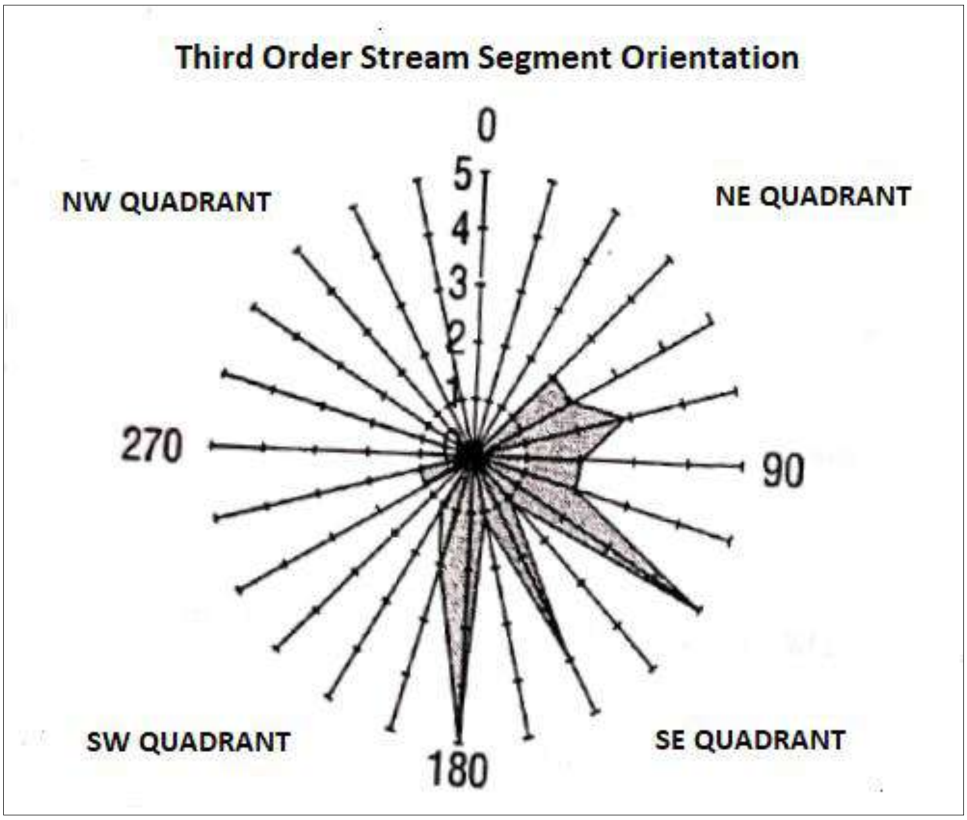
Directions or orientations of geographical objects often form interesting subjects in geographical studies. This concerns data, measured in terms of angles or azimuth or bearings from north, e.g., orientation of streams, watershed, paleo channels, sand dunes, wind, settlements, levee and so on. This type of data can be easily ordinated on a circle: hence, the term, circular statistics.

Circular data is of two types:

1. **Directional data** that conveys linear phenomena in which one end of the line is distinguishable from the other; and
2. **Oriented data** that are appropriate for phenomena without such directional distinction.

The simplest presentation of directional data is as points marked on the periphery of a circle with lines to the centre. With circular data, the distribution graph is made of segments of circles with radii proportional to frequency: the rose graph/star graph/vector graph. Rose diagrams are useful in geography fieldwork to analyse data containing magnitude and direction values. They are commonly used to display the direction, strength and frequency of wind or ocean waves, the orientation of the long axes of pebbles and the direction that cirques or corries face.

Third Order Stream Order Direction in the Dulung River Basin



Frequency Distribution

In frequency distributions of circular data, the null expectation is to have a uniform probability distribution over the entire possible range of values (i.e., between 0°E and 360°E). Therefore, the null random frequency distribution is a uniform distribution without the kind of modal peak value (as is common in univariate distributions). However, there are occasions where the values of directional data disperse around a preferred direction.

