2.2 Geographic phenomena
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2.2.1 Defining geographic phenomena

A GIS operates under the assumption that the relevant spatial phenomena occur in a two- or three-dimensional Euclidean space, unless otherwise specified. Euclidean space can be informally defined as a model of space in which locations are represented by coordinates—\((x, y)\) in 2D; \((x, y, z)\) in 3D—and distance and direction can defined with geometric formulas. In the 2D case, this is known as the Euclidean plane, which is the most common Euclidean space in GIS use.

In order to be able to represent relevant aspects real world phenomena inside a GIS, we first need to define what it is we are referring to. We might define a geographic phenomenon as a manifestation of an entity or process of interest that:

- Can be named or described,
- Can be georeferenced, and
- Can be assigned a time (interval) at which it is/was present.

The relevant phenomena for a given application depends entirely on one’s objectives. For instance, in water management, the objects of study might be river basins, agro-ecologic units, measurements of actual evapotranspiration, meteorological data, ground water levels, irrigation levels, water budgets and measurements of total water use. Note that all of these can be named or described, georeferenced and provided with a time interval at which each exists. In multipurpose cadastral administration, the objects of study are different: houses, land parcels, streets of various types, land use forms, sewage canals and other
forms of urban infrastructure may all play a role. Again, these can be named or described, georeferenced and assigned a time interval of existence.

Not all relevant phenomena come as triplets \((\text{description}, \text{georeference}, \text{time-interval})\), though many do. If the georeference is missing, we seem to have something of interest that is not positioned in space: an example is a legal document in a cadastral system. It is obviously somewhere, but its position in space is not considered relevant. If the time interval is missing, we might have a phenomenon of interest that is considered to be always there, i.e. the time interval is (likely to be considered) infinite. If the description is missing, then we have something that exists in space and time, yet cannot be described. Obviously this last issue very much limits the usefulness of the information.

Referring back to the El Niño example discussed in Chapter 1, one could say that there are at least three geographic phenomena of interest there. One is the Sea Surface Temperature, and another is the Wind Speed in various places. Both are phenomena that we would like to understand better. A third geographic phenomenon in that application is the array of monitoring buoys.
2.2.2 Types of geographic phenomena

The attempted definition of geographic phenomena above is necessarily abstract, and therefore perhaps somewhat difficult to grasp. The main reason for this is that geographic phenomena come in so many different ‘flavours’, which we will try to categorize below. Before doing so, we must make two further observations.

Firstly, in order to be able to represent a phenomenon in a GIS requires us to state what it is, and where it is. We must provide a description—or at least a name—on the one hand, and a georeference on the other hand. We will skip over the temporal issues for now, and come back to these in Section 2.5. The reason for this is that current GISs do not provide much automatic support for time-dependent data, and that this topic must be therefore be considered an issue of advanced GIS use.

Secondly, some phenomena manifest themselves essentially everywhere in the study area, while others only do so in certain localities. If we define our study area as the equatorial Pacific Ocean, we can say that Sea Surface Temperature can be measured anywhere in the study area. Therefore, it is a typical example of a (geographic) field.

A (geographic) field is a geographic phenomenon for which, for every point in the study area, a value can be determined.

Some common examples of geographic fields are air temperature, barometric pressure and elevation. These fields are in fact continuous in nature. Examples of discrete fields are land use and soil classifications. For these too, any location
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in the study area is attributed a single land use class or soil class. We discuss fields further in Section 2.2.3.

Many other phenomena do not manifest themselves everywhere in the study area, but only in certain localities. The array of buoys of the previous chapter is a good example: there is a fixed number of buoys, and for each we know exactly where it is located. The buoys are typical examples of (geographic) objects.

(Geographic) objects populate the study area, and are usually well-distinguished, discrete, and bounded entities. The space between them is potentially 'empty' or undetermined.

