Basic GIS Analysis

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Contents

1 Introduction to spatial analysis

Operations and data analysis tools, especially spatial analysis, are important components for the functionalities of a GIS. In the module "Basic Spatial Analysis" background information is provided about the performance and the application of operations in Spatial Analysis (SA). The module "Intermediate Spatial Analysis" offers advanced information about this topic in terms of special operations.

Learning Objectives

- You know the origin of SA as well as some relevant literature about this.
- You are able to describe the term "Spatial Analysis" concisely and know the position of SA in the GIS context.
- You are able to give an overview of essential SA functions in GIS and are able to assign these functions to various criteria.

1.1 GIS: Background and overview

This lesson will introduce the subject of spatial analysis (SA). In the first part, the historical background of SA in GIS will be discussed, followed by the concept of SA. Typical functions of SA are given in the last section.

1.1.1 Roots of Spatial Analysis in GIS

Despite their central role in geographic information systems, most spatial analysis methods emerged before and independently from GIS technology. Most of these methods have been integrated later into the GIS technology. GIS platforms provide several functions such as data acquisition, data management and visualization. The combination of these functions with analytical operations makes them even more efficient.

The origin of spatial analysis, known in the context of GIS of today, goes back many years. A selection of early articles about spatial statistics and quantitative spatial analysis is provided in the reader written by Berry et al. [**?**] . Some of these articles were written in the 1930s, but most of them were written in the 1950s and 1960s. The use of statistical and other quantitative methods for the analysis of spatial patterns and processes were especially prominent and developed in spatial sciences, which focus on the analysis of those spatial patterns and processes. Examples of such disciplines are regional science, quantitative geography or landscape ecology. In geography, the use of quantitative methods was coupled to a change of paradigm, called the "quantitative revolution". This trend was particularly pronounced in the 1960s and 1970s. It is well described in the books written by Abler [**?**] as well as by Haggett [**?**] and Haggett et al. [**?**] . At that time, geodetic sciences did not focus on the development of SA methods. However, since the 1980s , as GIS became a more integral platform, there was a growing convergence of methods used in SA involved in the development of GIS technology sciences. This development is well illustrated in the book written by Bill [**?**] .

With his background in geomatics, he devoted a large part of the content to data analysis, focusing specifically on SA . But which methods were developed before the advent of GIS technology? As stated in Fisher [**?**] , these were mainly quantitative methods for the characterization and analysis of:

- Patterns (e.g. distribution and arrangement)
- Shapes of geographic features (points, lines, areas and surfaces).

Initially, a geometric approach dominated the field, which was particularly concentrated on point pattern analysis as well as the characterization of networks. Later, the focus changed to the development of methods. The analysis of the intrinsic properties of the geographical area (e.g. the relative distance between spatial objects), processes of spatial preferences (e.g. positioning of shopping centers) and the analysis of spatial interactions, became more important in the development of methods. Within this time of development, methods of multivariate statistics were increasingly used and adjusted to the needs of spatial science; standard statistical packages have been linked to GIS for exploratory data analysis, statistical analysis and hypothesis testing. Examples for such statistical methods are stated below:

- Regression analysis
- Principal component analysis
- Linear discriminant analysis
- Trend surface analysis

As these methods were developed in other disciplines rather than spatial science, their use in spatial related analysis caused several problems as these methods did not take spatial heterogeneity or spatial dependence of samples distributed in space into account. As a consequence, methods for geostatistical analysis were developed from the late 1960s that perform better with spatially related data.

By the late 1970s, geometryoriented operations of spatial analysis (e.g. spatial query, point pattern analysis, polygon overlay, buffering etc.) and methods of geostatistical analysis were being made available in GIS. These days, typical commercial GIS packages provide a wide range of functions for geometric and geostatistical analysis. A big advantage of the incorporation of analysis functions in GIS is the connection between the tools of data acquisition, data modeling, data management and visualization. This enables the entire cycle of spatial data processing to be completed using one software to answer complex questions.

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Figure 1: gis_lifecycle.gif

1.1.2 Description of the Term "Spatial Analysis"

The definition of the term "spatial analysis" raises some problems, as stated by Bailey:

> "*One difficulty experienced in any discussion of links between GIS and spatial analysis is clarification of exactly what is to be considered as spatial analysis. The problem arises because, by its nature, GIS is a multi-disciplinary field and each discipline has developed a terminology and methodology for spatial analysis which reflects the particular interests of that field. In the face of such a diversity of analytical perspectives, it is difficult to define spatial analysis any more specifically than as: a general ability to manipulate spatial data into different forms and extract additional meaning as a result*" [**?**, p. 15]

This means that the questions and methods of spatial analysis grew "naturally". They have been developed in various sciences related to GIScience, which focus on different interests and topics of investigation. For example, a distance query to reveal all ski resorts within a certain distance could be a simple data retrieval for some, but for others a query could represent a complete spatial analysis.

The attempt at a definition fails. There is no possibility to define the term of spatial analysis but only to describe it. In order to give an idea, the following descriptions can be mentioned:

> "*A general ability to manipulate spatial data into different forms and extract additional meaning as a result.*" [**?**, p. 15]

> "*In broad terms one might define spatial analysis as the quantitative study of phenomena that are located in space.*" [**?**, p. 7]

The next section offers a wider and more complex view on the term "spatial analysis", which can be given various meanings. But first the position of SA in the GIS context should be discussed. There are the two major streams within quantitative SA: geometrically oriented and geostatistically oriented. A third stream, visual data analysis, recently arose. It is well known that maps can provide information about spatial patterns and processes (more details are provided in the module "Basic Presentation"). These three streams mentioned can be characterized as follows, using different approaches:

Geometric SA: The geometric approach is focused on geometric criteria (location of objects and attributes), and has mainly a descriptive effect. It cannot be used for hypothesis testing. Some examples using geometric SA include: the analysis of point distributions, network analysis (route calculation, shortest path), polygon overlay, analysis of distance relations, shape analysis, or the calculation of slope and exposure in elevation models.

Geostatistical SA: The geostatistical approach refers to spatially distributed (random) variables. This approach uses statistical methods for description but also for hypothesis testing. Some examples using geostatistical SA include: multivariate statistics, spatial correlation analysis (spatial autocorrelation), and geostatistical interpretation.

Explorative spatial visualization: This is a purely visual approach, in visualization as well as in interpretation. Visualization is a qualitative and explorative method to explore new data, to identify outliers and to formulate hypothesis.

These combined approaches offer a range of possible methods in spatial analysis as shown in the following image. Spatial analysis is not used as an end in itself but to get answers. Therefore, methods to represent phenomena and processes are needed but also appropriate methods to analyze these phenomena and processes. That means that a direct relationship exists between the methods of modeling and representation of geographic reality and spatial analysis techniques. The methods of spatial modeling and their impact on spatial analysis are discussed in the module "Basic Spatial Modeling".

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Figure 2: position_ra_in_gis.gif

1.1.3 Functions of Spatial Analysis

What operations are typically used as spatial analysis functions in GIS? Chou [?, p. 15] provides the most efficient description. Three different types are illustrated:

- Attribute query
- Spatial query
- Derive new data from existing data

Note that only some of these operations generate new data. The first two functions mentioned are simple queries, and the result consists of a selection of objects from the databases.

Spatial analysis functions can also be classified in regards to the data type involved in the spatial analysis (point, line, network, polygons/areas, surface), the data structure (vector vs. raster), or the conceptual model of space (discrete entity vs. continuous field [?]).

Bailey et al. [?] and Abler et al. [?] propose another differentiation of the functionality of spatial analysis. They distinguish the functions by their level of dynamics: E.g. static data (point distribution, surface area etc.), interactions between objects in space (for example interactions between two economic centers), or analysis of spatio-temporal changes). Depending on the author's point of view and his knowledge, organization and classification of SA functions are defined differently.

The lesson of the module "Basic Spatial Analysis" is organized using a mixed approach. The module is composed of lessons dedicated to the different analysis and application functions such as terrain analysis, accessibility analysis, and suitability analysis, etc. Albrecht [?] provides a nice classification of SA functions used in GIS (see also the illustration below). This classification was developed to deliver a universal interface for GIS. That is why this classification has two advantages: It gets the user's aspect (not the technical aspect), it is the briefest description, but it is a complete description of SA functions available in GIS (at least in commercial GIS). The term "spatial analysis" could be irritating. For this reason, a better description of SA would be "pattern analysis".

There is a very pragmatic approach in the following list provided by Goodchild [?] based on Goodchild [?] . It provides the typical function range of commercial GIS and operation components in data analysis. Other books provide overviews and discussions on the topic of the typical SA functions used in GIS, such as Aronoff [?] , Bill [?] , Burrough et al. [?] , or Jones [?] .

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Figure 3: Classification of spatial analysis functions [?]

Data analysis functions according to Goodchild (1990)

Counting and measuring:

- Measure number of items: The ability to count the number of objects in a class.
- Measure distances along straight and convoluted lines: The ability to measure distances along a prescribed line.
- Calculate bearings between points: The ability to calculate the bearing (with respect to True North) from a given point to another point.
- Measure length of perimeter of areas: The ability to measure the length of the perimeter of a polygon.
- Measure size of areas: The ability to measure the area of a polygon.
- Measure volume: The ability to compute the volume under a digital representation of a surface.

Function of spatial analysis:

- Point in polygon: The ability to superimpose a set of points on a set of polygons and determine which polygon (if any) contains each point.
- Line on polygon overlay: The ability to superimpose a set of lines on a set of polygons, breaking the lines at intersections with polygon boundaries.
- Polygon overlay: The ability to overlay digitally one set of polygons on another and form a topological intersection of the two, concatenating the attributes.
- Sliver polygon elimination: The ability to delete automatically the small sliver polygons which result from a polygon overlay operation when certain polygon lines on the two maps represent different versions of the same physical line.

- Nearest neighbor search: The ability to identify points, lines or polygons that are nearest to points, lines or polygons specified by location or attribute.
- Shortest route: The ability to determine the shortest or minimum cost route between two points or specified sets of points.
- Contiguity analysis: The ability to identify areas that have a common boundary or node.
- Connectivity analysis: The ability to identify areas or points that are (or are not) connected to other areas or points by linear features.
- Network analysis: Simple forms of network analysis are covered in shortest route and connectivity. More complex analyses are frequently carried out on network data by electrical and gas utilities, communications companies etc. These include the simulation of flows in complex networks, load balancing in electrical distribution, traffic analysis, and computation of pressure loss in gas pipes. In many cases these capabilities can be found in existing packages which can be interfaced to the GIS database.

Statistical analysis functions:

- Create lists and reports: This is the ability to create lists and reports on objects and their attributes in user-defined formats, and to include totals and subtotals.
- Calculate - arithmetic: The ability to perform arithmetic, algebraic and Boolean calculations separately and in combination.
- Complex correlation: The ability to compare maps representing different time periods, extracting differences or computing indices of change.

Terrain modeling:

- Spot heights: Given a digital elevation model, interpolate the height at any point.
- Heights along streams: Given a digital elevation model and a hydrology net, interpolate points along streams at fixed increments of height.
- Contours (isolines): Given a set of regularly or irregularly spaced point values, interpolate contours at user-specified intervals.

- Elevation polygons: Given a digital elevation model, interpolate contours of height at user-specified intervals.
- Watershed boundaries: Given a digital elevation model and a hydrology net, interpolate the position of the watershed between basins.
- View shed: Identification of the cells in an input raster that can be seen from one or more observation points.
- Generate view shed maps: Given a digital elevation model and the locations of one or more viewpoints, generate polygons enclosing the area visible from at least one viewpoint.
- Calculate slopes along lines (gradients): The ability to measure the slope between two points of known height and location or to calculate the gradient between any two points along a convoluted line which contains two or more points of known elevation.
- Calculate slopes of areas: Given a digital elevation model and the boundary of a specified region (e.g., a part of a watershed), calculate the average slope of the region.
- Calculate aspect of areas: Given a digital elevation model and the boundary of a specified region, calculate the average aspect of the region.
- Locations from traverses: Given a direction (one of eight radial directions) and distance from a given point, calculate the end point of the traverse.

Complex analysis:

- Combination of the analysis functions mentioned above.

Try to assign the functions defined by Goodchild [**?**] to the spatial analysis functions determined by Albrecht [**?**] . Specify Goodchild's with Albrecht's categories. Where do problems occur? Are there functions defined by Goodchild which cannot be assigned to Albrecht's categories (that could possibly indicate that Albrecht's classification is not universal)?

1.2 Summary

SA is a method used to manipulate spatial data and to produce results. It is used for example to classify objects, to calculate the distance between them or to compute their area. The range of methods consists of the geometric and geostatistical analysis as well as the interactive methods of spatial visualization. In GIS, these methods are used in combination.

In geography, SA techniques have been used as quantitative methods since the 1960s and 1970s. Since the 1980s there has been an increasing convergence between the methods used in SA. Since the embedding of data acquisition, data modeling, data management and visualization methods into GIS, the data processing became more efficient. Initially, the development of analysis methods in GIS was focused on geometry. Thus the analysis was heavily focused on characterization of point distributions and networks. Only later the methods became more focused on intrinsic properties of the geographic space. But at that time, the specific characteristics of spatial variables such as heterogeneity of the measured values as well as the spatial dependence had been neglected. Nowadays, GIS incorporates a big range of geometric and geostatistical analysis functions. The functions of a spatial analysis include classification, distance calculation, area analysis, terrain modeling, visualization and others.

Glossary

Explorative spatial visualization: This is a purely visual approach, in visualization as well as in interpretation. Visualization is a qualitative and explorative method to explore new data, to identify outliers and to formulate hypothesis.

Geometric SA: The geometric approach is focused on geometric criteria (location of objects and attributes), and has mainly a descriptive effect. It cannot be used for hypothesis testing. Some examples using geometric SA include: the analysis of point distributions, network analysis (route calculation, shortest path), polygon overlay, analysis of distance relations, shape analysis, or the calculation of slope and exposure in elevation models.

Geostatistical SA: The geostatistical approach refers to spatially distributed (random) variables. This approach uses statistical methods for description but also for hypothesis testing. Some examples using geostatistical SA include: multivariate statistics, spatial correlation analysis (spatial autocorrelation), and geostatistical interpretation.

2 Continuous spatial variables

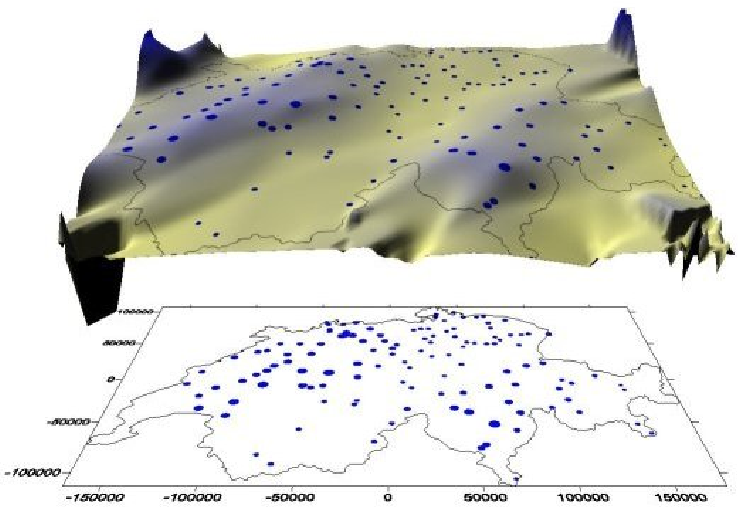

Figure 4: Precipitation surface of Switzerland - Niederschlagsoberfläche der Schweiz (oben), Karte der Messstationen (unten)

The figure shows a precipitation surface of Switzerland: the blue dots represent monitoring stations; their size corresponds to the amount of rainfall at that station. The different heights of the surface and their color are associated with rainfall as well. The issues addressed in this lesson are:

- How can we construct a continuous surface from approx. 100 monitoring stations?
- Which tool can help us do this?
- What knowledge is necessary and which methods exist?

What do we mean by "continuous spatial variables"?

In our example, rainfall is the variable. Let's perform a thought experiment: Imagine you could measure rainfall on any position along a route. You would have a spatially continuous measurement. Adjacent measurements would be either identical or vary only slightly (according to your definition of "neighborhood"). You may argue that precipitation often shows very well defined boundaries - and you're right. The "continuum of precipitation" is not mathematically perfect. Another example of a spatially continuous variable is sea level. However, virtually every natural spatially continuous phenomenon is subject to certain random fluctuations. Therefore, they can hardly be described in a mathematically perfect way (e.g. a function that exactly describes the rise of a slope, the distribution of different soil pH levels, or rainfall, etc.).