The normal distribution in circular statistics is known as the von Mise's distribution that has two parameters:

1. The mean direction (θ_M), and
2. The concentration parameter, K

The latter can be estimated from the mean resultant length, it has values that increase as the dispersal decreases:

K = 0 is interpreted as a uniform distribution

Table Showing the Parameters of Directional Analysis of a River Basin

MAP NO.: SOI 73 C/4

Stream ID.	θ	$X_i = \sin\theta_i$	$Y_i = \cos\theta_i$	Stream ID.	θ_i	$X_i = \sin\theta_i$	$Y_i = \cos\theta_i$
1-1	104°00′	0.97029	-0.24192	1-19	150°00′	0.50000	-0.86602
1-2	111°00′	0.93358	-0.35836	1-20	17°30′	0.30070	0.95371
1-3	160°00′	0.34202	-0.93969	1-21	149°00′	0.51503	-0.85716
1-4	90°00′	1.00000	0	1-22	96°00′	0.99452	-0.10452
1-5	134°00′	0.71933	-0.69465	1-23	99°00′	0.98768	-0.15643
1-6	84°00'	0.99452	0.10452	1-24	72°30′	0.95371	0.30070
1-7	57°00′	0.83867	0.54463	1-25	86°00′	0.99756	0.06975
1-8	29°00′	0.48480	0.87461	1-26	121°00′	0.85716	-0.51503
1-9	18°00′	0.30901	0.95105	2-1	101°00′	0.98162	-0.19080
1-10	3°00′	0.05233	0.99862	2-2	54°00′	0.80901	0.58778
1-11	63°30′	0.89493	0.44619	2-3	29°00′	0.48480	0.87461
1-12	50°00′	0.76604	0.64278	2-4	27°00′	0.45399	0.89100
1-13	27°00′	0.45399	0.89100	2-5	29°00′	0.48480	0.87461
1-14	344°00′	-0.27563	0.96126	2-6	84°00′	0.99452	0.10452
1-15	5°30′	0.09584	0.99539	2-7	67°30′	0.92387	0.38268
1-16	53°45′	0.80644	0.59130	3-1	59°00′	0.85716	0.51503
1-17	37°15′	0.60529	0.79600	3-2	105°00′	0.96592	-0.25881
1-18	347°40′	-0.21359	0.97692	-	-	22.79059	10.14527

$X_R = \Sigma \sin\theta_i$ $=22.79059$	**$Y_R = \Sigma \cos\theta_i$ $= 10.14527$**	**$\theta_M = \tan^{-1}(X_R / Y_R)$ $= \tan^{-1}(22.79059 / 10.14527)$ = 66°00′**
$L_R = \sqrt{[X_R^2 + Y_R^2]}$ $= \sqrt{[22.79059^2 + 10.14527^2]}$ $= 24.94669$	**$L_{RM} = L_R / n$ $= 24.94669 / 35$ $= 0.71276$**	**$\sigma_\theta = (1 - L_{RM})$ $= (1 - 0.71276)$ $= 0.28724$**
θ_M = Mean Direction; L_R = RESULTANT LENGTH; L_{RM} = Mean Resultant Length; σ_θ = Circular Variance; n = Total Number of Sample Streams		

As both the summations of X and Y components are positive,
Mean Direction = (66°00′ + 0°)
= 66°00′
Mean resultant length of all the channels in Basin A is small.
The magnitude of circular variance is also very low, implying very insignificant dispersion.

