Chapter 2

GIS CONCEPTS

To use GIS effectively, it is important to understand the basic GIS terminology and functionality. While each GIS software has slightly different naming conventions, there are certain principles common to all systems. At first, we briefly describe the GIS basics in general (for in depth information read Longeley et al., 2002, Clarke, 2002, or Burrough and McDonnell, 1998) and then we explain the principles of map projections and coordinate systems that are used to georeference the data.

2.1. GENERAL GIS PRINCIPLES

Data in the GIS database provide a simplified, digital representation of Earth features for a given region. Georeferenced data can be organized within GIS using different criteria, for example, as thematic layers or spatial objects. Each thematic layer can be stored using an appropriate data model depending on the source of data and their potential use.

2.1.1 Geospatial data models

Georeferenced data include a *spatial* (geometrical or graphical) component describing the location or spatial distribution of geographic phenomenon and an *attribute* component used to describe its properties. The spatial component can be represented using one of the two basic approaches (Figure 2.1):

- *field* representation, where each regularly distributed point or an area element (pixel) in the space has an assigned value (a number or no-data), leading to the *raster data model;*

- *geometrical objects* representation, where geographic features are defined as lines, points, and areas given by their coordinates, leading to the *vector data model.*

Depending on the scale, the representation of a geographic feature can change; for example, a river can be handled as a line at small scale or as a continuous 3D field (body of water) at a large scale. Similarly, a city can be represented as a point or an area. Note that we use the terms small and large scale in the cartographic sense, for example, 1:1million is small scale, 1:1000 is large scale.

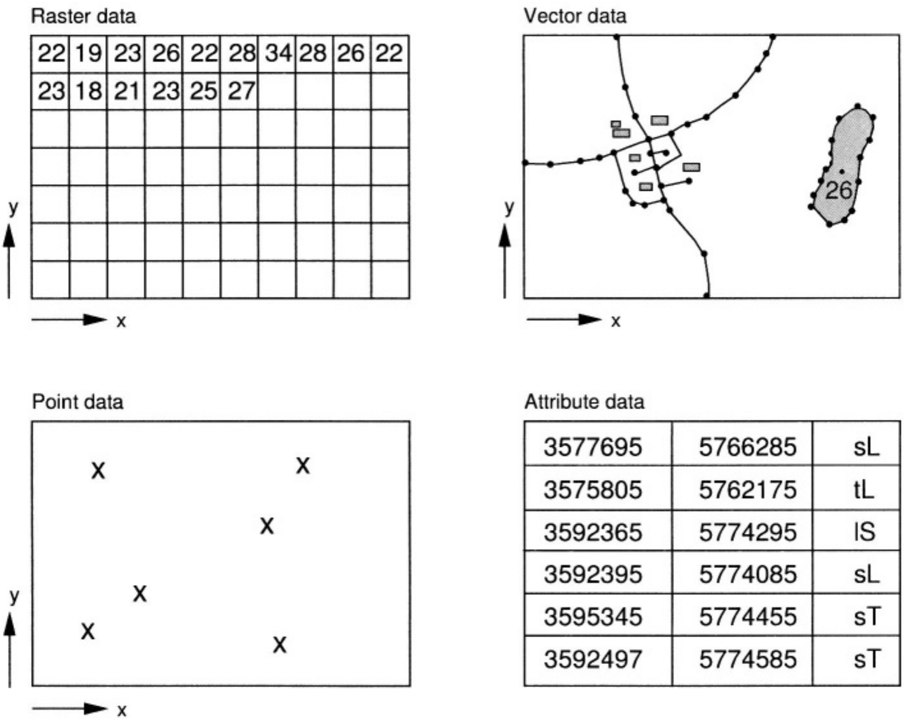

Figure 2.1. Data models in GIS: raster, vector, point data and attributes:
Raster data: rows and columns of values representing spatial phenomenon;
Vector data: representation by lines and areas;
Point data: values are assigned to individual points which are often irregularly distributed;
Attributes: descriptive data stored in a database table

To effectively use GIS, it is useful to understand the basic properties and applications of each data model (in older GIS literature, the raster and vector data models have been often referred to as raster and vector data formats).