Random Function

From statistics we know *deterministic* (i.e. exactly predictable and mathematically recordable) and *stochastic* (i.e. purely random, unpredictable) phenomena. An example for a deterministic phenomenon is the fall of an object: we can calculate in advance the position of the object along the slope line at any point in time. In contrast, rolling dice is a purely stochastic phenomenon. In spatial analysis, we find phenomena that fall between deterministic and stochastic. They are referred to as *random functions*. Let's do another thought experiment: take a look at the flash-animation below. The points represent measurements of height. The actual heights between the measurement points follow a function that we do not know. However, we will assume that the heights of the unknown profile are not just random but are similar to the known adjacent points. Let's create a profile along the blue dashed line. In other words, we define a linear function between the measurement points. The red solid line shows the actual height profile. In the last image you can see a comparison of both profile lines. The height in this example is a random function - it is neither exactly mathematically recordable nor purely coincidental!

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Figure 5: random_function.swf

Please note: although the grid spacing is actually using discrete spatial units, continuous spatial variables are generally better suited to a raster model.

Learning Objectives

- You can describe the main types of spatial sampling.
- You can provide information about the reasonable size of spatial samples.
- You have mastered the basics of explorative variography.

- You can explain why knowledge of spatial dependencies is important for the analysis of continuous variables.
- You know the fundamentals of spatial estimation methods (interpolation).
- You can reasonably name applications for interpolations.

2.1 Spatial sampling

How do we begin the analysis of continuous variables?

The first step is to create a spatial sample. For the example in the beginning (rainfall in Switzerland), this would be the meteorological measurement stations. Their positions are fixed and are not freely selectable (unless you use just a subset of all existing stations). However, if you want to analyze e.g. the distribution of contaminants in the soil you first need to define the measuring points. You must be aware of the following characteristics of the sample:

- Representativeness
- Homogeneity
- Spatial distribution of measurements
- Size (i.e. number of measurements)

Representativeness, homogeneity, spatial distribution, and size are related. A size of 5 monitoring stations for an estimation of the total Swiss rainfall would hardly make sense and is neither representative. Nor would the selection of all the Swiss-german monitoring stations be representative for the overall estimation of Swiss rainfall. The size could be sufficient but not the spatial distribution. Selecting all stations below 750 masl the sample could be sufficient according to size and distribution but the phenomenon is not homogeneously represented in the sample. A subsequent estimate would be significantly distorted mainly in the areas above 750 masl.

2.1.1 Characteristics

Representativeness

The phenomenon being analyzed should be represented in all forms in the sample. Minima and maxima are of particular importance. For the precipitation example this means that stations with peak values should be present in the sample. However, if we are planning our own sampling scheme we usually do not know whether or not we have recorded the locations of minima and maxima.

Homogeneity

As mentioned earlier, the spatial dependence of data among themselves is a very important prerequisite for a meaningful analysis. This relationship should be homogenous over the entire study area! Take the example of the precipitation monitoring stations: two stations at a distance of 2 km, for example should both have similar values in Ticino as well as in Jura, Fribourg, or Grison etc. This prerequisite is also called "stationarity".

Spatial distribution

Spatial distribution is of great importance. It can be completely random, regular, or clustered. You can see examples of these distributions below in the "Typology" section. An indication about the spatial distribution of a sample can be statistically obtained by using the "nearest neighbor" method, for example. It is one of the "point pattern analysis" techniques, i.e. methods that can help statistically characterize and analyze the spatial distribution of points.

Size

The size, i.e. the number of samples, depends on the phenomenon and the surface area. In some cases, practical limitations constrain the sample size. Think of measurements in difficult terrain, or technically complex and expensive measurements. It is impossible to provide an ideal sample size for any task.

2.1.2 Typology

Different types of design can be used in spatial sampling. The choice of the sampling design depends on the phenomenon investigated or may also be influenced by the methods of measurement.

Random sample

Note the ranges without samples - the phenomenon to be analyzed is underrepresented there.

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Figure 6: Random sample

Uniform random sample (with a minimum distance between points)

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Figure 7: Uniform random sample

Systematic random sample

The selection shown below is by no means complete. However, it shows that "systematic" does not necessarily mean, "square"!

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Figure 8: Examples of systematic samples

Stratified random sample with a regular grid (here at least two points per grid box)

Do you recognize the similarity of this type with the uniform sampling? The criterion here is not a minimum distance, but the division of the area into uniform subsets (strata).

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Figure 9: Stratified random sample with a regular grid

Stratified random sample with an irregular grid (hierarchical or authoritative sample)

The idea of a stratified random sample is applied here to an irregular grid. For example, this could represent administrative districts.

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Figure 10: Stratified random sample with an irregular grid

Clustered random sample

You should have good reasons for selecting this sampling design. This design could also be a primary stage for values to be averaged within the cluster.

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Figure 11: Clustered random sample

Clustered systematic sample

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Figure 12: Clustered systematic sample

Examples of different types of sampling

Have a look at the following Flash animation showing examples of different types of sampling applied to Switzerland. The digital elevation model is shown as background information.

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Figure 13: Examples of different types of sampling

2.2 Analysis of spatial dependence

After the appropriate spatial sample has been chosen, the next step is to determine whether spatial dependencies exist between the data, and to which extent. There are several methods to do this. The two which will be presented in the following section are:

- The variogram, or explorative variography, respectively
- "Moving window" statistics

Why do we have to worry about spatial dependencies at all? Is it not enough to have an accurate sample? No! Without spatial relationships between our samples we cannot make a statement about the points where no samples were taken. This goes back to a statement by Waldo Tobler, which is known as the "1st law of geography":

> "*(...) the first law of geography: everything is related to everything else, but near things are more related than distant things.*" [**?**]

In most cases, this legality is indeed true. However, we should not rely on it blindly, especially not while standing on the edge of a cliff...

2.2.1 Variogram

Let us first get acquainted with the problem by looking at an example: Imagine a digital terrain model and take samples. The value of a sample is the height above sea level. Adjacent samples may have been randomly taken along a valley floor of the same altitude. Another pair of samples with approximately the same distance between them may have been taken on a ridge. If you compare the values of the two pairs you will notice a match or at least a similarity of the values. Let's compare samples with a greater distance between them. It is possible that they have similar values but it is more likely that their values (i.e. the sea level) are dissimilar.

Variography is a method that performs this pairwise comparison for all of our samples: every point is compared to every other point. This can add up to a lot of pairs of points depending on the number of samples. To be exact, it adds up to *= n*(n-1)/2 (n ... number of samples)* . You might ask, "Where does the distance come into play?" While each point is compared to every other point, the distance (and direction) of the pairs is determined as well!

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3 lags (Lag 0, Lag1, Lag2) for a data point (value 58) are shown. The numbers are values of Swiss precipitation monitoring stations.
	Pairs of values:
	for Lag0
	`58,65`
	`58,91`
	`58,54`
	`58,72`
	for Lag1
	`58,45`
	`58,64`
	`58,82`
	etc.

Table 1: Legend missing

From these numerous pairs of values the so-called "*semivariance*" is calculated as a measure of similarity (and we can also interpret it as "dependency").

Please note: Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed. Formula for semivariance	**Please note:** Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed. ... Semivariance for the distance h **Please note:** Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed. ... Number of pairs within distance h **Please note:** Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed. ... Values at position i and j

Table 2: Legend missing

In simple words, the difference between the value pairs is squared and halved. This parameter is calculated for each distance interval h - only the value pairs within this distance are included in the calculation. This distance h is called a "*lag*". Enter all value pairs within one lag on a scatter plot and you will get the so-called *h-scatterplot*.

From the semivariances per lag, the *empirical* (or *experimental*) *semivariogram* is created as a line graph. Move the mouse over the lag points to display the corresponding h-scatterplot for the first 8 lags):

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Figure 14: Semivariogram (move the mouse over the lag-points to see the h-scatterplot of lag 0-7)

Can you imagine why there are clearly fewer points in the h-scatterplots of low distances than in those of the higher lags?

Because in the lower lags, fewer pairs of points are in a smaller overall area.

The x-axis shows the increasing distance between pairs of points; the y-axis shows the semivariance per lag. The circular symbols on the curve mark the individual lags. In this example, the lag interval is 15'000. How do we interpret a curve like that? The more similar the pairs of values are per lag, the lower the semivariance for this lag; the more dissimilar, the higher the semivariance and thus the curve rises. This curve confirms: the values of our data are more similar at low distance. There is a direct connection between the distance between the data points and their similarity in value! There are two key figures to keep in mind to help you describe this curve:

- *Range* - the distance h, where the curve flattens
- *Sill* - the value of semivariance where the curve reaches its range

If the lag interval in the example above is 15'000 then why is the first lag (= lag 0 or h0) not in the coordinate origin? Simply because the pairs of points in lag 0 are at a certain distance from one another. Their average distance is now the position for lag 0 on the x-axis. But why does the curve not start at semivariance 0, i.e. on the x-axis? Because the data in lag 0 are not all identical (this is often the case). That is the reason why the origin of the semivariogram curve usually lies just above the x-axis. This is called the nugget effect. This term comes from the use of this method in geological exploration. In samples of gold, nuggets can occur selectively, i.e. the values of immediately adjacent samples may differ considerably.

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Figure 15: a) Lag 0 includes all pairs of points within the first lag. The average distance between the points marks the lag on the x-axis; b) The pairs of points in lag 0 show different values; therefore, the semivariance is not equal to 0 but slightly above the x-axis (=nugget effect)

In the simplest form, the pairs of values of each point in every direction are formed and an *isotropic semivariogram* is created. As an extension and refinement to this method, variogram programs can create pairs of points in specific directions. By doing this, you can examine if values in your dataset have higher spatial dependencies in certain directions. Think about the example above with sea level: if - in your data - there is a valley running in N-S-direction, points in this direction will show higher similarities than in E-W-direction. The result is now an *anisotropic semivariogram*. If you have lost sight of the overall goal: all this information about spatial dependencies and its structure can be used to estimate the unknown values.

Use the following interactive semivariance calculator and enter pairs of values. First, choose similar values (up to 99), then vary the values and let them be more dissimilar. Observe how the semivariance changes! Note how easily the semivariance formula is implemented.

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Figure 16: Semivariance Calculator

What happens if you enter the same value for every point? Is it of any importance, in what order you enter the pairs of values?

- If all points have the same value, i.e. are identical, there is a perfect spatial dependency and the semivariance will be 0.
- The order of the pairs of values does not matter since negative values become positive by squaring them.

2.2.2 Moving Windows

Variography allows us to detect spatial dependencies. What it does not detect is whether or not these dependencies are uniform throughout the whole study area. There could be large regional differences and in that case, our variogram would not be representative for the entire area! It only provides information about the *spatial variability* of our data.

The simple technique of the "*moving windows*"-*statistics* can help. A "window" of defined size and shape is moved over the data, the moving distance is equal to the width of the window. All data located within the window section are statistically summarized: the number and average of all points inside the window, the minimum / maximum values, the standard deviation, the coefficient of variation (= standard deviation / mean), etc. The results are again points - the centers of the moving windows and as their attributes the statistical indicators of these windows. In the case of sparse data, the window is only moved by one half of the window width to obtain more data to calculate (= moving window with overlap). The principle is shown in this animation:

Please note:
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Figure 17: Principle of "Moving Windows Statistics"

Both window size and form may be varied with this method. In practice, it is used in an explorative way accordingly: an analysis is performed with windows of varying dimensions and the statistics are compared. In particular, the coefficient of variation is a significant parameter - if its values are > 1, this indicates a high variation (= high spatial variability) in this window pane.

Consider the following example of a "moving window"-statistic for the Swiss precipitation data. Regions with higher rainfall are relatively easy to spot; two of them form a kind of NE-SW axis. The size of 30x30 km and the option of overlap are chosen for the window. The size of such a window is shown as a gray square. There is also the possibility to omit windows with less than a defined number of points, e.g. 4, since with such few points no meaningful statistics can be calculated. That is why there are a few "holes". The mean values reflect the precipitation totals. However, the coefficient of variation is of particular interest because it indicates regions with larger value fluctuations. In this situation, the two highest values are located at the southern tip of Ticino.

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Figure 18: "Moving window"-statistic for the Swiss precipitation data

In which of the eight windows from the first example will you find the highest coefficient of variation and what value does it have?

Window 4 - the coefficient of variation has a value of 4.8 / 44 = 0.109

2.2.3 Correctly assigning semivariogram-parameters

Drag the terms to the correct position in the semivariogram figure. Don't worry - after several failed attempts you will get help.

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Figure 19: Correctly assigning semivariogramm-parameters

2.3 Spatial Interpolation

Examples of interpolation results

Click on the two pictures below to see a simulation of the changing chemical concentration.

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Figure 20: Concentration of chemicals in the soil [?]

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Figure 21: Chemical concentration in a water [?]

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Figure 22: Comparison of different interpolation methods [?]

The examples shown above are the result of careful and sophisticated interpolations from a wide range of potential applications.

After looking into sampling and the analysis of spatial dependencies in the previous chapter, we now proceed to the "heart" of this lesson - *spatial interpolations*. Many of these techniques do not count to the easiest application in spatial analysis. That is why we deliberately restrict ourselves to a brief overview of the methods. The following techniques of interpolation are discussed:

- Distance-based interpolation
- Geostatistic methods

The latter being the subject of advanced courses and is not discussed in detail. What actually are spatial "interpolations"? This refers to the computation of unknown values based on neighboring known values.

2.3.1 Typology

"Inverse distance" weighting, "radial basis" functions, "splines", "ordinary kriging", "natural neighbor", "polynomial regression" methods, "universal kriging", etc. These are just some interpolation methods found in commercial software. The diversity of methods and their parameterizations can be confusing. Therefore, we will first try to classify the methods into schemes. In the following table, different approaches can be seen:

Local vs. global interpolation

Global methods are applied to ALL data in the study area; local methods on the other hand, are only applied to spatially defined subsets. Global interpolation is therefore not suited for the determination of exact values but to assess global spatial structures.

As examples, you can see a linear trend surface which was determined by regression from Swiss rainfall data and shows a trend toward increased precipitation totals from SE to NW, and a local interpolation using a radial basis interpolation:

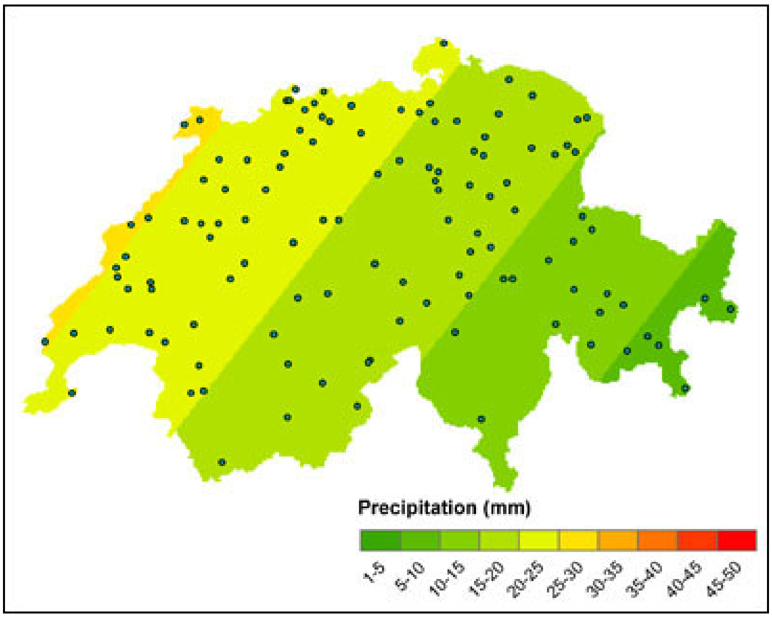

Figure 23: Example of a global interpolation - linear trend surface for Swiss rainfall data. (Provided by Ross Purves)

Exact vs. approximate interpolation

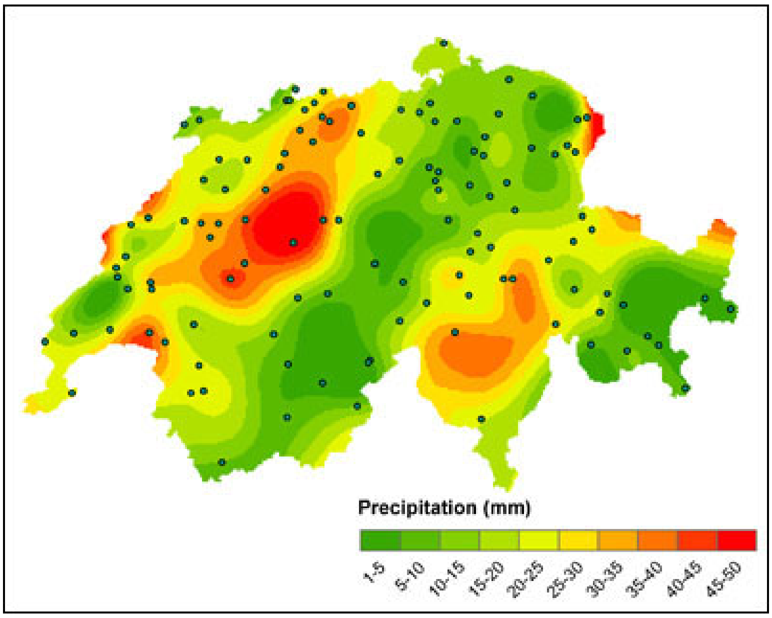

Figure 24: Example of a local interpolation - spline interpolation for Swiss rainfall data. (Provided by Ross Purves)

Exact interpolation means: the estimated surface passes through all points whose values are known. In approximate interpolation, the estimates of known points can vary from known values. The latter method can be usefully applied when the known data is already somewhat fuzzy.