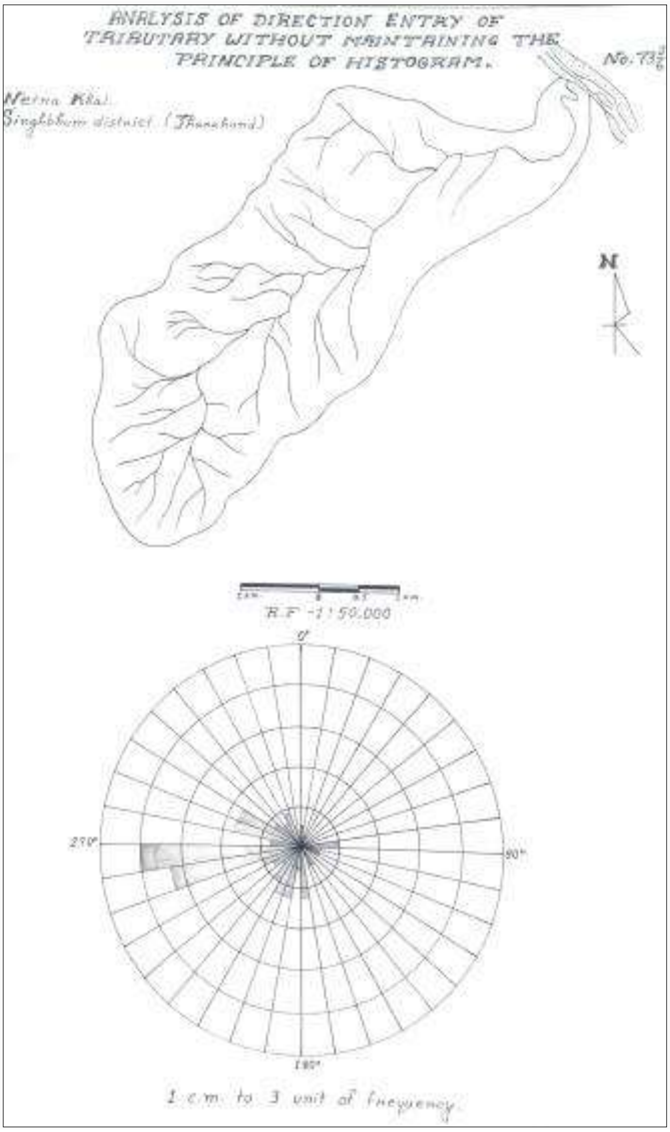
Dominant Direction

The dominant directions are computed by the cluster algorithm and fuzzy set theory. The dominance of those dominant directions is computed and used for similarity measurement. Dominant direction gives the direction; if the direction is not dispersed then result of vector is long and if the directions are spread, then the result of vector is shorter.

Table for Calculation of Dominant Direction Entry of Tributary

(Netra Khal of Singbhum District, Jharkhand)

Class Width	Frequency	**AU = SU √f** AU = Adjacent Unit, SU = Scale Unit, f = Frequency
0° – 10°	1	1
80° – 90°	3	1.73
100° – 110°	1	1
110° – 120°	1	1
150° – 160°	1	1
160° – 170°	1	1
170° - 180°	4	2
180° – 190°	1	1
190° – 200°	4	2
200° – 210°	4	2
210° – 220°	3	1.73
220° – 230°	1	1
230° – 240°	2	1.41
240° – 250°	3	1.73
250° – 260°	10	3.16
260° – 270°	12	3.46
270° – 280°	2	1.41
290° – 300°	5	2.24
300° – 310°	2	1.41
310° – 320°	1	1
320° – 330°	1	1
330° - 340°	2	1.41



5. Analysis of Shape: Measures Based on Axial Ratios, Perimeters to Areas, Areas to Axial Length.

The fundamental unit of virtually all watershed and fluvial investigations is the drainage basin. An individual drainage basin (catchment or watershed) is a finite area whose runoff is channelled through a single outlet. In its simplest form, a drainage basin is an area that funnels all runoff to the mouth of a stream. Drainage basins may be delineated on a topographic map by tracing their perimeters or drainage divides. A drainage divide is simply a line on either side of which water flows to different streams. Locally, the most famous drainage divide is the Continental Divide. Each drainage basin is entirely enclosed by a drainage divide.

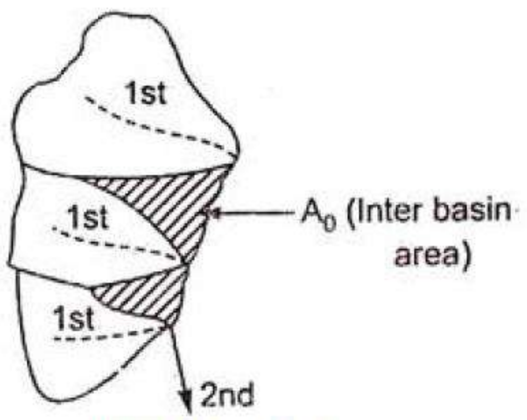
Drainage basins are commonly treated as physical entities. For instance, flood control along a particular river invariably focuses on the drainage basin of that river alone. Because drainage basins are discrete landforms suitable for statistical, comparative, and analytical analyses, innumerable means of numerically and qualitatively describing they have been proposed. This laboratory is an introduction to some of the means by which drainage basins are described, particularly via drainage basin morphometry. Morphometry is essentially quantitative, involving numerical variables whose values may be recovered from topographic maps. The importance of morphometric variables is their usefulness for comparisons and statistical analyses.