Raster data model. Raster is a regular matrix of values (Figure 2.1). If the values are assigned to *grid points,* the raster usually represents a continuous field (elevation, temperature, chemical concentration) and is sometimes called *lattice.* If the values are assigned to *grid cells* (area units), it represents an image (satellite image, scanned map, converted vector map). If the cell values represent category numbers, one or more attributes can be assigned to that cell using a database. For example, a soil type number 3 can have attributes describing its texture, acidity, color and other properties. The grid cells are organized and accessed by *rows* and *columns.* The area represented by a square grid cell is computed from the length of its side, called *resolution.* Resolution controls the level of spatial detail captured by the raster data. Most data are represented by a 2D raster, with the grid cell (unit area) called a *pixel;* volume data can be stored as a 3D raster with a unit volume called a *voxel.* General d-dimensional raster formats are used for spatio-temporal or multispectral data (e.g. HDF format[1]).

The raster data model is often used for bio-physical subsystems of the geosphere such as elevation, temperature, water flow, or vegetation. However, it can also be used for data usually represented by lines and polygons such as roads or soil properties, especially for scanned maps. The raster data model was designed with a focus on analysis, modeling and image processing. Its main advantage is its simplicity, both in terms of data management as well as the algorithms for analysis and modeling, including map algebra. This data model is not particularly efficient for networks and other types of data heavily dependent on lines, such as property boundaries. GRASS has extensive support for the raster data model.

Vector data model. Vector data model is used to represent areas, lines and points (Figure 2.1). In this section, we describe the vector data model using GRASS terminology; however, in other systems the definitions may be slightly different.

The vector data model is based on *arc-node* representation, consisting of non-intersecting curves called *arcs.* An arc is stored as a series of points given by (*x,y*) or (*x,y,z*) coordinate pairs or triplets (with height). The two endpoints of an arc are called *nodes.* Points along a curve are called *vertices.* Two consecutive (*x,y*) or (*x,y,z*) pairs define an *arc segment.* The arcs form higher level map features: *lines* (e.g., roads or streams) or *areas* (e.g., farms or forest stands). Arcs that outline areas (polygons) are called *area edges* or *area lines.* Each map feature is assigned a category number which is used to link the geometric data with descriptive, attribute data (such as category labels or multiple attributes stored in a database). For example, in a vector map layer "roads", a line can be assigned category number 2 with a text attribute "gravel road" and a numerical attribute representing its width.

In addition to the coordinate information, the vector data model often includes information about the data *topology* which describes the relative position of objects to each other. The rules which apply to the vector data with topology description are explained in the Section 6.1.1.

Linear features or polygon boundaries are drawn by straight lines connecting the points defining the arc segments. To reduce the number of points needed to store complex curves, some GIS include mathematically defined *curve sections* or *splines* which are used to compute the points with the required density at the time of drawing.

Vector data are most efficient for features which can be described by lines with simple geometry, such as roads, utility networks, property boundaries, building footprints, etc. Continuous spatial data can be represented by isolines or various types of irregular meshes using the vector data model; however, such representations usually lead to more complex algorithms for analysis and modeling. GRASS 5.3 provides basic support for the 2D vector model, while the GRASS 5.7 introduces 3D multiattribute vector model.

Point data model. The point data model is a special case of the vector data model. It is a set of independent points given by their coordinates representing point features (e.g. a city or a church) or samples of continuous fields (e.g., elevation, precipitation), often irregularly distributed. A value or a set of attributes (numerical or text) is assigned to each point. Point data are often represented using the vector data model. GRASS up to version GRASS 5.3 allows the user to store point data in a special data model designated as sites while GRASS 5.7 manages point data in the Vector model.