Gradual vs. abrupt interpolation

This distinction mainly refers to the resulting estimation surface. Were there breaklines (naturally abrupt changes in values such as in cliffs or lakefronts) included in the interpolation or not?

Deterministic vs. stochastic interpolation

Techniques of deterministic interpolation are based on exactly predetermined (= deterministic) spatial contexts; in stochastic approaches on the other hand, random elements have an impact as well. Deterministic methods show clear disadvantages in interpolating natural spatial phenomena, since a given degree of uncertainty always exists.

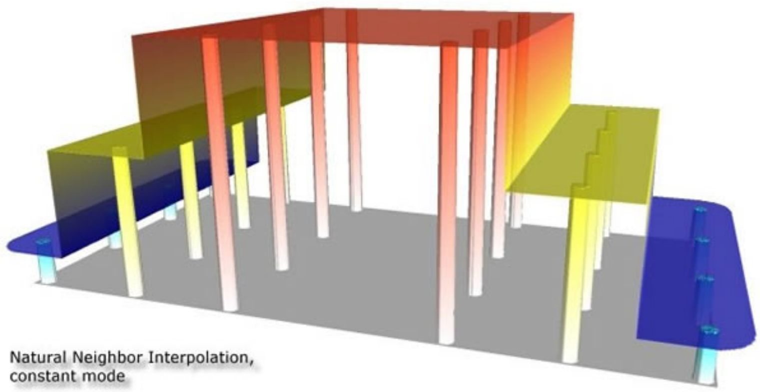

Figure 25: Exact Interpolation: the estimated surface passes exactly through the known points (here schematically shown as columns) [?]

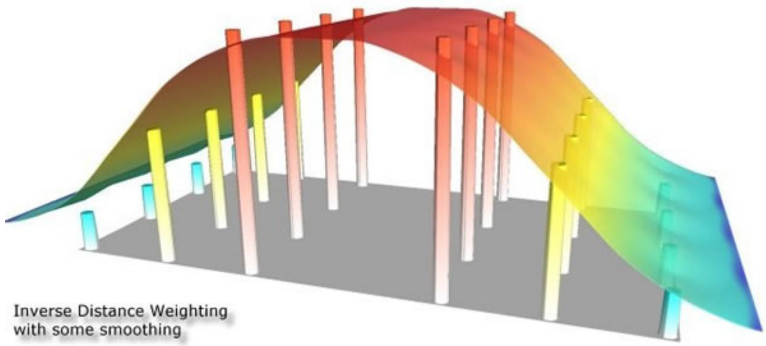

Figure 26: Approximate Interpolation: the estimated surface does NOT pass through the known points (here schematically shown as columns) [?]

2.3.2 Distance-based interpolation

In the simplest case, we can proceed with distance-based methods the same way as with the "moving windows" method (Page 24): we define a certain "neighborhood" of known data points around the unknown position to be estimated each time; the arithmetic mean of these known measurement values is our estimate (= *moving average*). The neighborhood can be defined in different ways:

- A spatially fixed shape (rectangle, circle, etc.)
- A certain number of nearest neighboring points

However, this method is quite fuzzy because of the different distances between the position to be estimated and the poor integration of known points in the interpolation. The actual distance-based methods use exactly these distances between the estimation points and the known measurement points to weigh their influence in the calculation of the estimated value. By the way, they require a linear spatial correlation between the phenomena.

Using the so-called "*Inverse Distance Weighting*" method or IDW, the weight of any known point is set inversely proportional to its distance from the estimated point. It is calculated as follows:

Please note: Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed. Inverse Distance Weighting IDW - basic formula	**Please note:** Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed. = value to be estimated **Please note:** Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed. = known value d_i ..., d_n = distances from the n data points to the point estimated n

Table 3: Legend missing

In most cases, you will find the following variation, in which the influence of the distance can be additionally controlled by an exponent (which is preset to 2 in most programs).

Please note: Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed. Most common form of IDW formula with added distance weighting exponent	**Please note:** Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed. = value to be estimated **Please note:** Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed. = known value $d\ ^p\ _i$ ..., $d\ ^p\ _n$ = distances from the n data points to the power of p of the point estimated

Table 4: Legend missing

The lower the exponent, the more uniformly all neighbors are incorporated into the calculation (regardless of their distance), and therefore, the "smoother" the estimated surface. The higher the exponent, the more accentuated and "unsettled" is the surface because only the weight of the nearest neighbors is integrated in the interpolation (see the following interactive animation).

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Figure 27: IDW surface estimates of the Swiss rainfall data

Advantages of the IDW interpolation:

- It allows for very fast calculations
- Different distances are integrated in the estimation
- The distance-weighting exponent is able to precisely control the influence of the distances

Disadvantages of the IDW interpolation:

- It is not possible to do a direction-dependent weighting. That means that spatially oriented relationships are ignored (e.g. elevation points along a ridge).
- Unsightly artefacts are the so-called "Bulls-eyes" - these are circular areas of equal values around the known data points. However, applying a variation of the IDW-Interpolation developed by Shepard [**?**] can reduce the Bulls-eyes:

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Figure 28: IDW "Bulls eye" effect: concentric areas of the same value around the known points - an unwanted artefact of the IDW interpolation.

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Figure 29: IDW modified after Shepard: the Bulls-eyes are definitely reduced.

Inverse Distance Weighting (IDW) - interactive animation

The following interactive animation shows 10 data points (blue) with known measurement values (numbers next to the points) and one point, which value is to be calculated (red). At the start of the animation, this value is calculated from the given values and distances. To get to know the principles of IDW interpolation better, you can now experiment with this animation:

- Change the position of one or all points with your mouse.
- Modify the default values for the known points (allowing a total of max. 4 digits).
- Set the distance-weighting exponent to a value other than 2 (total max. 4 digits allowed).

Answer the following questions keeping the experiment in mind:

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Figure 30: Interaktive IDW-Animation

1. Which measurement values influence the result even more when exponent is set higher?
2. If the exponent is set to 0, how do different distances influence the estimation, or what does the result solely depend on in this case?

1. The higher the distance exponent is set, the more influence **the values of the nearest neighbors have on the result.**
2. Is the distance exponent set to 0 (zero), a weight of 1 is assigned to any distance, i.e. all distances are absolutely equal. **The result depends only on the measured values themselves and not on the distance.** The interpolation no longer has a spatial component.

2.3.3 Geostatistical Interpolation

One of the disadvantages of the *IDW interpolation* is the lack of direction-specific (anisotropic) information. Therefore, spatial correlations are ignored and are not integrated into the result of the estimation. This disadvantage is leveled out by geostatistical interpolations.

The name "geo" already points to the most important feature of these methods: spatial-statistical parameters constitute the main basis for these interpolation methods.

The *variogram* or the *variography* (i.e. the method to derive it from spatial point data) is the basis for a successful geostatistical interpolation.

Geostatistical interpolations are advanced and to some extent complicate methods. Their sensible application requires a large amount of knowledge and experience. At this point, a few keywords about their implementation will be sufficient.

The main procedures are the *Kriging methods*. They are named after a South African engineer, D.G. Krige. In his diploma thesis in 1951, he laid the foundations for kriging. However, the main developments come from the work of G. Matheron in the 1960s.

Using variography, we get indications of how similar or dissimilar the measurement values of adjacent data points are as a function of their distance from each other.

Variography

a) First, we constitute pairs of all the data points and compare their two values. Of each data pair we know the difference (semivariance) and the distance (h):

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Figure 31: Variogram cloud, differences between data points vs. spatial distance between these points

b) Second, we divide the distances (x-axis) into intervals (so-called lags) and we take the mean of the semivariances of the data pairs within (red dots). By connecting these red points of every lag, we get the experimental variogram. This curve describes how similar the values of two adjacent positions are as a function of their distance from each other.

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Figure 32: Experimental variogram, the differences are averaged per defined class (h1...h5 = lag intervals)

c) To better handle this representation of spatial (dis-)similarity, we can construct simple curve functions onto the *experimental variogram* to match it as well as possible. This curve is called the *theoretical variogram*.

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Figure 33: Theoretical variogram, a theoretical variogram function is matched onto the sequence of the averaged differences per class (= per lag).

Now, we attempt Kriging by incorporating our data into this model of spatial continuity - the model that we have developed or found in the section about variogram modeling. Based on such a model we can calculate error variance for our estimations and seek their minimum.

Interpolation with Kriging is a kind of curve fitting: from our known data points we have derived a model of how the spatial relationships might be designed. Based on that model we now estimate the unknown points. If we consider it in two dimensions only (for simplicity), we work with a regression technique: a curve fitting.

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Figure 34: Kriging in zwei Dimensionen: Die blau umrandeten Quadrate sind unsere bekannten Datenpunkte, die rote Linie ist der geschätzte Verlauf, und die grünen Linien repräsentieren die statistischen Rahmenparameter aus unserem Modell [**?**]

You often hear the term "exact interpolator" in connection with Kriging, just like IDW and some other estimation methods. This means that a surface estimated with one of these methods is intersecting the known data points. If we perform the Kriging calculation at a position of a known value, Kriging will typically give us exactly that value in return.

In comparison, see below for the result of an inverse distance weighting compared to that of a Kriging interpolation:

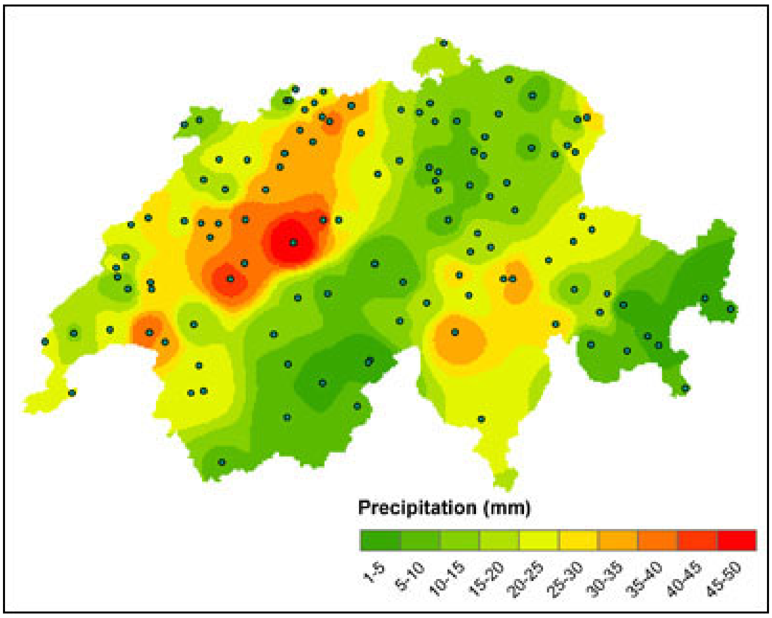


Figure 35: Estimation surface by using inverse distance weighting; Swiss rainfall data; Note that there are some „corona"(regions of the same values) around known data points. (Provided by Ross Purves).

Other important parameters for interpolations: Search neighborhood

All interpolation methods can additionally be controlled by the definition of a *search neighborhood*, i.e. how many or which known data points are used to calculate an unknown position. If we ignore this neighborhood, all available known data are used for the estimation of every point. In the case of the Swiss rainfall data, this would mean that for the calculation of a precipitation value in Ticino, the values of observation stations in Jura are included as well. This just does not make any sense.

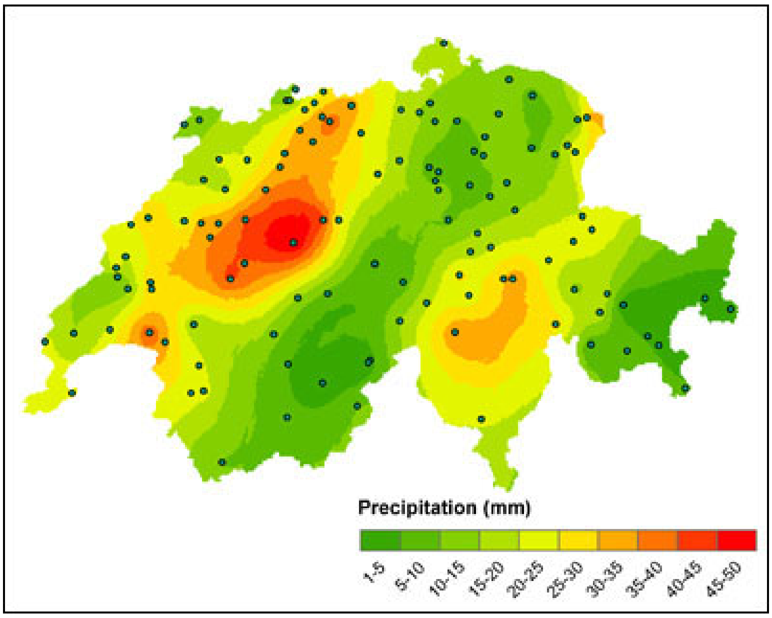


Figure 36: Result of a Kriging interpolation with Swiss rainfall data; here, no corona are to observe because the Kriging method „knows“spatial relationships. It obtains this information from the variogram. (Provided by Ross Purves).

2.4 Summary

Spatially continuous phenomena such as rainfall or sea level cannot simply be described by a mathematical function. To analyze these variables, a spatial sample, i.e. a certain number of measurement points, is set up. To visualize a continuous spatial variable, the values between the measurement points need to be interpolated. First, the spatial sample or the set-up of the measurement points must be defined according to these characteristics: representativeness, homogeneity, a spatially optimal distribution, and sufficient number of points. Depending on the phenomenon and the measurement method, the design type of the spatial sample can vary (e.g. random sample, systematic sample, stratified sample, or clustered sample). Before the interpolation, we need to check if there is a dependency between the spatial data. Two methods are suited for this purpose: variography or the “moving windows-method. Variography shows spatial dependency of the samples but not whether or not this dependency is equally distributed over the whole study area. For this, the “moving window-method is applied. For the interpolation itself, several approaches with different consequences exist. Two ways to interpolate are presented here: the distance-based interpolation IDW (inverse distance weighting), and the geostatistical interpolation. With IDW, different distances are incorporated differently into the estimation. The influence of the distance weighting can be controlled by choosing the distance-weighting exponent. The higher the exponent, the more influence the measurement values of the adjacent points have on the result. However, it is not possible to have a direction-dependent weighting. With the geostatistic interpolation, the variography as the basis is derived from statistically distributed parameters. From the variography, the similarity of adjacent data points as a function of their distance from each other is indicated. The most important geostatistic interpolation methods are the Kriging methods.

3 Spatial Queries

PLEASE NOTE: this lesson has been translated from German to English. However, some of the figures are still in German.