Watershed Perimeter (P_p):

Watershed perimeter is the outer boundary of the watershed that enclosed its area. It is measured along the divides between watersheds. It is the indicator of watershed size and shape.

Watershed Area (A_w):

Drainage area, basin area and catchment area are the synonyms of watershed area. It is the area surrounded by the ridge line / divide of that watershed. It can be expressed in m^2, hectares or Km^2. It is an important morphological feature as the amount of runoff is influenced by it. Watershed area is having two components, stream area and inter basin.



View of Inner Basin Area

The stream area discharges its runoff to stream order number 1 but inter basin area discharge its runoff directly to the stream order higher than 1.

Watershed Shape:

It is an important parameter from hydrological point of view and it refers to the shape of boundary line of watershed or drainage basin. The basin shape is determined as the shape of projected surface on the horizontal plane of basin map. The study of basin shape is important to predict the stream discharge as it mainly governs the rate at which the water is supplied to the main channel. Three parameters viz. Elongation Ratio (R_e), Circulatory Ratio (R_c) and Form Factor (R_f) are used for characterizing drainage basin shape.

Watershed may have several shapes. Broadly we may consider fan shaped (circular) and fern shaped (elliptical) watershed. Shape is closely related to contribution of runoff to outlet.

In fan shaped watershed the runoff from various parts accumulates to outlet at almost same time thus magnitude of peak runoff is high.

In fern shaped watershed the runoff from various parts reach gradually to outlet thus magnitude of runoff is lower as compare to fan shaped watershed.

The watershed shape is reflected by number of parameters like form factor, shape factor, circulatory ratio, elongation ratio and compactness coefficient.

Form Factor (R_f):

Form factor, introduced by Horton (1932) is the numerical index commonly used to represent different basin shapes. It is defined as the ratio of basin area to the square of the basin length. Here the length to be used is not necessarily the maximum length but is to be measured from a point on the watershed-line opposite the head of the main stream.

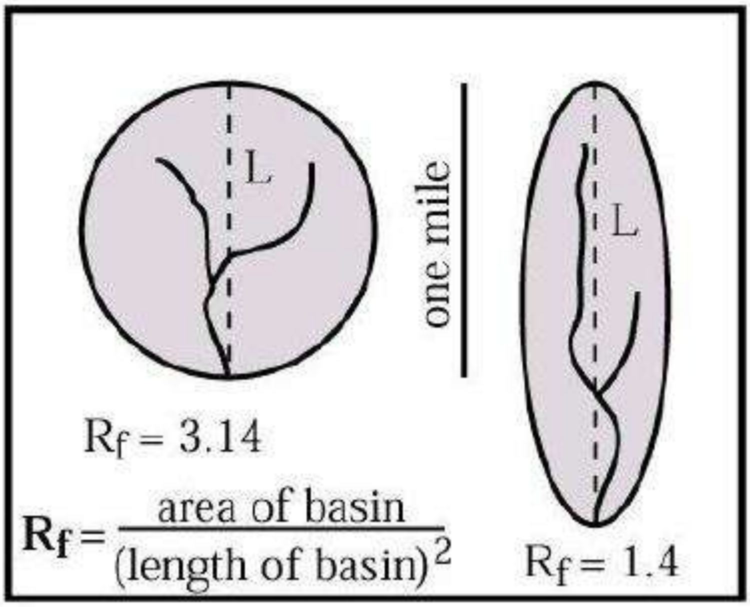
$$F = \frac{M}{L^2}$$

Where, M is the drainage-area in square miles and L its length.

This factor has been considerably used in connection with maximum flood-discharge formulas. In the case of long, narrow drainage-basins, such as basins occupying synclinal valleys and rift valleys, the form factor is truly an important indicator for the flood analysis. For drainage- basins of Irregular form, especially those with permeable soils, form factor is not a sensitive indicator of hydrologic characteristics.