Attributes – GIS and databases. Attributes are descriptive data providing information associated with the geometrical data. Attributes are usually managed in external or internal GIS database management systems (DBMS). The databases use the corresponding coordinates or identification numbers to link the attribute to the geometrical data. Other systems such as PostGIS[2] also allow the user to store geometrical data into the database. GRASS 5.3 offers a limited internal database and several interfaces to external databases (PostgreSQL, ODBC interface to various DBMS). The GRASS internal database supports only a single attribute for each vector object or cell category. GRASS 5.7 provides extended capabilities as it includes a SQL-DBMS engine.

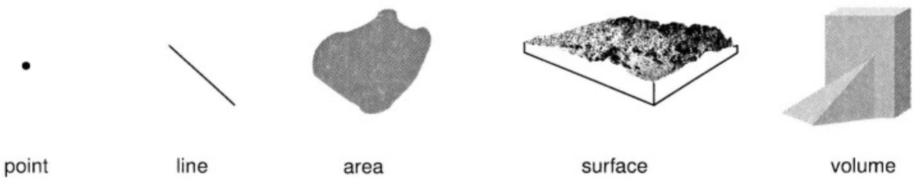

Figure 2.2. Data dimensions in a Geographical Information System (after Rase, 1998:19)

Data model transformations. The same phenomenon or feature can be represented by different data models. GIS usually includes tools for transformation between the vector, raster and site data. For example, elevation can be measured as point data, then interpolated into the raster map layer which is then used to derive contour lines as vector data. Note that transformations between different data models are usually not lossless (there can be a loss or distortion of information due to the transformation).

Dimensions of geospatial data. In general, Earth and its features are located and evolve in 3D space and time. However, for most applications a projection of geospatial data to a flat plane is sufficient; therefore two-dimensional representation of geographical features (with data georeferenced by their horizontal coordinates) is the most common. Elevation as a third dimension is usually stored as a separate data layer representing a surface within three-dimensional space (often referred to, not quite correctly, as a 2.5-dimensional representation, Figure 2.2). Elevation can be also added as a z-coordinate or an attribute to vector and point data. If there is more than a single value associated with a given horizontal location, the data represent a volume and are three-dimensional (e.g. chemical concentrations in groundwater, or air temperature). Three-dimensional data can change in time, adding the fourth dimension. GIS provides the most comprehensive support for 2D data. GRASS 5.3 includes a 3D raster model for volume data and a multidimensional, multi-attribute site data format (see Brandon et al., 1999; Neteler, 2001a); however, only a limited number of modules is available for volume data.

2.1.2 Organization of GIS data

GIS can be implemented as a comprehensive, multipurpose system (GRASS, ArcGIS), as a specialized, application oriented tool (MapQuest), or as a subsystem of a larger software package supporting handling of geospatial data needed in its applications (e.g. hydrologic modeling system, geostatistical analysis software, or a real estate services Web site). The multipurpose systems are often built from smaller components or modules which can be used independently in application oriented systems.

The multipurpose GIS usually stores the georeferenced data as thematic *map layers*. Each geographic feature or theme, such as streams, roads, vegetation, or cities is stored in a separate map layer using the vector or raster data model. The map layers can then be combined to create different types of new maps as well as perform analysis of spatial relations. GRASS and most of the proprietary GIS products are based on this data organization.

For certain applications, especially those based on discrete, object based representation of geographical features, the *object oriented* approach to data management is used. Within this approach, data are stored as closed objects with coordinates and attribute information. Objects include characteristics and methods. The characteristics describe the data structure, the methods include the information about the data exchange with other objects. The advantage of this concept is in the possibility to generate complex data structures connected to objects, allowing an efficient management of data for such applications as utilities or land register. The main disadvantage of this concept is that the management of continuous data, which are important for physical geography and landscape ecology, is unfavorable in object oriented form. GRASS does not use the object oriented approach to data organization, although some modules (`nviz`) and add-on libraries (GDAL) have object oriented design.