A simple rule-of-thumb is that natural geographic phenomena are usually fields, and man-made phenomena are usually objects. Many exceptions to this rule actually exist, so one must be careful in applying it. We look at objects in more detail in Section 2.2.4.
Elevation in the Falset study area, Tarragona province, Spain. The area is approximately $25 \times 20$ km. The illustration has been aesthetically improved by a technique known as ‘hillshading’. In this case, it is as if the sun shines from the north-west, giving a shadow effect towards the south-east. Thus, colour alone is not a good indicator of elevation; observe that elevation is a continuous function over the space.

**Figure 2.2**: A continuous field example, namely the *elevation* in the study area of Falset, Spain. Data source: Department of Earth Systems Analysis (ESA, ITC)
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2.2.3 Geographic fields

A field is a geographic phenomenon that has a value ‘everywhere’ in the study area. We can therefore think of a field as a mathematical function $f$ that associates a specific value with any position in the study area. Hence if $(x, y)$ is a position in the study area, then $f(x, y)$ stands for the value of the field $f$ at locality $(x, y)$.

Fields can be discrete or continuous. In a continuous field, the underlying function is assumed to be ‘mathematically smooth’, meaning that the field values along any path through the study area do not change abruptly, but only gradually. Good examples of continuous fields are air temperature, barometric pressure, soil salinity and elevation. Continuity means that all changes in field values are gradual. A continuous field can even be differentiable, meaning we can determine a measure of change in the field value per unit of distance anywhere and in any direction. For example, if the field is elevation, this measure would be slope, i.e. the change of elevation per metre distance; if the field is soil salinity, it would be salinity gradient, i.e. the change of salinity per metre distance. Figure 2.2 illustrates the variation in elevation in a study area in Spain. A colour scheme has been chosen to depict that variation. This is a typical example of a continuous field.

Discrete fields divide the study space in mutually exclusive, bounded parts, with all locations in one part having the same field value. Typical examples are land classifications, for instance, using either geological classes, soil type, land use type, crop type or natural vegetation type. An example of a discrete field—in this case identifying geological units in the Falset study area—is provided in Figure 2.3. Observe that locations on the boundary between two parts can be as-
signed the field value of the ‘left’ or ‘right’ part of that boundary. One may note that discrete fields are a step from continuous fields towards geographic objects: discrete fields as well as objects make use of ‘bounded’ features. Observe, however, that a discrete field still assigns a value to every location in the study area, something that is not typical of geographic objects.

Essentially, these two types of fields differ in the type of cell values. A discrete field like landuse type will store cell values of the type ‘integer’. Therefore it is also called an integer raster. Discrete fields can be easily converted to polygons, since it is relatively easy to draw a boundary line around a group of cells with the same value. A continuous raster is also called a ‘floating point’ raster. A field-based model consists of a finite collection of geographic fields: we may be interested in elevation, barometric pressure, mean annual rainfall, and maximum daily evapotranspiration, and thus use four different fields to model the relevant phenomena within our study area.
Observe that—typical for fields—with any location only a single geological unit is associated. As this is a *discrete* field, value changes are discontinuous, and therefore locations on the boundary between two units are not associated with a particular value (i.e. with a geological unit).

**Figure 2.3**: A discrete field indicating geological units, used in a foundation engineering study for constructing buildings. The same study area as in Figure 2.2.

Data source: Department of Earth Systems Analysis (ESA, ITC)
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Data types and values

Since we have now differentiated between continuous and discrete fields, we may also look at different kinds of data values which we can use to represent our ‘phenomena’. It is important to note that some of these data types limit the types of analyses that we can do on the data itself:

1. **Nominal data values** are values that provide a name or identifier so that we can discriminate between different values, but that is about all we can do. Specifically, we cannot do true computations with these values. An example are the names of geological units. This kind of data value is called *categorical data* when the values assigned are sorted according to some set of non-overlapping categories. For example, we might identify the soil type of a given area to belong to a certain (pre-defined) category.

2. **Ordinal data values** are data values that can be put in some natural sequence but that do not allow any other type of computation. Household income, for instance, could be classified as being either ‘low’, ‘average’ or ‘high’. Clearly this is their natural sequence, but this is all we can say—we can not say that a high income is twice as high as an average income.