The aim of spatial queries and their analysis is to detect spatial relationships between elements of one or more subjects, in order to locate spatial objects. The results of such analysis can be used in decision making. This lesson is divided into four units. An introduction to the subject and the most important terms are provided in the first unit. These terms will be discussed in more detail in the other units.

Learning Objectives

- You know the objects of queries and are able to establish a connection between database structure and query possibilities.
- You are able to formulate a thematic query and to execute a simple and a complex query.
- You understand the basics of a geometric query and know how to perform the most important queries.
- You know the topological relationships between the objects and are able to formulate a topological query.

3.1 Introduction to spatial queries

The database structure, which is included in a GIS, enables the logical, *consistent*[1] and ordered storage and management of data. Both thematic and geometric information are stored in the form of tables. In the discipline of geoinformation, the term data analysis includes all those investigations, queries, evaluations, etc., which are carried out on structured and stored spatial data. When a query is performed to obtain and answer to a spatial question, the data are accessed through the basic elements of this structure which is made up of tables, fields, data sets, values and connections.

Citation:

"*The deduction of new information from existing spatial data is one of the main tasks of a geoinformation system.*

Spatial analysis comprises analysis and synthesis of spatial data to a unity [...] Every spatial analysis implies the professional interpretation of the resuslts." [**?**]

Example of a query:

„*Which proportion of the inhabitants of Zürich lives more than 200m away from a public transport stop?*“

[1] Gewährleisten der Widerspruchsfreiheit innerhalb einer Datenbank; d. h., dass der Inhalt einer Datenbank alle vordefinierten Konsistenzbedingungen („Constraints“) erfüllt.

3.1.1 The information system

An information system is a questionanswer system based on a data set. This system contains tools for the computer based analysis and handling of information. Such a system is called geographic information system (GIS) if the data are geographically referenced [?] . A GIS is composed of various individual components. Some of these functions are basic, while others are more complicated or required for special applications. The user interface, query functions and the data management system play an important role in *MISSING TEXT*. The user interface enables the user to communicate with the system. It allows users to start operations, query information, etc. Via the user interface, analysis functions can be executed through accessing the data. Data access and data management in general is controlled by the database management system.

Have a look at the following illustration to get an idea of information systems:

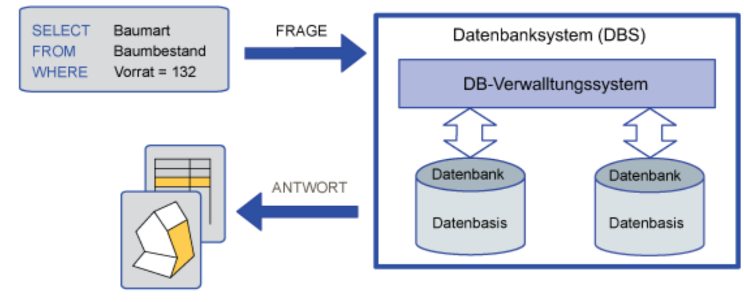


Figure 37: Fig. A: Architecture of a database

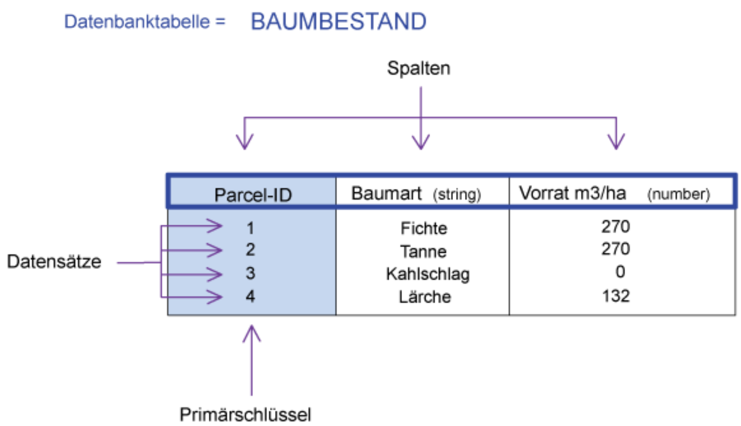


Figure 38: Fig. B: Structure of a table

3.1.2 The basic components of geographical information

A commercial GIS stores spatial data and its attributes in separate data files in which corresponding lines are linked by a unique identification number. This identification number allows a GIS to search for attribute values and to display them based on spatial query criteria, and vice versa.

In the geometric representation of an object, information about its attributes can be derived by selecting this object in a GIS. There is also the possibility to identify an object by its geometric representation by selecting its entry in the attribute table.

The data structure comprises the connection of thematic and geometric information. The geometry is expressed in the spatial reference. A spatial reference is assigned to all the objects in a greater or lesser extent. Spatial references describe the location and extent of this geographic information. In addition to the metric properties (geometry), topological properties should also be mentioned. Topological properties are expressed by information about e.g. relations of neighborhood (what object is neighboring?), containedness (does an object contain other objects?), overlap (is an object overlapped by other objects?), etc. In addition to geometric and topological properties, thematic properties are also assigned to each object. They are stored in tables. The geometric and thematic information affect each other. These socalled objects are subject to temporal changes. [?] .

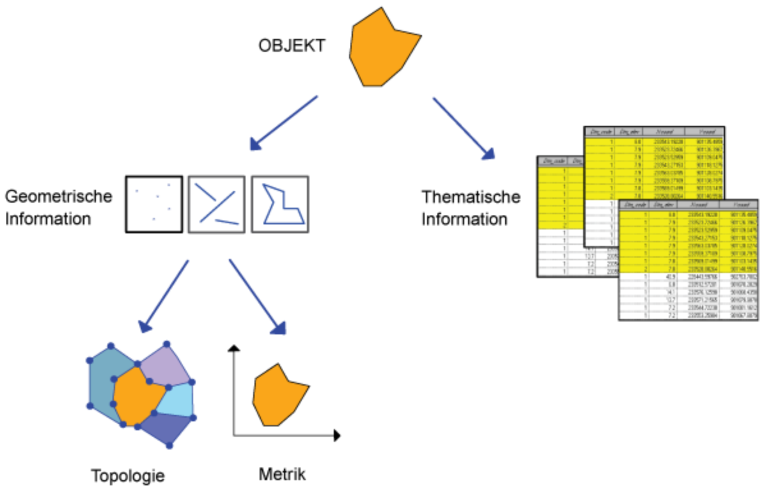


Figure 39: Fig. C: Basic components of a GIS

Example 1:

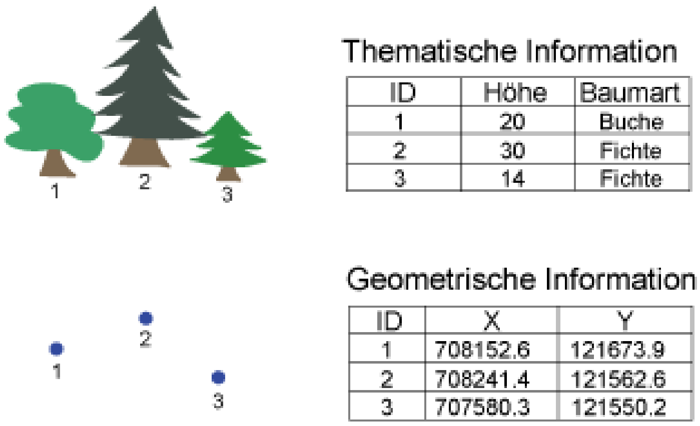
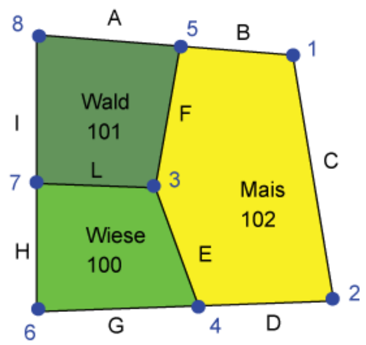


Figure 40: point_tree.png

Example 2:



Thematische Information

ID	Name	Ertrag
100	Wiese	....
101	Wald	....
102	Mais	....

Geometrische Information

ID	Perimeter	Fläche
100	....	....
101	....	....
102	....	....

Geometrische Information

ID	X	Y
1	708241.4	121673.9
2	707580.3	121562.6
3	709010.3	121550.2
4	708875.8	121976.6
5	710405.6	120500.5
6	721512.5	120574.0
7	723649.2	1206457
8	723634.4	120788.2

Topologische Information

ID	FROM NODE	TO NODE	LEFT POLYGON	RIGHT POLYGON	LENGTH
A	8	5	outside	101	....
B	5	1	outside	102	....
C	1	2	outside	102	....
D	2	4	outside	102	
E	4	3	100	102	
F	3	5	101	102	
G	4	6	outside	100	
H	6	7	outside	100	
I	7	8	outside	101	
L	8	3	101	100	

Figure 41: topo_geom.png

3.1.3 Query classification

The aim of spatial selection and analysis is to determine spatial relationships between one or more subjects in order to locate those elements in space. The results can then be used for decisionmaking. Performing a query, a number of criteria have to be formulated. To do so, the following approaches are possible:

- Thematic query:

  Selection of all objects which achieve the required conditions (attributes). E.g.: “Select all spruce trees.

- Geometric query:

  Selection of all objects which achieve the required spatial conditions. E.g.: “Select all the houses that are located less than 250 m away from the river.

- Topological query:

  Selection of all objects which achieve the required conditions regarding the spatial relations between the objects. For example: “Select all the buildings that are lying in zone 1.

Subquery

Queries can be performed on the entire data set or a subset of the data. Subsets are generated via queries. A subquery is a `SELECT` statement that is incorporated in a `SELECT` , `SELECT...INTO` , `INSERT...INTO` , `DELETE` , `UPDATE` statement or in another subquery. A subquery is composed of three parts.

Part	Description
Comparison	predicate and a comparison operator that compares the predicate with the result of the subquery.
Expression	An expression that is searched for in the result of the subquery.
SQL statement	A SELECT statement according to the usual format of the SELECT statement. It must be in parentheses.

Table 5: Legend missing

Example:

```
SELECT * FROM product WHERE product-ID IN (SELECT product-ID FROM
orders WHERE discount >= .25);
```

A query can be classified in two ways, based on the result:

- Direct query:

  Data are accessed interactively by the user or by an application program. Thus, a subset can be extracted, while the original data remains unchanged. The selection commands can be entered in command lines or query masks. More complex queries that require multiple single line commands can be prepared as sequences of command lines (batch, macro). In order to formulate queries, there is a formal query language. Many GIS support *SQL*[2] (Structured Query Language) as query language for thematic topics (see unit "Thematic Selection).

- Manipulation:

  By manipulating, new geographic information elements can be created. These new elements can be used for analysis purpose in further steps. In general, the new objects have to be previously conceptually modeled , and their data structure has to be implemented in the GIS. Some GIS can generate a minimal data structure (without thematic attributes) automatically. New information can be generated combining different objects. They can be used for further analysis.

[2]"Acronym for Structured Query Language. A syntax for retrieving and manipulating data from a relational database. SQL has become an industry standard query language in most relational database management systems" , e.g. Oracle, DB2, Access, etc.

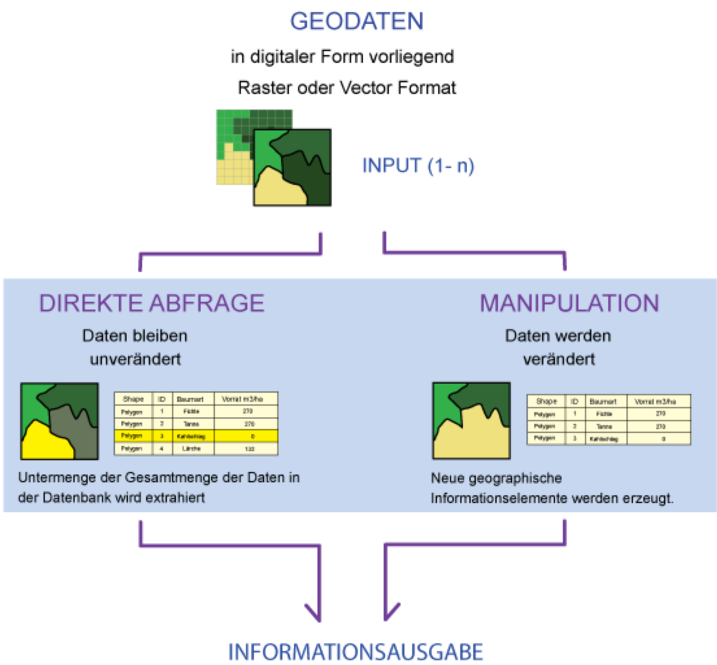


Figure 42: Fig. D: Classification of the query into direct query and manipulation

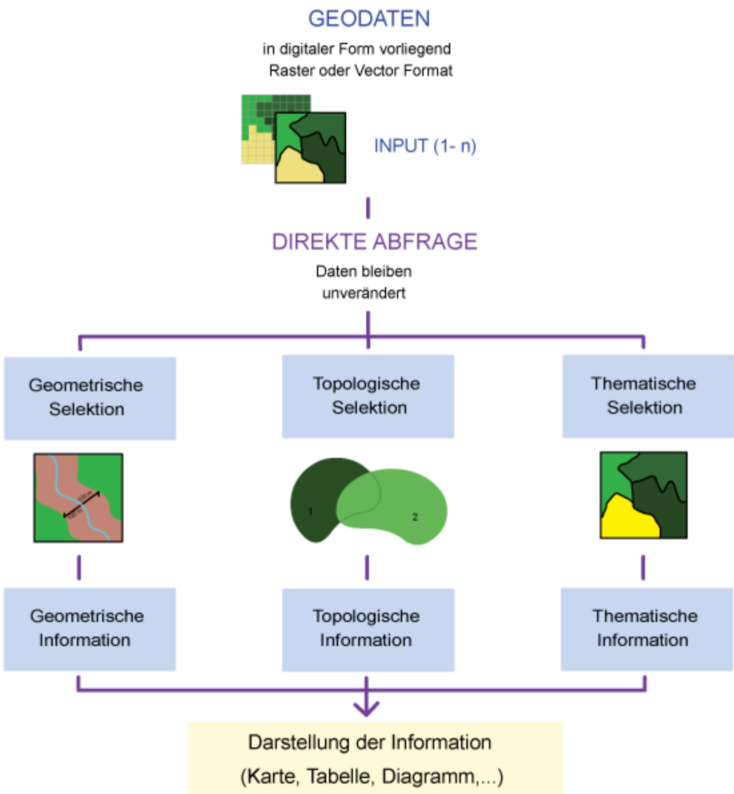


Figure 43: Fig. E: Splitting the direct query

3.1.4 Input / Output of a query

A query relates to specific datasets and the data type defines whether a certain query is possible or not. The common data types in a GIS are vector and raster and also tables. Thus, the queries on raster data are different than the queries on vector data, although the question to be answered is the same. The number of data sets included into the query also plays a role. The query can refer to a single or multiple data sets. The relationships between the data involved in the query are given via the *topology*[3] (geometry) or the tables (theme). Tables can also be related to each other. The content of the tables can be linked via key attributes. Thus, a query can be performed over several linked tables.

BAUMBESTAND		
PARCEL-ID	Baumart	Vorrat m3/ha
1	Fichte	270
2	Tanne	270
3	Kahlschlag	0
4	Lärche	132

m 1

HOLZBEDARF	
Baumart	Bedarf %
Fichte	5
Tanne	4
Lärche	2

Figure 44: Fig. F: Linked tables

The result of a query can be presented in different forms. The result should be presented in a form which is easy for the user to read. Normally, the results are presented as maps, tables, or figures, or in another format which allows data sharing. The following are examples of data presentation:

1. Digital data transfer
2. Interactive graphics on screen
3. Tables, reports, and similar representations
4. Passive graphics in form of maps

Some examples

[3]Die Topologie beschäftigt sich mit den räumlichen und strukturellen Eigenschaften der geometrischen Objekte unabhängig von ihrer Ausdehnung und ihrer Form. Die topologischen Eigenschaften äussern sich in Beziehung der Nachbarschaft, des Enthaltenseins, der Überschneidung und Ähnlichem.