A large volume of geospatial data is nowadays distributed through *Internet based GIS*. The data sets are stored on central server(s) and users access the data as well as the display and analysis tools through the Internet. Examples are the interactive National Atlas of the U.S.[3], MapQuest[4] or UMN/MapServer Gallery[5]. Almost every multipurpose GIS software includes tools supporting development of Web-based applications. GRASS can be used with UMN/MapServer, an Open Source project for developing Web-based GIS applications which supports a variety of spatial requests like making maps, scale-bars, and point, area and feature queries (see Chapter 13). Other projects such as ICENS Spatial Information System[6] and Grules[7] are using JAVA to connect GRASS to the Internet. Internet GIS can be enhanced by interactive 3D viewing capabilities using GeoVRML[8] as well as by multimedia features adding photographs, video, animations or sound to the georeferenced data.

2.1.3 GIS functionality

While creating digital and hardcopy maps has been the core GIS function over the past decade, the emphasis is shifting towards spatial analysis and modeling. GIS functionality is rapidly evolving and currently covers a wide range of areas, for example (read in more detail at Wadsworth and Treweek, 1999):

- integration of geospatial data from various sources: projections and coordinate transformations, format conversions, spatial interpolation, transformations between data models;

- visualization and communication of digital georeferenced data in form of digital and paper maps, animations, virtual reality (computer cartography);

- spatial analysis: spatial query, spatial overlay (combination of spatial data to find locations with given properties), neighborhood operations, geostatistics and spatial statistics;

- image processing: satellite and airborne image processing, remote sensing applications;

- network analysis and optimization;

- simulation of spatial processes: socioeconomic such as transportation, urban growth, population migration as well as physical and biological, such as water and pollutant flow, ecosystem evolution, etc.

This functionality is used to solve spatial problems in almost every area of our lives. Here are a few examples. In the area of socioeconomic applications, GIS can be used to find directions, locate a hospital within a given distance from a school, find optimal locations for a new manufacturing facility, design voter districts with given composition and number of voters, identify crime hot spots in a city, select optimal evacuation routes, manage urban growth. GIS plays an important role in conservation of natural resources and management of natural disasters, such as identification and prevention of soil erosion risk, forest resource management, ecosystem analysis and modeling, planning of conservation measures, flood prediction and management, pollutant modeling, etc. GIS is also being increasingly used in agriculture, especially in the area of precision farming.

2.2. MAP PROJECTIONS AND COORDINATE SYSTEMS

The basic property of GIS, as opposed to other types of information systems, is that the stored data are georeferenced. That means that the data have defined their location on Earth using coordinates within a georeferenced coordinate system. The fact that the Earth is an irregular, approximately spherical object

Ellipsoid name	*Region of use*
Airy 1858	Great Britain
Airy modified	Ireland
Australian National	Australia
Bessel 1841	Austria, Chile, Croatia, Czech Rep., Germany, Greece, Indonesia, Netherlands, Slovakia, Sweden, Switzerland
Bessel modified	Norway
Clarke 1880	Africa, France
Clarke 1866	North America, Philippines
Everest 1830	Afghanistan, Myanmar, India, Pakistan, Thailand, and other countries in southern Asia
GRS 1980	North America, worldwide
Hayford (International) 1909	Belgium, Finland, Italy, all countries using ED50 system
New International 1967	many other regions
Krassovsky 1938	Albania, Poland, Romania, Russia and neighboring countries
WGS 1984	North America, worldwide
WGS 1972	NASA satellite

Table 2.1. Selected standard ellipsoids as used in various countries

makes the definition of an appropriate coordinate system rather complex. The coordinate system either has to be defined on a sphere or ellipsoid, leading to a system of geographic coordinates or the sphere has to be projected on a surface that can be developed into a plane where we can define the cartesian system of coordinates (*easting, northing and elevation;* see Sections 2.2.2).