Shape Factor

It is defined as the ratio between watershed area (Aw) and the square of main flow path. It is a dimensionless number and will always be less than 1.



Basin shape for a given area, as basin length increases the value R_f decreases.

The value R_f should be comparable among basins of very different size. To calculate R_f, simply measure the linear distance (L) between the mouth of the basin and the point most distant from the mouth and use the formula:

$$R_f = \frac{A_b}{L^2}$$

Elongation Ratio (Re):

S. A. Schumm (1956) used the elongation ratio as an index to mark the shape of drainage basin. It is defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length. It is also a dimensionless parameter.

$$R_e = \frac{D_c}{L_{bm}}$$

Where, R_e = elongation ratio, D_c = diameter of circle which area is same to the given drainage basin and L_{bm} = maximum basin length.

The value of Re varies from 0 (in highly elongated shape) to 1.0 (in the circular shape).Thus higher the value of elongation ratio more circular shape of the basin and vice-versa. Values close to 1.0 are typical of regions of very low relief, whereas that of 0.6 to 0.8 are usually associated with high relief and steep ground slope.

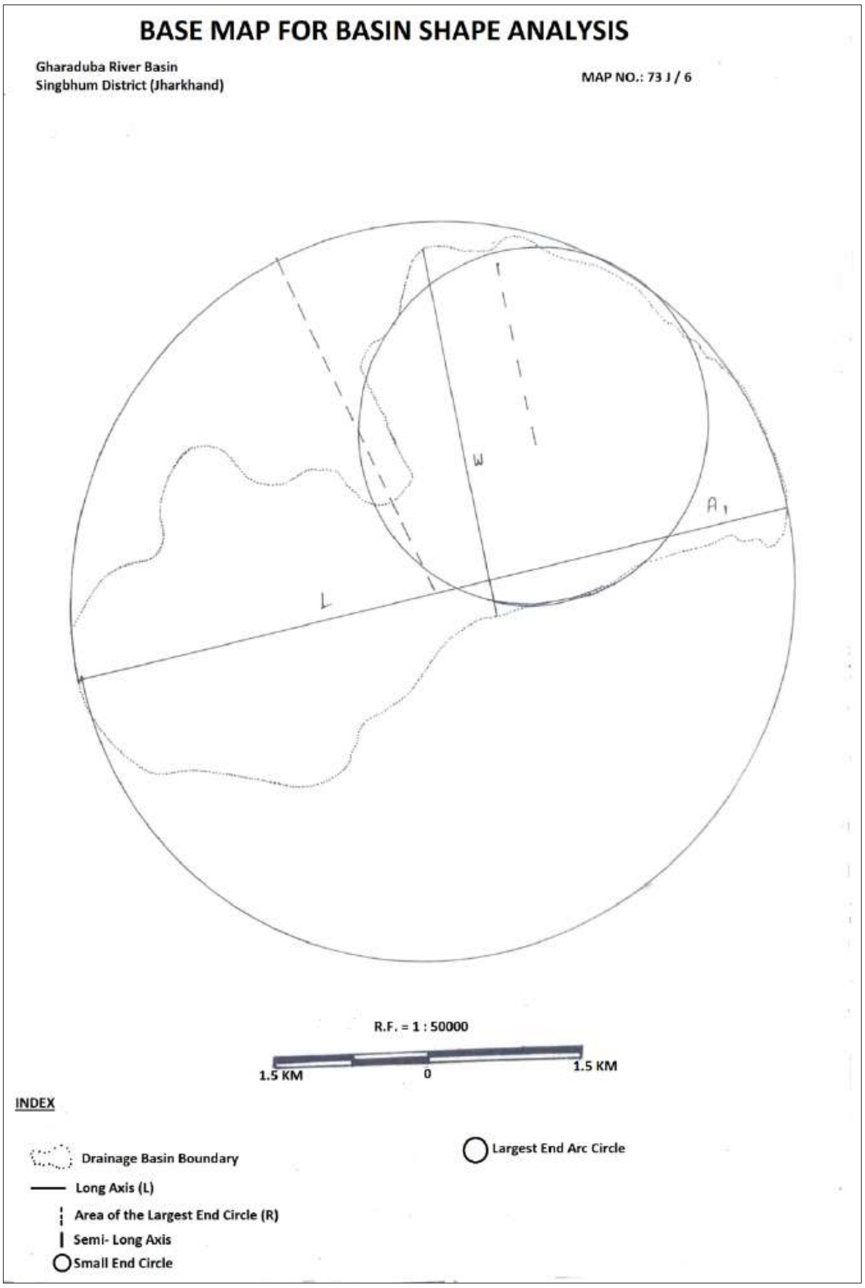
Elongation ratio	Shape of watershed
< 0.7	Elongated
0.8-0.7	Less elongated
0.9-0.8	Oval
> 0.9	Circular

