Section 2. Creating and Using GIS Datasets#

2.4 Projections and Coordinate Systems#

These matter because at some point there is a need to integrate information from different projects in order to study the results together or in the context of something new. Projections are increasingly important because of the widespread availability of affordable satellite navigation devices that enable one or more locations to be accurately recorded and the data retrieved for later use. Coordinate systems are important because these provide the means of specifying a location. This section aims to introduce these topics but cannot be a replacement for the excellent texts on the subjects, to which reference is made in the text and where the necessary detail will be found.

2.4.1 Why do we need Projections?

Our planet Earth is not in fact a sphere, although it is often most convenient to treat it as such, as indeed is done by the various satellite positioning systems. Even if the Earth were a perfect sphere, there would remain a problem, because spheres make rather inconvenient notebooks or publication media. Imagine a set of paper maps replaced with set of balls or curved plates! Unfortunately it is not possible to accurately and completely represent the surface of a sphere on any other type of surface: for example, having peeled an orange, the peel only joins up again when back in the orange shape. The process of rendering the surface of a sphere onto another type of surface is likened to placing a light source within the sphere and *projecting* the surface as an image onto the destination medium as though that were a screen. How this works is a matter for the textbooks; however, because the process inevitably introduces elements of distortion into the result, because the result is not on the surface of a sphere, it is necessary to understand something of the implications.

There is an additional complication: not only is the Earth not a sphere, it is not actually a regular geometric shape: it is flattened at the poles and over the oceans and bulges at the Equator and over the continents. Sometimes this shape is treated as an ellipsoid or an oblate spheroid, but the term most generally used is *Geoid* - which simply means *Earth-shaped*. As a result, there is no single elegant solution but many alternatives, as different parts of the Earth's surface require different types of solution. Sadly, the choice of the wrong projection for a particular purpose or location can have very serious consequences.

There are four key characteristics of any representation of a three dimensional phenomenon or of a planimetric representation: shape, scale, direction and area. These are also characteristics of projections but, with the source being a transformation from the curved surface of the Geoid, it is not possible to preserve all four - except on the Geoid. The loss of one or more of these characteristics means that the result is a compromise between fidelity to the surface of the Earth and the flat represntation on paper or the computer screen. This also means that there are different types of projection for different applications.

2.4.2 Properties and Types of Projection

There are four classes of projection properties and three classes of type. It is theoretically possible for there to be projections of each type and property, and combinations of up to three of each of the properties but there are combinations that are uncommon. This guide can only explore some of the most common types of projection, the literature must be consulted for others.

Conformal projections

Conformal projections preserve *shape*. However, especially where the coordinate system is Cartesian, *area* will be distorted; it is only possible to preserve shape for small parts of the Earth's surface and no projection can preserve shape at a regional or global scale.

Equal-area projections

Equal-area projections preserve the *area* of the represented part of the Earth's surface but at the expense of distortion to shape and possibly angle and or scale. For very small areas of the Earth's surface, the extent of distortion to shape may be difficult to measure. Some equal-area projections do not yield Cartesian coordinate systems.

Equidistant projections

Equidistant projections maintain correct scaled distance between selected points but, as with all other projections, no projection can preserve true distance everywhere on the map.

Azimuthal projections

Azimuthal projections preserve direction between all points represented and are sometimes called *true-direction* projections. Azimuthal projections are typically used for maps used to support navigation.

Conic projections

Conic projections work as though a cone of paper has been placed on the Earth. Conic projections where the cone only touches the surface along a single circle are said to have *one standard parallel*, whilst those which intersect the surface are said to have two. The simplest conic projections *sit* on a pole, *polar conic* projections, with the others are termed *oblique*. In conic projections, the meridians, lines of longitude, meet at the tip of the cone and the parallels, lines of latitude, are parallel to each other, but not necessarily equally spaced. The cone is generally opened out along the line opposite the *central meridian*. Conic projections are sometimes used for polar regions, but are more often used for regions that have a large horizontal, East to West, extent: the *Lambert Conic Conformal* projection is often used for representing the co-terminal states of the USA.