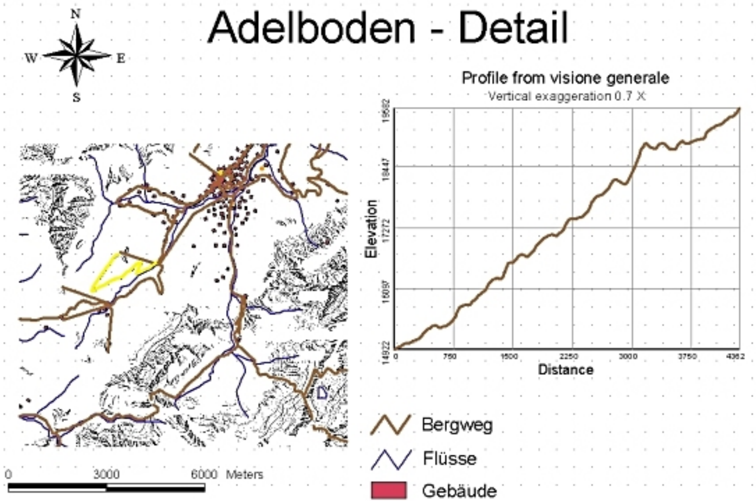


Figure 45: profile.jpg

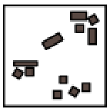
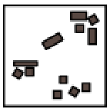
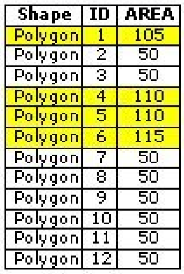
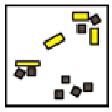
Layer 1	Layer 2	Inputs	Query	Type	Res. table	Res. graphic
	**Please note:** Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed.		Find the buildings, which have an area of more than $100m^2$.	**THEM**		

Table 6: Legend missing

Shape	ID	AREA
Polygon	1	105
Polygon	2	50
Polygon	3	50
Polygon	4	110
Polygon	5	110
Polygon	6	115
Polygon	7	50
Polygon	8	50
Polygon	9	50
Polygon	10	50
Polygon	11	50
Polygon	12	50

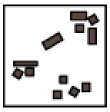
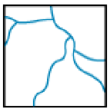
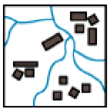
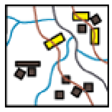
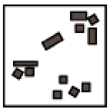
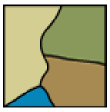
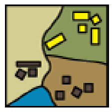
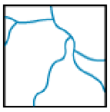
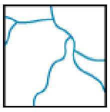
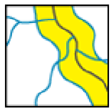
<table>
<tr>
<td></td>
<td></td>
<td></td>
<td>Find the buildings, which have an area of more than 100m^2 and which are within a distance of 100m to Adelriver.</td>
<td>GEOM + THEM</td>
<td><table><tr><th>Shape</th><th>ID</th><th>AREA</th></tr><tr><td>Polygon</td><td>1</td><td>105</td></tr><tr><td>Polygon</td><td>2</td><td>50</td></tr><tr><td>Polygon</td><td>3</td><td>50</td></tr><tr><td>Polygon</td><td>4</td><td>110</td></tr><tr><td>Polygon</td><td>5</td><td>110</td></tr><tr><td>Polygon</td><td>6</td><td>115</td></tr><tr><td>Polygon</td><td>7</td><td>50</td></tr><tr><td>Polygon</td><td>8</td><td>50</td></tr><tr><td>Polygon</td><td>9</td><td>50</td></tr><tr><td>Polygon</td><td>10</td><td>50</td></tr><tr><td>Polygon</td><td>11</td><td>50</td></tr><tr><td>Polygon</td><td>12</td><td>50</td></tr></table></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Find the buildings, which are completely within the forest.</td>
<td>TOPO</td>
<td><table><tr><th>Shape</th><th>ID</th><th>AREA</th></tr><tr><td>Polygon</td><td>1</td><td>105</td></tr><tr><td>Polygon</td><td>2</td><td>50</td></tr><tr><td>Polygon</td><td>3</td><td>50</td></tr><tr><td>Polygon</td><td>4</td><td>110</td></tr><tr><td>Polygon</td><td>5</td><td>110</td></tr><tr><td>Polygon</td><td>6</td><td>115</td></tr><tr><td>Polygon</td><td>7</td><td>50</td></tr><tr><td>Polygon</td><td>8</td><td>50</td></tr><tr><td>Polygon</td><td>9</td><td>50</td></tr><tr><td>Polygon</td><td>10</td><td>50</td></tr><tr><td>Polygon</td><td>11</td><td>50</td></tr><tr><td>Polygon</td><td>12</td><td>50</td></tr></table></td>
<td></td>
</tr>
<tr>
<td>Please note: Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed.</td>
<td></td>
<td></td>
<td>Find the area, which is within a distance of 100 m to Adelriver.</td>
<td>GEOM</td>
<td><table><tr><th>Shape</th><th>BUFFDIS</th></tr><tr><td>Polygon</td><td>100</td></tr></table></td>
<td></td>
</tr>
</table>

Table 6: Legend missing

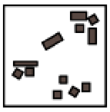
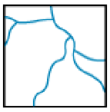
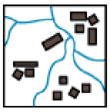
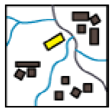
<table>
<tr>
<td></td>
<td></td>
<td></td>
<td>Find the building, which is closest to Adelriver.</td>
<td>GEOM</td>
<td>
<table>
<tr><th>Shape</th><th>ID</th><th>AREA</th></tr>
<tr><td>Polygon</td><td>1</td><td>105</td></tr>
<tr><td>Polygon</td><td>2</td><td>50</td></tr>
<tr><td>Polygon</td><td>3</td><td>50</td></tr>
<tr><td>Polygon</td><td>4</td><td>110</td></tr>
<tr><td>Polygon</td><td>5</td><td>110</td></tr>
<tr><td>Polygon</td><td>6</td><td>115</td></tr>
<tr><td>Polygon</td><td>7</td><td>50</td></tr>
<tr><td>Polygon</td><td>8</td><td>50</td></tr>
<tr><td>Polygon</td><td>9</td><td>50</td></tr>
<tr><td>Polygon</td><td>10</td><td>50</td></tr>
<tr><td>Polygon</td><td>11</td><td>50</td></tr>
<tr><td>Polygon</td><td>12</td><td>50</td></tr>
</table>
</td>
<td></td>
</tr>
</table>

Table 6: Legend missing

Exercise

What does the spatial information in a GIS mainly consist of?

3.1.5 Questions

Question 1

How can space related information be divided?

Question 2

Which approaches can be used to formulate a query?

Question 3

Describe the inputs which should be used to answer the following questions and what would the outputs look like:

„Find all buildings which are located on parcels with a minimal area of 1000 m^2 *and a distance of more than 250m to the highway“.*

3.2 Thematic query

Thematic *queries*[4] result in the selection of thematic information. This process is comparable to a query of a conventional database, whose data have no spatial reference.

Query language

In a GIS, queries are performed either with *SQL* or internal query languages. In a standard GIS the commands are directly entered; in contrast, in a desktop GIS, the commands have to be selected using a dialogue system. The functionalities of SQL are explained in the “Database Management and Systems Module (lesson 4: Structured Query Language SQL (www.gitta.info/RelQueryLang/en/)).

In the following examples, some userfriendly interfaces for SQL formulations of thematic queries are shown. With a few clicks the desired SQL commands are compiled. Behind the interface, the SQL syntax is used to query the database.

Example 1: ArcView Interface

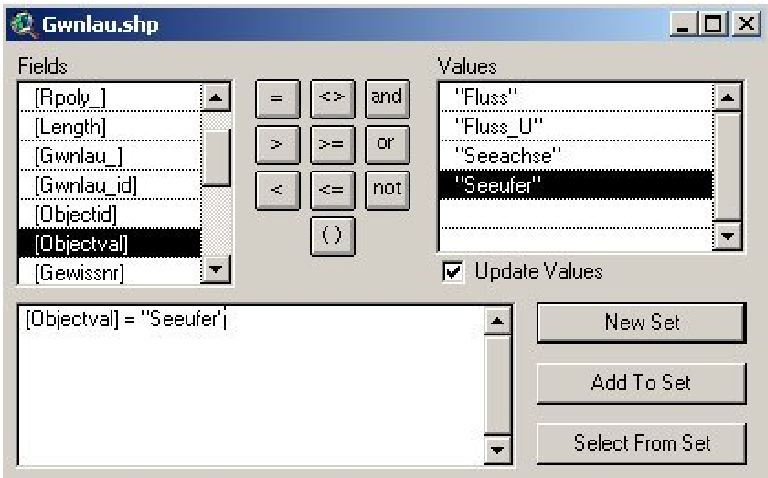


Figure 46: arcview_abfrage.jpg

Example 2: ArcGIS Interface

[4]Die Abfrage ermittelt räumliche Beziehungen zwischen Elementen eines oder mehrerer Themen, um auf dieser Basis eine Lokalisierung von Objekten zu erreichen. Die Analyseergebnisse können dann bei konkreten Fragestellungen zur Entscheidungsfindung beitragen.

Query operators

A particular feature that distinguishes a GIS is the possibility to query specific thematic information about selected objects. The thematic query relies on the analysis of technical data (attribute data). The query is performed using adequate selecting operators. In the following, three categories of *operators*[5] are presented:

- Relational operators: Besides the equal sign, relational operators can be used to formulate queries as well.
- Arithmetic operators: These operators are used for numeric attributes. E.g. there is the possibility to calculate the mean of an attribute or the sum of attribute values from a series of objects.
- Logic operators: Conditions are formulated with logic operators. The semantics (meaning) of these operators are similar to the meaning "AND, "OR etc.

[5]In search algorithms, operators enable the logical conjunction of search items using keywords like AND, OR, and NOT.

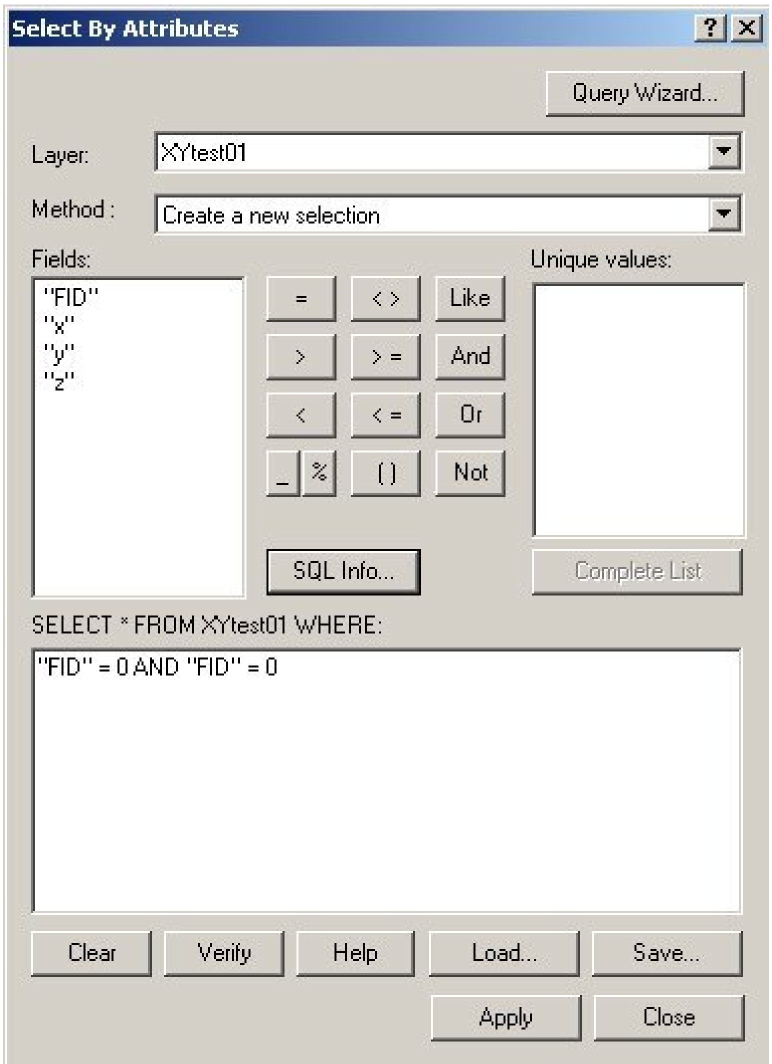


Figure 47: arcgis_abfrage.jpg

3.2.1 Relational operators

The relational operators are not only used for numeric attributes, but also for text attributes and other data types. The comparisons “greater than, “less than etc. are related to the position of an “alphabetical order used in a computer.

Relational operators	**sometimes, other spellings are used**
=	EQ (equal to)
>	GT (greater than)
>=	GE (greater than or equal to)
<	LT (less than)
<=	LE (less than or equal to)
<>	NE (not equal to)

Table 7: Legend missing

SQL provides the following additional functions for analysis (aggregate functions):

- Avg function (average)
- Count function (number)
- Min, Max function (minimum, maximum)
- StDev, StDevP function (standard deviation, standard deviation of the population)
- Sum function (sum)
- Var, VarP function (variance, variance of the population)

An example - relational operators

INPUT

QUERY AND RESULTS

SQL operator	**Result: table**	**Result: graphic**

Table 8: Legend missing

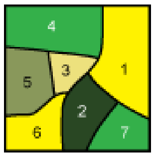
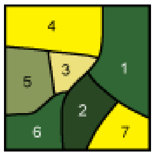
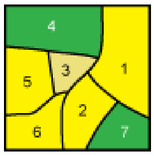
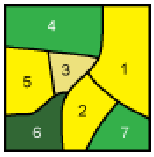
<table>
<tr>
<td>SELECT * FROM Parzelle WHERE Baumart = 'Fichte';</td>
<td><table><tr><th>Shape</th><th>ID</th><th>Baumart</th><th>Vorrat</th><th>Bodentyp</th></tr><tr><td>Polygon</td><td>1</td><td>Fichte</td><td>250</td><td>Braunerde</td></tr><tr><td>Polygon</td><td>6</td><td>Fichte</td><td>130</td><td>Podzol</td></tr></table></td>
<td>
</td>
</tr>
<tr>
<td>SELECT Baumart, Vorrat, Bodentyp FROM Parzelle WHERE Bodentyp = 'Redzina';</td>
<td><table><tr><th>Baumart</th><th>Vorrat</th><th>Bodentyp</th></tr><tr><td>Lärche</td><td>120</td><td>Redzina</td></tr><tr><td>Lärche</td><td>100</td><td>Redzina</td></tr></table></td>
<td>
</td>
</tr>
<tr>
<td>SELECT * FROM Parzelle WHERE Vorrat >120;</td>
<td><table><tr><th>Shape</th><th>ID</th><th>Baumart</th><th>Vorrat</th><th>Bodentyp</th></tr><tr><td>Polygon</td><td>1</td><td>Fichte</td><td>250</td><td>Braunerde</td></tr><tr><td>Polygon</td><td>2</td><td>Tanne</td><td>250</td><td>Pseudogley</td></tr><tr><td>Polygon</td><td>6</td><td>Fichte</td><td>130</td><td>Podzol</td></tr><tr><td>Polygon</td><td>5</td><td>Buche</td><td>300</td><td>Lithosol</td></tr></table></td>
<td>
</td>
</tr>
<tr>
<td>SELECT * FROM Parzelle WHERE Vorrat >= (SELECT AVG (Vorrat) FROM Parzelle);</td>
<td><table><tr><th>Shape</th><th>ID</th><th>Baumart</th><th>Vorrat</th><th>Bodentyp</th></tr><tr><td>Polygon</td><td>1</td><td>Fichte</td><td>250</td><td>Braunerde</td></tr><tr><td>Polygon</td><td>2</td><td>Tanne</td><td>250</td><td>Pseudogley</td></tr><tr><td>Polygon</td><td>5</td><td>Buche</td><td>300</td><td>Lithosol</td></tr></table></td>
<td>
</td>
</tr>
</table>

Table 8: Legend missing

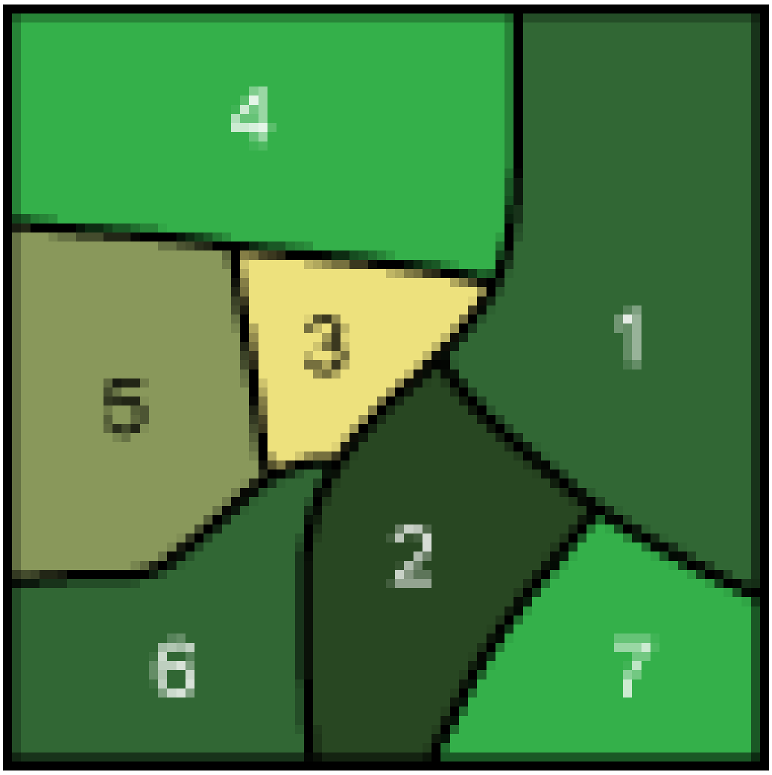


Figure 48: Graphic

Shape	ID	Baumart	Vorrat_m³/ha	Bodentyp
Polygon	1	Fichte	250	Braunerde
Polygon	2	Tanne	250	Pseudogley
Polygon	3	Kahlschlag	0	Braunerde
Polygon	4	Lärche	120	Redzina
Polygon	5	Buche	300	Lithosol
Polygon	6	Fichte	130	Podzol
Polygon	7	Lärche	100	Redzina

Figure 49: Table „Parcels: tree species (Baumart), stock (Vorrat), and soil type (Bodentyp)“

3.2.2 Arithmetic operators

Arithmetic operators are used for numerical attributes. For example, there is the possibility to calculate the mean or the sum of attribute values from a series of objects. The following operators can be used as arithmetic operators: Multiplication (*), division (/), addition (+) and subtraction () as well as the exponent operator (exp) and modulo operator (%).