Because GRASS keeps the projects organized by LOCATIONs, where each LOCATION has a unique map projection and coordinate system, it is important to understand the relevant terminology before starting to work with geospatial data.

2.2.1 Map projection principles

When working with GRASS, the projection and coordinate system must be defined when a new project (LOCATION in GRASS terminology) is defined. The map projection definition is stored in an internal file within the given LOCATION. It is used whenever the data need to be projected into a different projection or when calculations requiring information about the Earth's curvature are performed. Different parameters are needed to define different projections and coordinate systems; therefore, it is important to understand the map projection terminology.

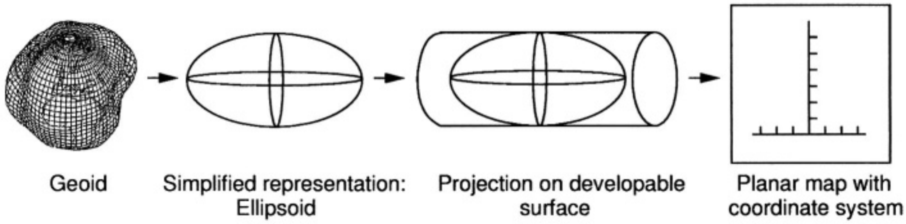

Figure 2.3. Earth's surface representation in map projections and coordinate systems

Shape of the Earth. Shape of the Earth is usually approximated by a mathematical model represented by an *ellipsoid* (also called a spheroid). A variety of cartographic ellipsoids have been designed to provide the best-fit properties for certain portions of the Earth's surface, see for example Table 2.1.

While the ellipsoid describes the shape of the Earth by a relatively simple mathematical function, the *geoid,* a physical approach to the description of the Earth's shape, undulates responding to the distribution of the Earth's mass which locally varies. The geoid is the equipotential surface of Earth's gravity field and corresponds to the mean sea level. For map projections, the ellipsoids are usually sufficient for horizontal positioning; however, the geoid has to be used for exact elevation calculations.

Geodetic or map datum. A set of constants specifying the coordinate system used for calculating the coordinates of points on Earth is called a *geodetic datum.* Horizontal datums define the origin and orientation of a coordinate system used to calculate the horizontal coordinates (usually northing and easting). Vertical datums define the coordinate system origin for calculating the elevation coordinate (mean sea level). For map layers to match, their coordinates must be computed using the same datum. Different datums mean a shift in the origin of the coordinate system, and that means a shift of the entire map.

Map projection. To transform a curved Earth surface into a plane (flat sheet of paper or a computer screen), a *map projection* is used. Direct projection of a spherical object to a plane cannot be performed without distortion. The most common approach is to project the spheroid onto a *developable surface,* such as a cylinder or a cone which can be developed into a plane without deformation (tearing or stretching), see Figure 2.3. A large number of different projections have been designed with the aim to minimize the distortion and preserve certain properties. In general, the projections can be divided into three major groups (for a mathematical description refer to Bugayevskiy and Snyder, 2000:20-22):

- *conformal,* preserves angles (shapes for small areas), used for navigation and most national grid systems;
- *equidistant,* preserves certain relative distances, used for measurement of length;
- *equivalent,* preserves area, used for measurement of areas.

Each of these properties (angle, distance, area) is preserved at the expense of the others. Because there is no perfect solution, the map projection is selected depending on the application. Most coordinate systems used for land surface mapping use conformal projections.

The developable surfaces can either touch the spheroid (tangent case) or intersect it (secant case). Based on the geometry of the developable surface, the projections can be divided into:

- *cylindrical,* which transform the spherical surface to a tangent or secant cylinder;
- *conic,* which use the tangent or secant cone;
- *azimuthal,* which use a tangent or secant plane (flat sheet).