Circularity Ratio (R_c)

V. C. Miller (1935) used the term 'circulatory ratio' to indicate the basin shape. It is the ratio of the area of the basin (A_u) to the area of the circle (A_c) having same circumference as the basin perimeter. It is dimensionless. Theoretically, the value of circularity ratio varies from 0 (in line) to 1 (in a circle). Miller in his study reported that the value of R_c varies from 0.6 to 0.7. It is expressed as:

$$R_c = \frac{A_u}{A_c}$$

Some Other Important Formulas for Basin Shape Analysis



A. Basin Shape Analysis Based on Axial Ratio

1. Form Analysis (F) = L / W

Where, L = Length of long axis and W = Width perpendicular to long axis.

2. Elongation (E) = W / L

Where, W = Width perpendicular to long axis and L = Length of long axis.

3. Circulatory (C) $= \sqrt{\mathbf{LW/L^2}}$

Where, L = Length of long axis and W = Width perpendicular to long axis.

B. <u>Basin Shape Analysis based on Perimeter of Area</u>

Circulatory (1) = $4A / P^2$

Where, A = Area of basin, P = Perimeter of basin ($2\pi R$).

C. <u>Basin Shape based on Area</u>

1. Shape Factor (1) = A_i / A

$A_i = \pi R^2$

Where, A_i = Area of the smallest enclosing circle, A = Area of basin.

2. Shape Factor (2) = $A_c – A_i / A$

$A_c = \pi R^2$

Where, A_c = Area of the largest enclosing circle, A = Area of basin.

D. <u>Basin Shape based on Area and Axial Length</u>

1. Form Ratio = A / L^2

Where, A = Area of basin, L = Length of long axis.

2. Ellipticity Index $= \frac{\pi\left(\frac{1}{2}\times L\right)L}{A}$

Where, L = Length of long axis, A = Area of basin.

3. Circulatory $= \frac{4A}{LP}$

Where, A = Area of basin, L= Length of long axis, P = Perimeter of basin.

4. Compactness (1) $= \frac{2\sqrt{\pi A}}{P}$

Where, Where, A = Area of basin, P = Perimeter of basin.

5. Compactness (2) $= \frac{P^2}{4\pi A}$

Where, Where, A = Area of basin, P = Perimeter of basin.

6. Thickness Ratio (TR) = $4\pi (A / P^2)$

Where, Where, A = Area of basin, P = Perimeter of basin.

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GEO 496.2: RESEARCH EXERCISE IN GEOGRAPHY

Final year students are required to organise an individual field work on a specific environmental issue and generation of report (within about 50 A4 size pages including 15-20 maps/diagrams/field photographs).

Every student should follow the prescribed format of research report as proposed by the Midnapore City College, Midnapore, West Bengal, India.

Students should follow the following format (as per proposed by the Midnapore City College):

1. Cover Page
2. Certificate (Should be printed in College letter head)
3. Approval Sheet
4. Declaration
5. Acknowledgement
6. Abstract
7. Table of Contents
8. List of Tables
9. List of Figures
10. Introduction
11. Literature Review
12. Aims and Objectives
13. Material and Methods
14. Results
15. Discussion
16. Conclusions
17. Future Scope

(For details about the proposed format of research report/dissertation, please see the lab manual of MCC-GEO-PG-Semester – III)

DISCLAIMER

This self-learning material is based on different books, journals and web sources.