Arithmetic operators

+

-

*

/

exp

%

The first five operators are selfexplanatory. The modulo operation gives the remainder from integer division. For example:

5 % 2 = 1

6 % 2 = 0

An example - arithmetic operators

INPUT

<table>
<tr><th>SQL operator</th><th>Result</th></tr>
<tr><td>SELECT Baumart, Vorrat,
Bodentyp, Vorrat*2/100 as
Holznutzung
FROM Parzelle
WHERE Vorrat > 120;</td><td>
<table>
<tr><th>Shape</th><th>ID</th><th>Baumart</th><th>Vorrat</th><th>Bodentyp</th><th>Holznutzung</th></tr>
<tr><td>Polygon</td><td>1</td><td>Fichte</td><td>250</td><td>Braunerde</td><td>5</td></tr>
<tr><td>Polygon</td><td>2</td><td>Tanne</td><td>250</td><td>Pseudogley</td><td>5</td></tr>
<tr><td>Polygon</td><td>6</td><td>Fichte</td><td>130</td><td>Podzol</td><td>2.6</td></tr>
<tr><td>Polygon</td><td>5</td><td>Buche</td><td>300</td><td>Lithosol</td><td>6</td></tr>
</table>
</td></tr>
</table>

Table 9: QUERY AND RESULT

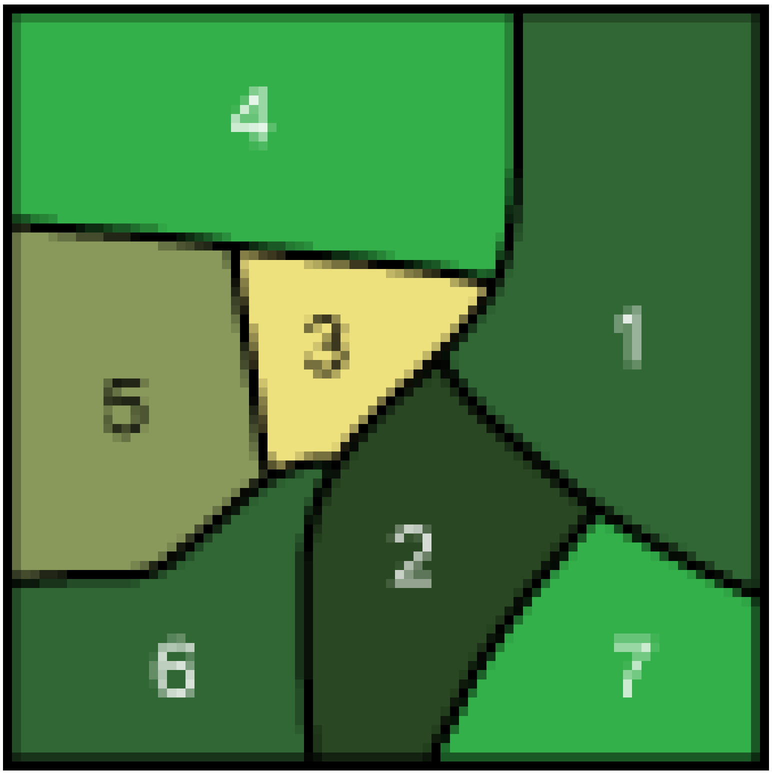


Figure 50: Graphic

Shape	ID	Baumart	Vorrat_m³/ha	Bodentyp
Polygon	1	Fichte	250	Braunerde
Polygon	2	Tanne	250	Pseudogley
Polygon	3	Kahlschlag	0	Braunerde
Polygon	4	Lärche	120	Redzina
Polygon	5	Buche	300	Lithosol
Polygon	6	Fichte	130	Podzol
Polygon	7	Lärche	100	Redzina

Figure 51: Table „Parcels: tree species (Baumart), stock (Vorrat), and soil type (Bodentyp)“

3.2.3 Logical operators

Arbitrarily complex conditions can be formulated. Thereby concatenations of the individual conditions have to be extended. Complex queries are formulated by combining different attributes.

For such queries, **logical operators** are used to combine the expressions (with two possible values “true or “false).

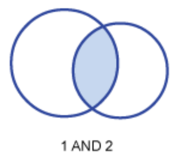
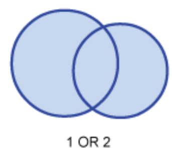
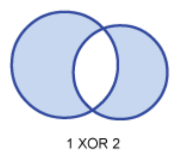
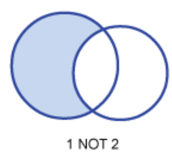
Logical operators	**Meaning**	**Result**	**Venn diagrams**
AND	Intersection	True, if both are true.	
OR	Union	True, if at least one is true.	
XOR	Symmetric difference; excluding OR	True, if exactly one is true, but not both.	
NOT	Set difference (complement)	True, if one is false.	

Table 10: Legend missing

To make such queries understandable, Venn diagrams are used. Have a look at the previous table and the following explanation.

The circles number 1 and 2 graphically represent two conditions : the shaded area represents the true statement, while the part outside the circle does not correspond to a result.

To explain this situation, the above example is used.

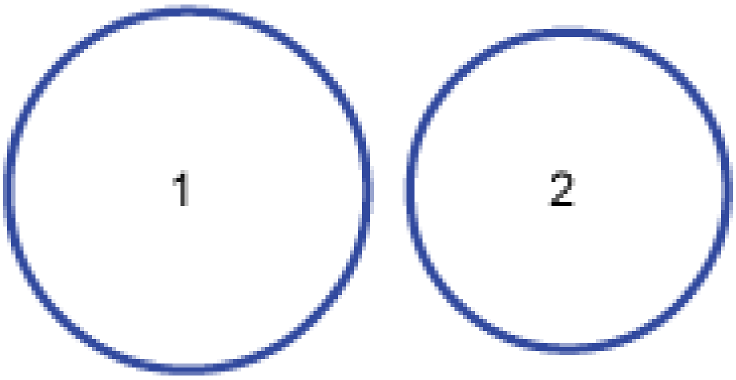


Figure 52: kreis_1_2.png

Circle 1 : Tree species = „larch“

Circle 2 : Stock > 110 m^3 /ha

Some examples

In the following, it is shown for each operator how SQLqueries are formulated and how the results are presented.

INPUT

Example 1:

Operator	Query	SQL
AND	Find all parcels that are forested with larch and where the stock is greater than 110m^3 /ha.	**select** ParzelleID, Baumart, Vorrat **from** Parzelle **where** Baumart = „Lärche“**and** Vorrat > 110

Table 11: Legend missing

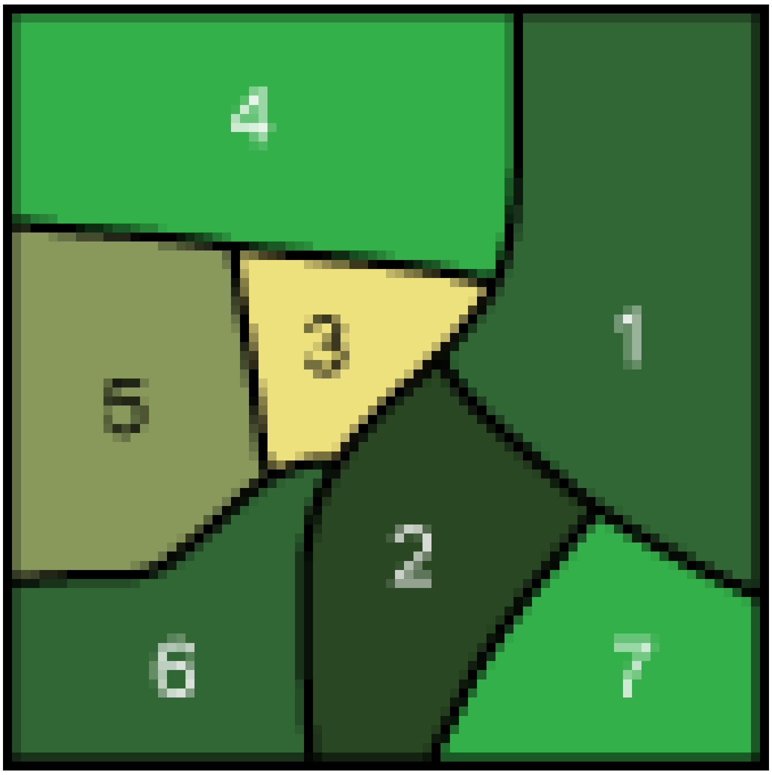
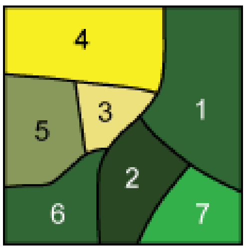


Figure 53: Graphic



Shape	ID	Baumart	Vorrat_m³/ha
Polygon	1	Fichte	250
Polygon	2	Tanne	250
Polygon	3	Kahlschlag	0
Polygon	4	Lärche	120
Polygon	5	Buche	300
Polygon	6	Fichte	130
Polygon	7	Lärche	100

Table 12: Legend missing

Example 2:

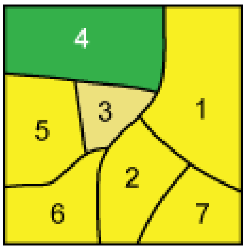
Operator	**Query**	**SQL**
OR	Find all parcels that are forested with larch or where the stock is greater than 110m^3 /ha.	**select** ParzelleID, Baumart, Vorrat **from** Parzelle **where** Baumart = „Lärche“ **or** Vorrat > 110

Table 13: Legend missing

Shape	ID	Baumart	Vorrat_m³/ha

XOR	Find all parcels that are forested with larch or where the stock is greater than 110m^3 /ha, but which do not meet both of these conditions.	**select** ParzelleID, Baumart, Vorrat **from** Parzelle **where** Baumart = „Lärche“ **xor** Vorrat > 110

Table 15: Legend missing



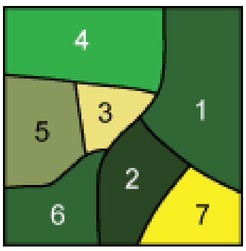
Shape	ID	Baumart	Vorrat_m^3/ha
Polygon	1	Fichte	250
Polygon	2	Tanne	250
Polygon	3	Kahlschlag	0
Polygon	4	Lärche	120
Polygon	5	Buche	300
Polygon	6	Fichte	130
Polygon	7	Lärche	100

Table 16: Legend missing

Example 4:

Operator	Query	SQL
NOT	Find all parcels which are forested with larch but where the stock is not greater than 110m^3 /ha.	**select** ParzelleID, Baumart, Vorrat **from** Parzelle **where** Baumart = „Lärche“ **not** Vorrat > 110

Table 17: Legend missing



Shape	ID	Baumart	Vorrat_m^3/ha
Polygon	1	Fichte	250
Polygon	2	Tanne	250
Polygon	3	Kahlschlag	0
Polygon	4	Lärche	120
Polygon	5	Buche	300
Polygon	6	Fichte	130
Polygon	7	Lärche	100

Table 18: Legend missing

Shape	ID	Baumart	Vorrat_m³/ha
Polygon	1	Fichte	250
Polygon	2	Tanne	250
Polygon	3	Kahlschlag	0
Polygon	4	Lärche	120
Polygon	5	Buche	300
Polygon	6	Fichte	130
Polygon	7	Lärche	100

Figure 54: Table

Figure 55: vertical_arrow.png

Figure 56: vertical_arrow.png

Figure 57: vertical_arrow.png

Figure 58: vertical_arrow.png

3.2.4 Combination of operators

By combining operators, it is possible to link multiple conditions.

The Boolean operators are not commutative. That means, in complicated expressions the result depends on the mathematically defined order of the subparts of the expression. Using brackets, the order can be completely changed [?] .

Nested Queries

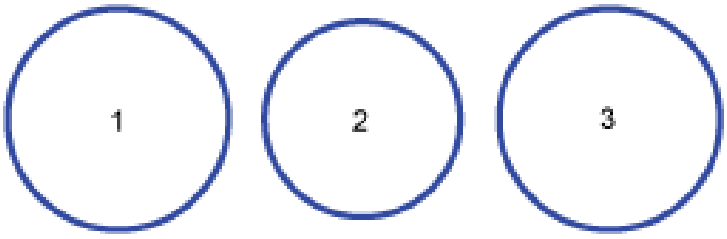


Figure 59: 3nested.png

Circle 1: Tree species = „Larch“

Circle 2: Stock > 110 m^3 /ha

Circle 3: Density > 80%

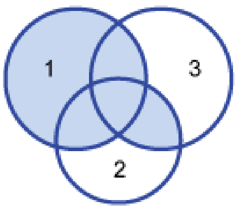
Venn-diagram	Condition	Corresponding SQL query
	(3 AND 2) OR 1	**Select** * **from** Parcel **where** (Density > 80% and Stock > 110 m^3 /ha) or Tree species = „Larch“

Table 19: Legend missing

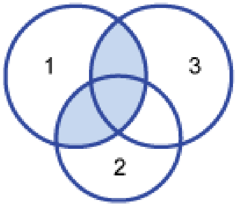
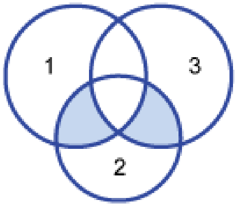
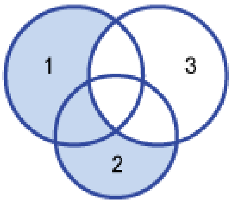
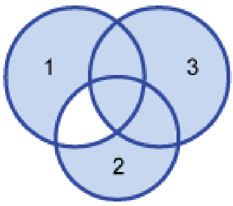
	1 AND (3 OR 2)	**Select** * **from** Parcel **where** Tree species = „Larch“ and (Density > 80% or Stock > 110 m^3 /ha)
	(3 XOR 1) AND 2	**Select** * **from** Parcel **where** (Density > 80% xor Tree species = „Larch“) and Stock > 110 ^{3} /ha
	(2 OR 1) NOT 3	**Select** * **from** Parcel **where** (Stock > 110 m^3 /ha or Tree species = „Larch“) not Density > 80%
	3 OR (2 XOR 1)	**Select** * **from** Parcel **where** Density > 80% or (Stock > 110 m^3 /ha xor Tree species = „Larch“)

Table 19: Legend missing

Applications

Try to solve the following exercises. Consider, in particular, which operator is used:

Select all the roads of the type “Nebenstrasse, where the speed is limited to

50km/h (select the objects by clicking on the rows of the table).