The points or lines where a developable surface touches or intersects the spheroid are called *standard points* and *standard lines* with zero distortion (e.g. standard parallel for tangent cone or two standard parallels for secant cone). That means that the projected maps (or in the GIS the projected data) do not have uniform scale for the entire area, and the true map scale is preserved only along the standard lines. To minimize distortions, some projections reduce the scale along the standard parallel(s) or central meridian(s). This is expressed as a *scale factor* smaller than 1.0 in the definition of such a projection.

Transverse projections use developable surfaces rotated by 90° so that the standard (tangent) line is a meridian called *central meridian* instead of a standard parallel. *Oblique projections* may use any rotation defined by azimuth where *azimuth* is an angle between a map's central line of projection and the meridian it intersects, measured clockwise from north. Snyder, 1987, provides an excellent manual on map projections with map examples for many important projections.

Coordinate system. To accurately identify a location on Earth, a *coordinate system* is required. It is defined by its origin (e.g. prime meridian, datum), coordinate axes (e.g. x, y, z), and units (angle: degree, gon, radiant; length: meter, feet).

Projection Type	*Country*
Transverse Mercator	Albania, Australia, Austria, Denmark, Finland, Germany, Great Britain, Ireland, Italy, Luxembourg, Norway, Poland, Portugal, Russia, Spain, Sweden, USA
Oblique Mercator	Hungary, Madagascar, Malaysia, Switzerland
Lambert Conformal Conic	Belgium, France, Portugal, USA
Stereographic	Netherlands (oblique aspect), Poland, Romania, UPS (polar regions)

Table 2.2. Selected projections used in various countries

The following general coordinate systems are commonly used in GIS:

- *geographic* (global) coordinate system (latitude-longitude);
- *planar (cartesian) georeferenced* coordinate system (easting, northing, elevation) which includes projection from an ellipsoid to a plane, with origin and axes tied to the Earth surface;
- *planar non-georeferenced* coordinate system, such as image coordinate system with origin and axes defined arbitrarily (e.g. image corner) without defining its position on the Earth.

Note that for planar georeferenced systems *false easting* and *false northing* may be used. These are selected offset constants added to coordinates to ensure that all values in the given area are positive.

For mapping purposes, each country has one or more *national grid systems.* Information about national grid systems can be obtained from the national cartographic institutes or from the Internet ASPRS site[9]. A national grid system is defined by a set of parameters such as ellipsoid, datum, projection, coordinate system origin and axes, etc. Examples of worldwide and national grid systems are UTM (Universal Transverse Mercator), Gauss-Krüger, Gauss-Boaga, or State Plane, with the projections listed in the Table 2.2. Information about the grid system used to georeference digital geospatial data is a crucial component of the metadata and allows the user to integrate and combine data obtained from different sources.

2.2.2 Common coordinate systems

Geographic coordinate system: latitude-longitude. The most common coordinate system used for the global data is the spherical coordinate system which determines the location of a point on the globe using latitude and longitude. It is based on a grid of meridians and parallels, where *meridians* are the longitude lines connecting the north and south poles and *parallels* are the latitude lines which form circles around the Earth parallel with the *equator.* The longitude of a point is then defined as an angle between its meridian and the *prime meridian* (0° east, passing through the Royal Observatory in Greenwich, near London, UK). The latitude of a point is defined as an angle between the normal to the spheroid passing through the given point and the equator plane. The longitude is measured 0-180° east from prime meridian and 0-180° west, where 180° longitude is the international date line. Latitude is measured 0-90° north and 0-90° south from equator.

Geographic coordinates can be expressed in two notations:

- decimal degree;
- sexagesimal degree.

Decimal values of W and S are expressed as negative numbers, N and E as positive numbers (e.g. Murcia, Spain: -1.167°, 38.0°). Values given in sexagesimal system always use positive numbers together with N, S, E, W (Murcia, Spain: 1:10:00W, 38:00:00N). It is not difficult to convert between these notations.