Cylindrical projections

Cylindrical projections can be envisaged as a sheet of paper wrapped around the Earth to form a cylinder. In cylindrical projections, the meridians are all parallel and equally spaced and the parallels intersect the meridians at right angles but need not be equally spaced. In *Normal* cylindrical projections, the paper is wrapped around the equator and is open at the poles. In *Transverse* cylindrical projections, the paper is wrapped around the poles and open at two sides to the Equator. The well known *Mercator* projection is a *normal cylindrical* projection, whilst the *Transverse Mercator* projection is the *transverse* form. The British National Grid system, introduced in 1936, is a *Transverse Mercator* projection, as are UTM (which is widely used in the US) and the *Gauss Conformal* or *Gauss-Krüger* projection widely used in mainland Europe. The *Cassini* projection, used for the early *County Series* mapping of Great Britain, is also a *transverse cylindrical* projection and is well suited for mapping regions that have limited horizontal extent but extend considerably North to South.

Planar projections

Planar projections work as though a flat piece of paper is placed tangential to the Earth's surface and can take *polar*, where the point of tangency is a pole, *equatorial*, where the point of tangency is on the Equator, or *oblique* forms. The *polar* form is the most common planar projection, in *azimuthal* form being often used for mapping polar regions.

Geographic projection

The literature also often refers to a concept of a *geographic* projection yet, properly, this is not a projection at all. In the *geographic* projection position is represented by spherical coordinates of angles relative to the centre of the Earth, degrees of *Latitude*, and angles around the Equator relative to a reference *Meridian*, degrees of *Longitude*. The reference, *prime*, meridian, zero degrees, is arbitrarily chosen to be the Greenwich Meridian. There is usually no geoid associated with this concept, thus it is not possible to measure distance or area but it is possible to estimate direction. When assoicated with the *WGS84* spheroid, this equates to the positioning system used by satellite navigation systems.

2.4.3 Coordinate Systems

Coordinate systems provide a means of communicating the location of some feature represented on a map in terms of that map representation. The most commonly used are termed *Cartesian*, after Descartes, and comprise a regular grid relative to two or three axes at right angles to each other, as in a graph or chessboard. There are many types of Cartesian coordinate systems, from mixtures of letters and digits, as with a chessboard, to numeric offsets from an origin, as with a graph. It is not strictly necessary for a Cartesian coordinate system to use the same units or unit interval on each axis, although using different units or intervals for the horizontal axes is liable to lead to considerable confusion for anyone seeking to *read* the map or plan. Some of the impacts on end users of the choice of projection and coordinate system are discussed by Monmonier (1996).

Cartesian coordinates

These are familiar to most people and are those used in archaeological site grids, comprising a set of measurements along axes set at right angles to each other. Typically these measurements are *in metres*, as in the British National Grid, but *feet* are used in the USA.

Spherical coordinates

These are measurements of angles relative to the centre of a sphere and relative to a central *prime meridian*. The *Greenwich Meridian*, the meridian passing through Greenwich, in south west London and as measured by Sir George Airy in 1851 was adopted internationally in 1884. More recently and based on measurements from satellite observation, an *International Earth Rotation and Reference Systems* meridian, the *IERS Reference Meridian (IRM)*, was established for use by satellite navigation systems. The IRM is very slightly to the East of Airy's Greenwich Meridian.

Other coordinate systems

Postal codes provide a means of referencing the location of properties, or small groups of properties, and have given rise to a geography based on these references. In the UK, Postcodes are widely used for social science applications, such as Census work and the unit is also used by emergency services and planners.

2.4.4 Datums

Every projection requires a *Datum*, which provides the reference grounding to the Earth's surface. The datum provides the reference parameters for the coordinate system to *lock* it to the surface of the Earth. All datums define the geoid to be used for approximating the shape of the Earth when calculating position and it is critically important to use the correct datum, or positional calculations can become wildly inaccurate. The datum also defines the zero point for measuring altitude or depth. Ordnance Survey define a number of datums for use for Great Britain, based on the Airy Spheroid; the choice of datum is dependent on scale and location within Great Britain and there is a general purpose datum for use with small scale mapping, eg 1:50000.

2.4.5 Further Reading

This guide is not the place to teach map projections, coordinate systems or datums. Some of the following publications assume the reader to have some understanding of the topics concerned, although Kennedy and Kopp (2000), Monmonier (1996) and Snyder (1987) all provide at least some introductory material. Snyder (1987) is the key authority, especially should formulae for individual projections be required. Bugayevsiy and Snyder (1995) and Yang, Snyder and Tobler (2000) also include discussions and formulae relating to mapping in Russia and the former USSR and the Peoples Republic of China respectively.