Please note:
Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed.

Figure 60: strasse_uebung_and.swf

Select all the roads (all road types), where the speed is limited to 50km/h (select the objects by clicking on the rows of the table).

Please note:
Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed.

Figure 61: strasse_uebung_or.swf

Select all the roads, where the speed is limited to 50km/h and which are not “Nebenstrassen that have no limited velocity of 50km/h. Select also all the roads which are “Nebenstrasse and which have no speed limit of 50km/h (select the objects by clicking on the rows of the table).

Please note:
Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed.

Figure 62: strasse_uebung_xor.swf

Select all the roads, where the speed is limited to 50km/h, but which are not “Nebenstrassen (select the objects by clicking on the rows of the table).

Please note:
Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed.

Figure 63: strasse_uebung_not.swf

3.2.5 Formulate queries

SETUP INFORMATION FOR TUTORS: **Setup a discussion forum, e.g. in WebCT**

Formulate possible queries for the example below and try to differentiate the different query types. Publish your article in the discussion forum on WebCT.

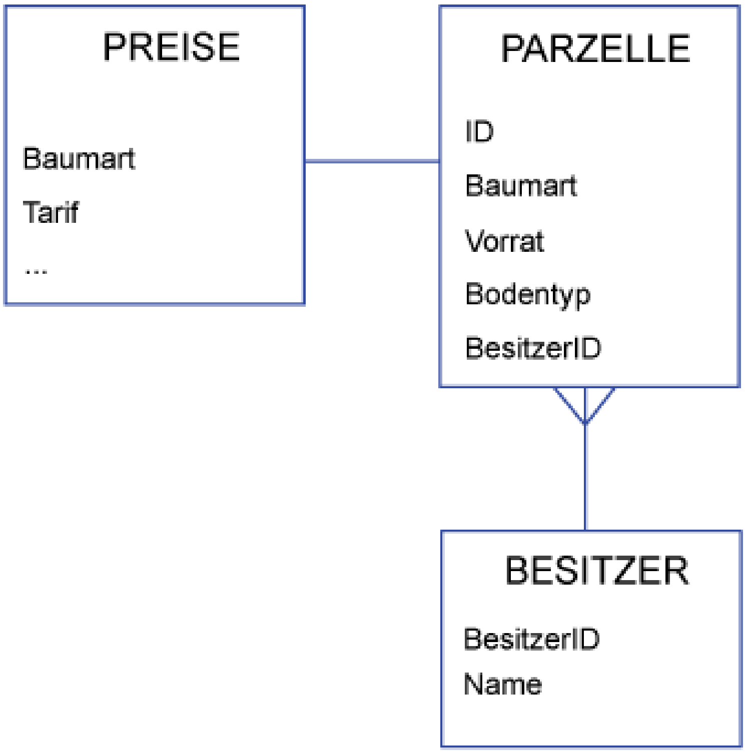


Figure 64: small_model.png

Parzelle TABLE

Shape	ID	Baumart	Vorrat	Bodentyp	BesitzerID
Polygon	1	Fichte	250	Braunerde	1
Polygon	2	Tanne	250	Pseudogley	1
Polygon	3	Kahlschlag	0	Braunerde	2
Polygon	4	Lärche	120	Redzina	3
Polygon	5	Buche	300	Lithosol	2
Polygon	6	Fichte	130	Podzol	3
Polygon	7	Lärche	100	Redzina	3

Figure 65: tab_parzelle2.jpg

Besitzer TABLE

BesitzerID	Name
1	Gustav Meier
2	Stephan Rohr
3	Hildegard Muster

Figure 66: tab_besitzer.jpg

Preis TABLE

Baumart	Tarif
Fichte	200
Tanne	180
Buche	170
Lärche	210

Figure 67: tab_preis.jpg

3.3 Geometric query

In addition to the information and search options based on theme, analysis functions based on spatial (geometric and topological) selection criteria are also implemented in GIS. In this unit, the geometric query is discussed. The geometry can be measured, such as the area or the perimeter of an object, or the distance or direction between two objects, respectively (measuring functions). To explain these concepts, it is important to distinguish between raster and vector models.

3.3.1 The geometric primitives

In **VECTOR MODELS** , information is assigned to points. All the other structures (lines and polygons) are based on points. The geometry of all other structures can be derived based on the coordinates of the points, such as the length of the connection line between two points, the area of a surface, and the distance between two objects [**?**] .

The three geometric primitives are arranged in 2D space, as shown in the following table.

Point

A 2D point is defined by the x and ycoordinates.

Line

Line segments consist of one or more point pairs. Two points of a segment can be connected by a straight line or an arc. This means that lines can be made up of straight lines, curves, or a mixture of the two.

Polygon

Polygons (areas) are composed of connected lines that form a closed geometric shape. The enclosed area is the polygon.

Complex geometries can be modeled as ordered sequences of the geometric primitives.

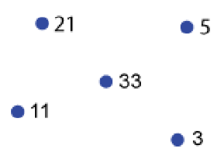
DESCRIPTION	GRAPHIC	TABLE
Point Position, no area. Defined by the coordinates.		**21** 3 5 **33** 5 4 **11** 2 3 **5** 8 4.5 **3** 7 1.5

Table 20: Legend missing

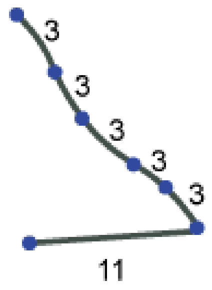
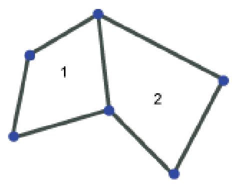
<table>
<tr>
<td>Line
Length, no width.
Defined by several segments, which always connect two points.</td>
<td>
</td>
<td>3
2 6
2.5 5
3 4
4 3
5 2.5
6 1.5
END
11
2 1
6 1.5
END</td>
</tr>
<tr>
<td>Area
Area and perimeter.
Defined by several segments, which form a closed polygon.</td>
<td>
</td>
<td>1
1 2
2 5
5 6
6 3
END
2
5 6
10 4
9 1
6 3
END</td>
</tr>
</table>

Table 20: Legend missing

In **RASTER MODELS** , all values are stored in a simple array (matrix). In addition, there is a file header, which contains the following information:

- Number of rows and columns
- Cell size
- Minimum value of x and ycoordinates

For example:

Ncols 270

Nrows 476

Xcorner 708152.60

Ycorner 121673.90

Cellsize 1

NODATA_Value -9999

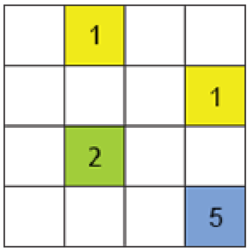
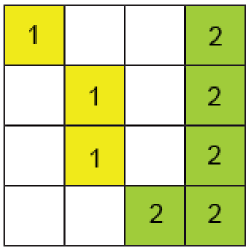
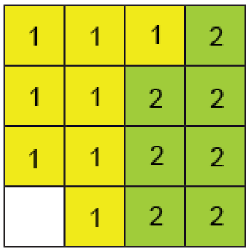
<table>
<tr><th>DESCRIPTION</th><th>GRAPHIC</th><th>TABLE</th></tr>
<tr><td>Point
One cell</td><td></td><td><table><tr><th>Value</th><th>Count</th></tr><tr><td>1</td><td>2</td></tr><tr><td>2</td><td>1</td></tr><tr><td>5</td><td>1</td></tr></table></td></tr>
<tr><td>Line
Several neighboring cells in which normally one cell is connected at the edges and corners with just one or two neighboring cells.</td><td></td><td><table><tr><th>Value</th><th>Count</th></tr><tr><td>1</td><td>3</td></tr><tr><td>2</td><td>5</td></tr></table></td></tr>
<tr><td>Area
Group of neighboring cells connected at the edges and corners.</td><td></td><td><table><tr><th>Value</th><th>Count</th></tr><tr><td>1</td><td>8</td></tr><tr><td>2</td><td>7</td></tr></table></td></tr>
</table>

Table 21: Legend missing

3.3.2 Geometric measurement functions

Geometry is a property of an object, just as is the thematic. With the appropriate measuring functions, queries can be performed. The general geometric queries are listed below:

Position - where (x, y)?

Vector model

Returns the position of each point from the map as x and ycoordinates.

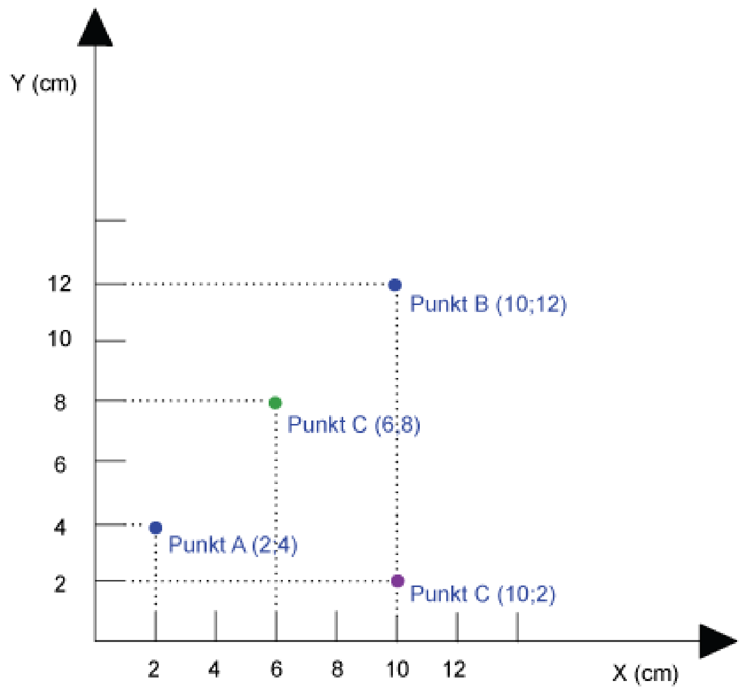


Figure 68: vector_location.png

Raster model

Example: Block encoding

Value	**No. Cell**	**Location**

Table 22: Legend missing

1	8	4,2 5,2 6,2 4,3 5,3 4,4 5,4 5,5
2	7	7,2 6,3 7,3 6,4 7,4 6,5 7,5

Table 22: Legend missing

Distance

Vector model

For vector data, the distance between two objects is calculated according to the Pythagorean Theorem and corresponds to the shortest distance.

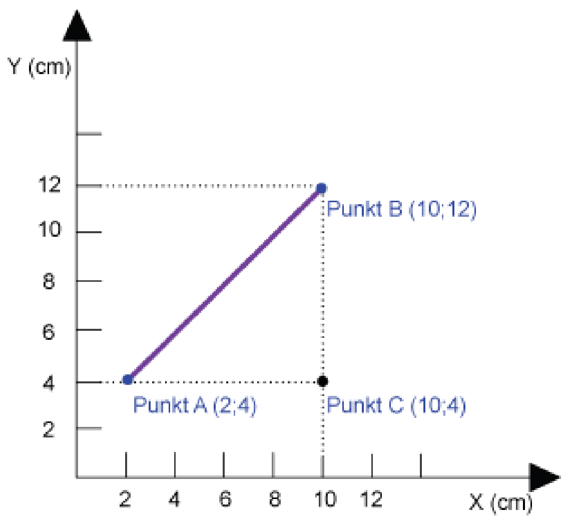
 Euclidean distance	Distance between point A and B $AB = \sqrt{AC^2 + BC^2}$ **Example:** The distance is **11,3 cm.**

Table 23: Legend missing

Raster model

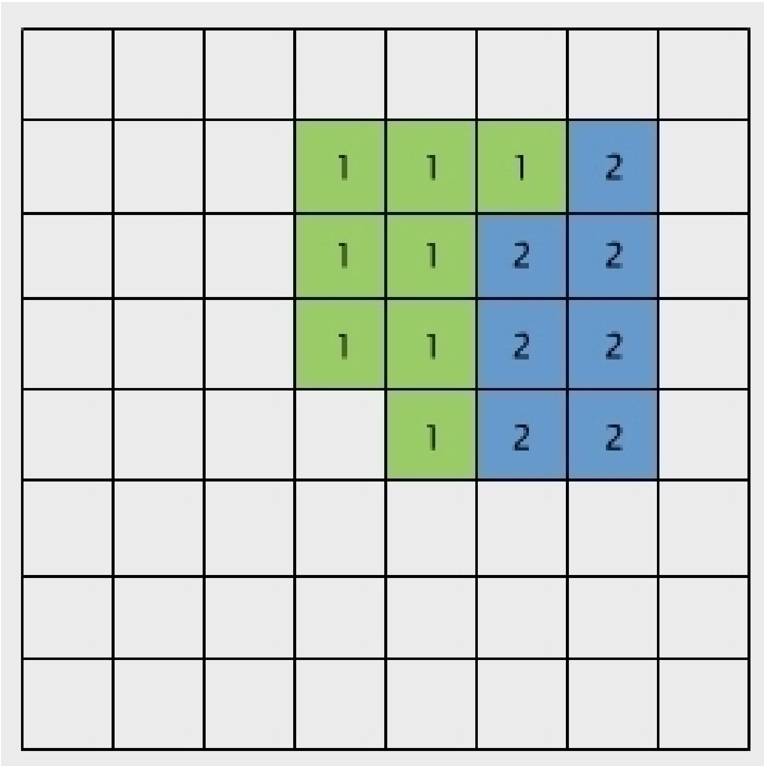


Figure 69: raster_location.jpg

In the raster model, there are three different approaches to measure the distance between points.

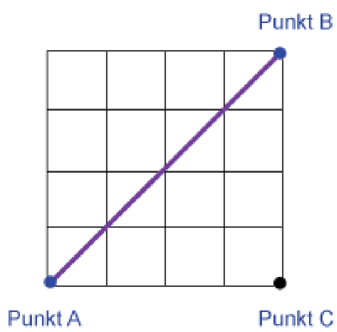
 Euclidean distance	Straight line between point A and point B $AB = \sqrt{AC^2 + BC^2}$ **Beispiel:** Mit einer Auflösung von 2 cm beträgt die Distanz **11,3 cm.**

Table 24: Legend missing

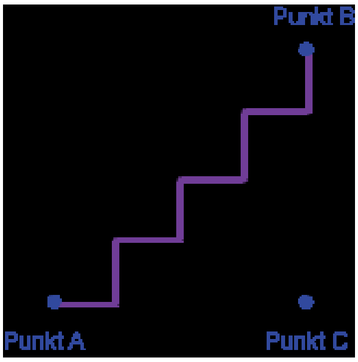
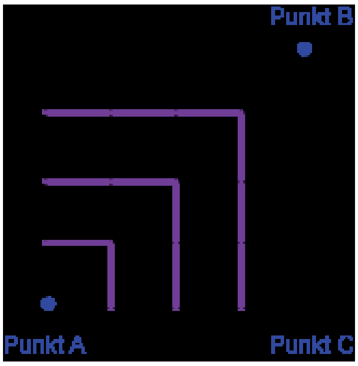
 Manhattan distance	Distance along the cell boundary between points A and B. **Example:** Using a resolution of 2 cm, the distance is **16 cm.**
 Neighborhood	Concentric zones with same distance around point A. **Example:** Using a resolution of 2 cm, the distance is **11,3 cm.**

Table 24: Legend missing

Practical examples

WHERE

In ArcInfo *"Measuring Where* returns the x, y position of a selected point on a map.

LENGTH

In ArcInfo *"Length"* returns the length of a line section, which consists of two or more points.