Universal Transverse Mercator Grid System. The Universal Transverse Mercator (UTM) Grid System is used by many national mapping agencies for topographic and thematic mapping, georeferencing of satellite imagery and in numerous geographical data servers. It applies to almost the entire globe (area between 84° N and 80° S). The pole areas are covered by the Universal Polar Stereographic (UPS) Grid System not explained here; please refer to Robinson et al., 1995 or other authors.

UTM is based on a Transverse Mercator (conformal, cylindrical) projection with strips (zones) running north-south rather than east-west as in the standard Mercator projection. UTM divides the globe into 60 zones with a width of 6° longitude, numbered 1 to 60, starting at 180° longitude (west). Each of these zones will then form the basis of a separate map projection to avoid unacceptable distortions and scale variations. Each zone is further divided into strips of 8° latitude with letters assigned to from C to X northwards, omitting the letters I and O, beginning at 80° south (Robinson et al., 1995:101).

The origin of each zone (central meridian) is assigned an easting of 500,000 m (false easting, Maling, 1992:358). For the northern hemisphere the equator has northing set to zero, while for the southern hemisphere it has northing 10,000,000 m (false northing). To minimize the distortion in each zone, the scale along the central meridian is 0.9996, leading to a secant case of the Transverse Mercator projection with two parallel lines of zero distortion. Note that UTM is used with different ellipsoids, depending on the country and time of mapping.

For GIS applications, it is important to realize that each UTM zone is a different projection using a different system of coordinates. Combining maps from different UTM zones into a single map using only one UTM zone (which can be done relatively easily using GIS map projection modules) will result in significant distortion in the location, distances and shapes of the objects that originated in a different zone map and are outside the area of the given zone. To overcome the problem, a different coordinate system should be used and the data re-projected. For a quick reference, you can find the UTM zone numbers in the Unit 013 "Coordinate System Overview" of the NCGIA Core Curriculum in GIS.[10]

Lambert Conformal Conic Projection based systems. The Lambert Conformal Conic (LCC) projection is one of the best and most common for middle latitudes. It uses a single secant cone, cutting the Earth along two standard parallels. The tangent cone version with a single standard parallel case is also used. When working with LCC based coordinate systems, the following parameters have to be provided: the standard parallel(s) (one or two), the longitude of the central meridian, the latitude of projection origin (central parallel), false easting and, sometimes, false northing (you may recall that false easting and northing are shifts of the origin of the coordinate system from the central meridian and parallel).

State Plane Coordinate System. The State Plane Coordinate System used by state mapping agencies in the U.S.A. is based on different projections depending on the individual state shape and location, usually LCC or a Transverse Mercator with parameters optimized for each state. Various combinations of datums (NAD27, NAD83) and units (feet, meters) have been used, so it is important to obtain all relevant coordinate system information (usually stored in the metadata file) when working with the data georeferenced in the State Plane Coordinate System. GIS projection modules often allow to define the State Plane system by providing the name of the state and the county, however, the parameters should always be checked, especially when working with older data.

Gauss-Krüger Grid System. The Gauss-Krüger Grid System is used in several European and other countries. It is based on the Transverse Mercator Projection and the Bessel ellipsoid. The zones are 3° wide, leading to 120 strips. The zone number is divided by 3 according to longitude of central meridian. Adjacent zones have a small overlapping area. The scale along the central meridian (scale factor) is 1.0.