3. **Interval data values** are quantitative, in that they allow simple forms of computation like addition and subtraction. However, interval data has no arithmetic zero value, and does not support multiplication or division. For instance, a temperature of 20 °C is not twice as warm as 10 °C, and thus centigrade temperatures are interval data values, not ratio data values.

4. **Ratio data values** allow most, if not all, forms of arithmetic computation.
Rational data have a natural zero value, and multiplication and division of values are possible operators (distances measured in metres are an example). Continuous fields can be expected to have ratio data values, and hence we can interpolate them.

We usually refer to nominal and categorical data values as ‘qualitative’ data, because we are limited in terms of the computations we can do on this type of data. Interval and ratio data is known as ‘quantitative’ data, as it refers to quantities. However, ordinal data does not seem to fit either of these data types. Often, ordinal data refers to a ranking scheme or some kind of hierarchical phenomena. Road networks, for example, are made up of motorways, main roads, and residential streets. We might expect roads classified as motorways to have more lanes and carry more traffic and than a residential street.
2.2.4 Geographic objects

When a geographic phenomenon is not present everywhere in the study area, but somehow ‘sparsely’ populates it, we look at it as a collection of geographic objects. Such objects are usually easily distinguished and named, and their position in space is determined by a combination of one or more of the following parameters:

- *Location* (where is it?),
- *Shape* (what form is it?),
- *Size* (how big is it?), and
- *Orientation* (in which direction is it facing?).

How we want to use the information about a geographic object determines which of the four above parameters is required to represent it. For instance, in an in-car navigation system, all that matters about geographic objects like petrol stations is where they are. Thus, location alone is enough to describe them in this particular context, and shape, size and orientation are not necessarily relevant. In the same system, however, roads are important objects, and for these some notion of location (where does it begin and end), shape (how many lanes does it have), size (how far can one travel on it) and orientation (in which direction can one travel on it) seem to be relevant information components.

Shape is usually important because one of its factors is *dimension*. This relates to whether an object is perceived as a point feature, or a linear, area or volume feature. The petrol stations mentioned above apparently are zero-dimensional, i.e.
they are perceived as points in space; roads are one-dimensional, as they are considered to be lines in space. In another use of road information—for instance, in multi-purpose cadastre systems where precise location of sewers and manhole covers matters—roads might well be considered to be two-dimensional entities, i.e. areas within which a manhole cover may fall.

Figure 2.4 illustrates geological faults in the Falset study area, a typical example of a geographic phenomenon that is made up of objects. Each of the faults has a location, and here the fault’s shape is represented as a one-dimensional object. The size, which is length in case of one-dimensional objects, is also indicated. Orientation does not play a role in this case.

We usually do not study geographic objects in isolation, but more often we look at collections of objects viewed as a unit. These object collections may also have specific geographic characteristics. Most of the more interesting collections of geographic objects obey certain natural laws. The most common (and obvious) of these is that different objects do not occupy the same location. This, for instance, holds for the collection of petrol stations in an in-car navigation system, the collection of roads in that system, the collection of land parcels in a cadastral system, and in many more cases. We will see in Section 2.3 that this natural law of ‘mutual non-overlap’ has been a guiding principle in the design of computer representations of geographic phenomena.

Collections of geographic objects can be interesting phenomena at a higher aggregation level: forest plots form forests, groups of parcels form suburbs, streams, brooks and rivers form a river drainage system, roads form a road network, and SST buoys form an SST sensor network. It is sometimes useful to view geographic phenomena at this more aggregated level and look at characteristics like...
coverage, connectedness, and capacity. For example:

- Which part of the road network is within 5 km of a petrol station? (A coverage question)

- What is the shortest route between two cities via the road network? (A connectedness question)

**Figure 2.4:** A number of geological faults in the same study area as in Figure 2.2. Faults are indicated in blue; the study area, with the main geological era’s is set in grey in the background only as a reference.

Data source: Department of Earth Systems Analysis (ITC)
• How many cars can optimally travel from one city to another in an hour? (A capacity question)

Other spatial relationships between the members of a geographic object collection may exist and can be relevant in GIS usage. Many of them fall in the category of topological relationships, discussed in Section 2.3.4.