Figure 2.4 illustrates the coordinate system, the x-axis is defined by the central meridian, the y-axis by the equator. The northing values are positive north

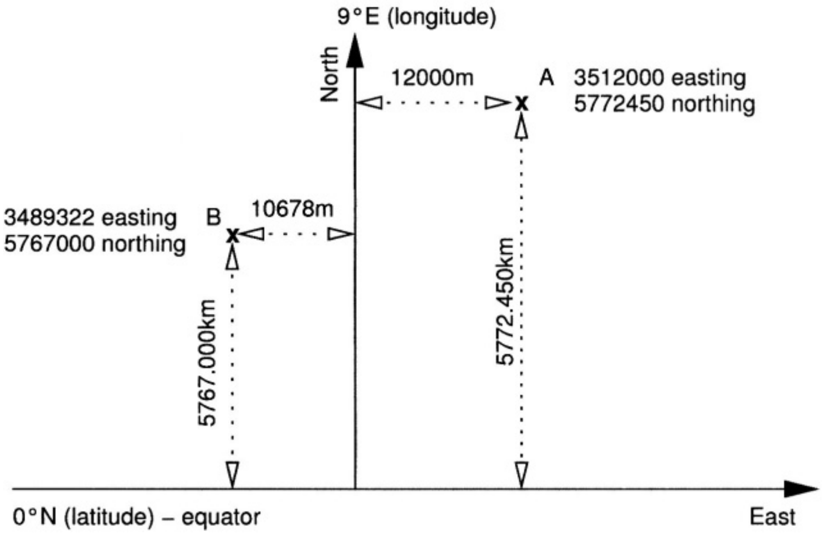

Figure 2.4. Example for the Gauss-Krüger Grid System with two points A and B

from the equator, the easting values are measured from the central meridian. To avoid negative values, a false easting of 500,000 m is defined in addition to the third of the longitude of the central meridian. For example the false easting for the 9° E central meridian is 3,500,000 m (9/3 = 3, value composed with 500,000 m to 3,500,000 m).

2.2.3 North American and European Datums

In general, a large number of georeferencing datums exists, here we focus on three examples. The North American Datum 1983 (NAD83) is a geodetic reference system which uses as its origin the Earth's center of mass, whereas the old North American Datum 1927 (NAD27) had a different origin, making it useful only in North America. GPS receivers which are mostly based on the WGS84 datum (other local datums can be selected in the GPS receiver's menu) also use the Earth's center of mass as their system's origin.

When using maps based on different datums, a datum transformation to a common datum is required. For example, a change from NAD27 to NAD83 system leads to a shift for the entire map. Overlapping maps based on different datums of the same region would not co-register properly without datum transformation. In the continental United States a few common assignments between datums and ellipsoids are in use: NAD27 datum with Clarke 1866 ellipsoid, NAD83 datum with GRS80 ellipsoid, and WGS84 datum with WGS84 ellipsoid.

It is important to know that the NAD27 and NAD83 datums are 2D horizontal datums used for horizontal coordinates (easting and northing). WGS84 is a 3D datum (x, y and height). Separate vertical datums used with these systems are NGVD29 and NAVD88. GRASS does not handle such separate vertical datums so these transformation needs to be done outside GRASS.

NOTES

1 HDF format and tools,
`http://hdf.ncsa.uiuc.edu`
2 PostGIS DBMS, `http://postgis.refractions.net`
3 National Atlas of the U.S., `http://nationalatlas.gov`
4 MapQuest, `http://www.mapquest.com`
5 UMN/MapServer Gallery, `http://mapserver.gis.umn.edu`
6 ICENS Spatial Information System,
`http://196.3.4.220:8000/jdb/icens.sivs?class=gis`
7 Grules (GRASS JAVA Server),
`http://grules.sourceforge.net`
8 GeoVRML, `http://www.geovrml.org`
9 Information about national grid systems: ASPRS: Grids & Datums,
`http://www.asprs.org/asprs/resources/grids/`
European coordinate systems,
`http://www.mapref.org`
A comprehensive, general list of projection transformations is available at
`http://www.remotesensing.org/geotiff/proj_list/`
10 Unit 013 Coordinate System Overview in the NCGIA Core Curriculum in GIS,
`http://www.ncgia.ucsb.edu/education/curricula/giscc/units/u013/u013.html`