WITHIN A CERTAIN DISTANCE

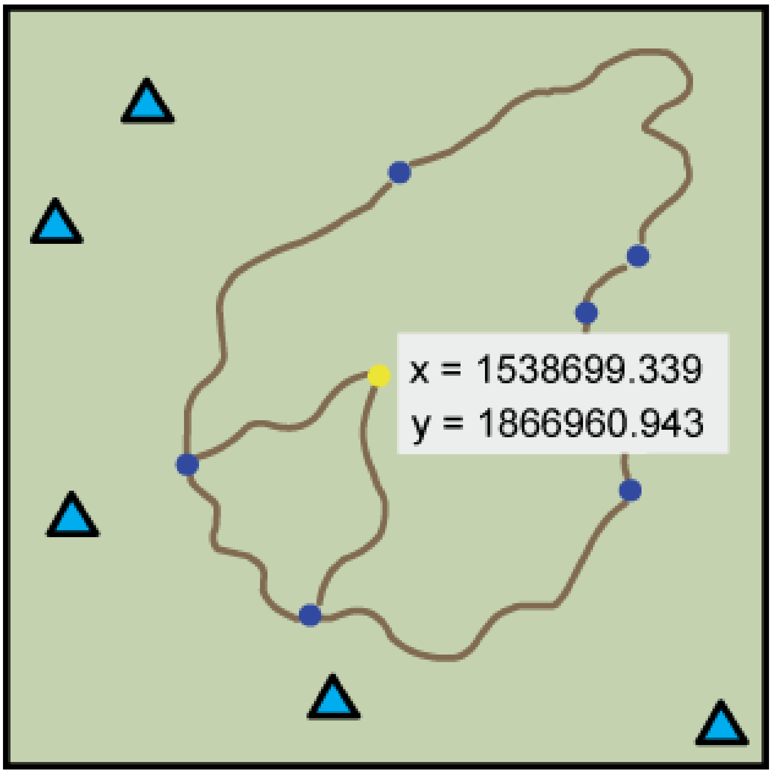


Figure 70: wo.png

Two objects are lying “within a certain distance if the distance between them is smaller than the given distance. Traditional GIS software offer preprogrammed tools to answer these questions.

Question 1:

Select all mountain peaks that are less than 500m away from the cabins (planimetric).

Question 2:

Select all the trees that are less than 200m away from the collection point.

Size

Vector data model

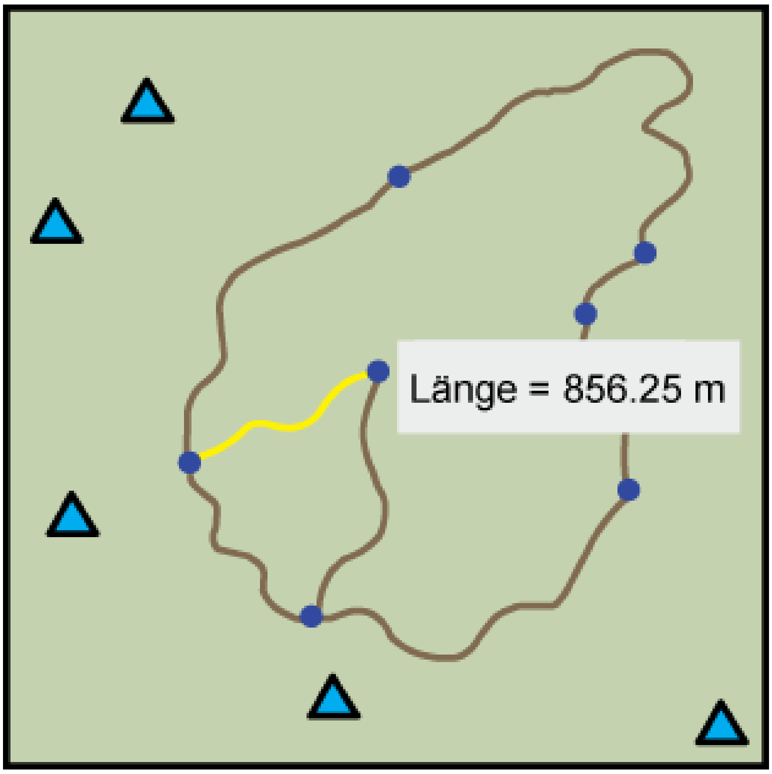
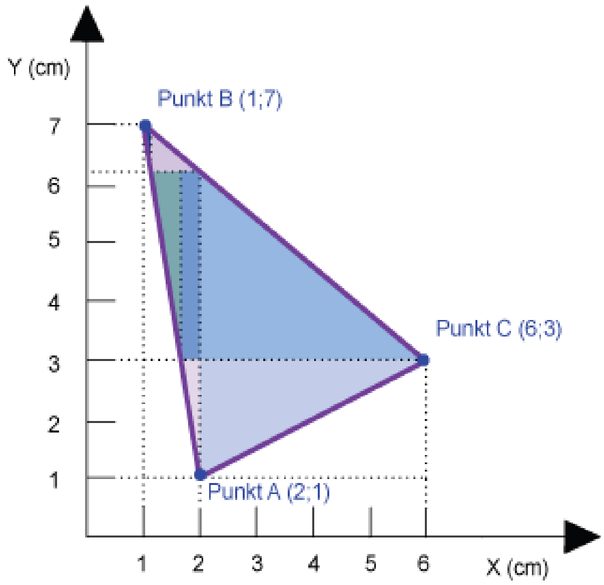


Figure 71: length.png

Table 25: Legend missing

<table>
<tr>
<td>


</td>
<td>

$$AB = \sqrt{1^2 + 6^2} = 6.08$$

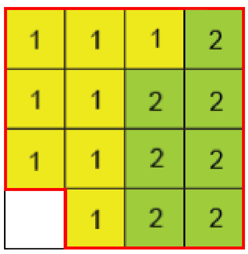
$$AC = \sqrt{4^2 + 2^2} = 4.47$$

$$BC = \sqrt{5^2 + 4^2} = 6.4$$

PERIMETER
Sum of the length of all single sections
AREA
Sum of the area of the simple geometric shapes (e.g. triangles and rectangles), into which the main objec can be devided.
</td>
</tr>
</table>

Table 25: Legend missing

Raster data model

<table>
<tr>
<td>


</td>
<td>
PERIMETER
Number of cell edges, which delimit the object, multiplied by the resolution of the cells.
Example:
Using a cell resolution of 2cm, the perimeter is 32 cm .
AREA
Number of cells, which define the object, mutliplied by the area of one cell..
Example:
Using a cell resolution of 2cm, the area is 60 cm^2 .
</td>
</tr>
</table>

Table 26: Legend missing

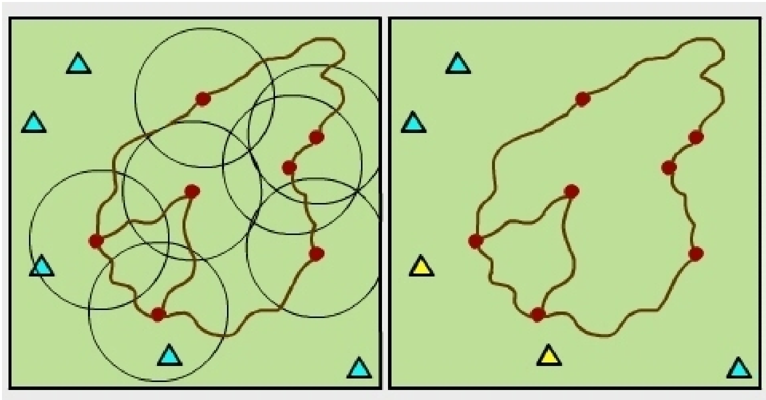


Figure 72: closest.jpg

Proximity analysis / buffering

Vector data model

A buffer is a spatial expansion around points, lines and polygons defined by a distance.

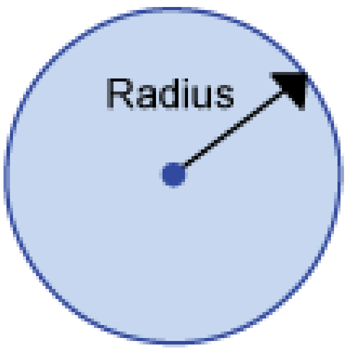
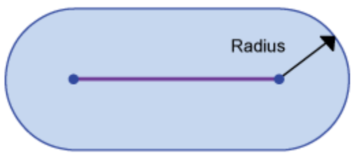
	**Point buffer**
	**Line buffer**

Table 27: Legend missing

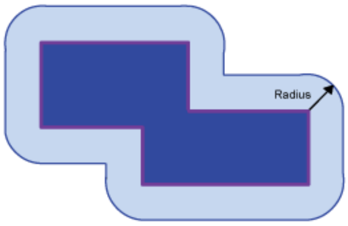
	**Polygon buffer**

Table 27: Legend missing

Raster data model

In the raster data model, *proximity* is calculated for the entire raster. Then a certain distance is chosen. For in-depth look have a look at the lesson Accessibility (www.gitta.info/Accessibilit/en/).

Applications

Vector data model

Question 1:

Canopy of trees

Vector data model

Raster data model

Question 2:

Calculation of the flooded area

Vector data model

Raster data model

Question 3:

Flooding zone of a lake

Vector data model

Raster data model

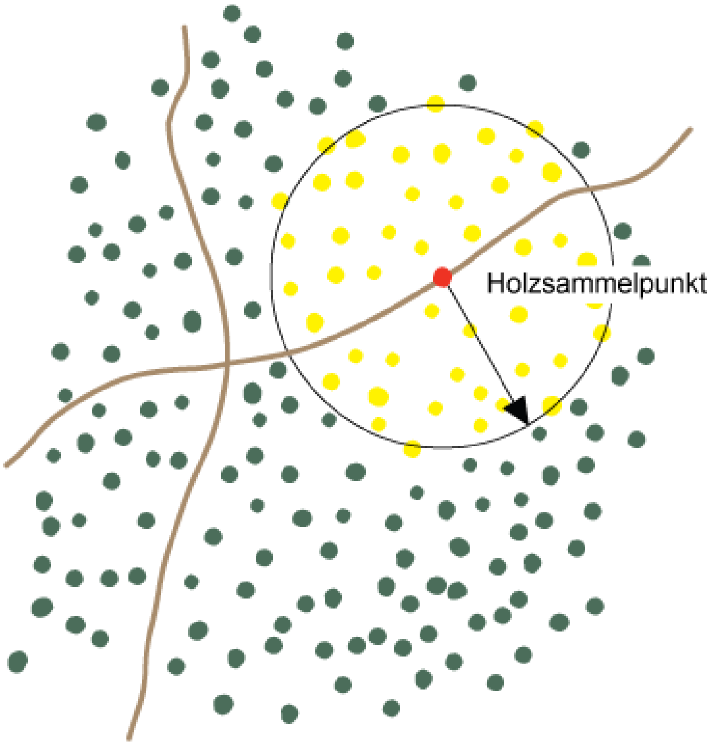


Figure 73: holzsammlung.png

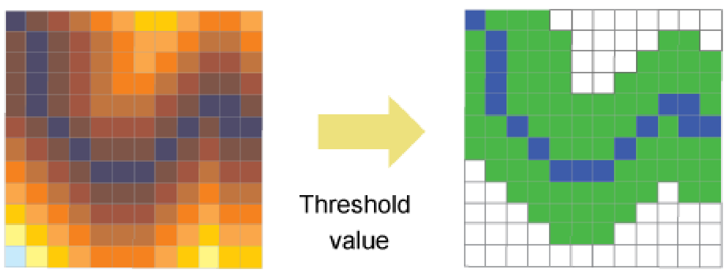


Figure 74: proximity2.png

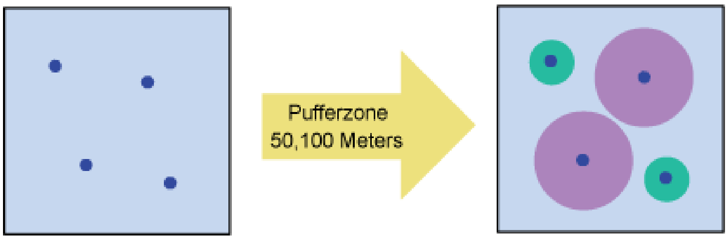


Figure 75: buffer_vector_point.png

Figure 76: buffer_raster_point.png

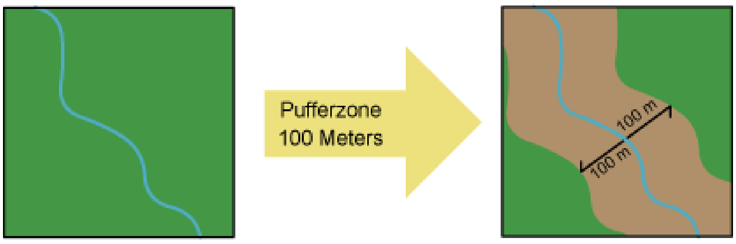


Figure 77: buffer_vector_line.png

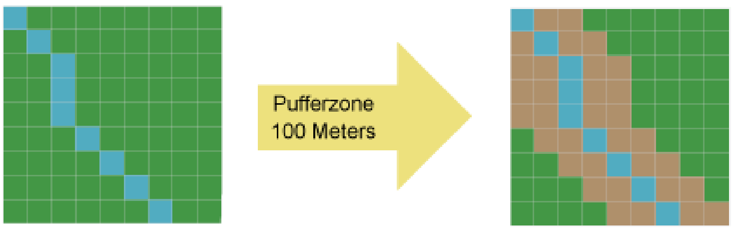


Figure 78: buffer_raster_line.png

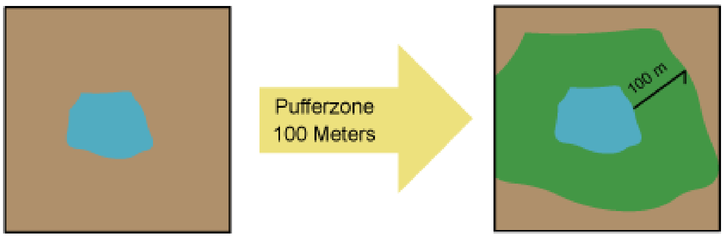


Figure 79: buffer_vector_poly.png

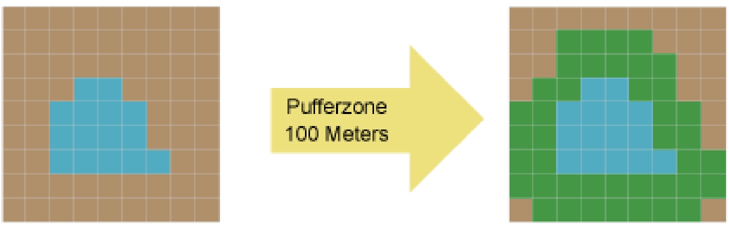


Figure 80: buffer_raster_poly.png

3.4 Topological query

Standing at a crossroad, holding a situation map in the hands, it is realtively easy to determine which roads are crossing and which buildings are situated next to each other [?] . The implementation and further use of such functions in a GIS, however, require some knowledge.

While spatial selection criteria select objects based on their location, and while thematic queries identify elements with regards to their properties, the topological selection criteria are based on the topological arrangement of objects in space. Topological arrangements of objects are accessed through features such as “next, “part of or “within.

In a GIS, spatial relationships are named “topology. Topological relations are made up of the geometric primitives: Point (simplest element), line (connected points), polygons (connected lines) [?] . Based on these structures, the system is able to identify topological relationships and perform analyses.

3.4.1 Topological relations

Topology deals with spatial and structural properties of geometric objects, independent of their extension, type, or geometric form. Among the types of topological properties of objects there are: the number of dimensions an object has or the relationships that exist between objects. All topological properties are invariant to any continuous deformation of space [**?**] . The topology simplifies analysis functions, as the following examples show: joining adjacent areas with similar properties. It is important to distinguish between vector data formats and raster data formats. For example, imagine an area represented by a vector data model: it is composed of a border, which separates the interior from the exterior of the surface. The same area represented by a raster data model consists of several grid cells. There is no border existing as a separating line. Thus, the algorithms implemented for vector data models are not valid for raster data models. In the following example, we only show topological operations in vector data models.

VECTOR An interesting method for the classification of topological relations was proposed by Egenhofer [**?**] [**?**] . It is called the 9intersection schema. This intersection scheme is an elegant approach for the classification of topological configurations. The basic idea is based on the concept that each element is composed of a boundary (b), an interior (i), and an exterior (e). The concept of interior, boundary and complement (exterior) are defined in the general topology.

Boundary

The boundary consists of points or lines that separate the interior from the exterior. The edge of a line consists of the endpoints. The boundary of a polygon is the line that defines the perimeter.

Interior

The interior of an object consists of points, lines or areas that are in the object but do not belong boundary.

Complement

The complement, also called exterior, consists of the points, lines and areas which are not in the object.

The basic method used to compare two geometrical objects is to analyze the intersections between all the possible pairs that can be built with the interior, exterior and boundary of these two objects. Based on the resulting "intersection matrix, the relationships between the two geometrical objects can be classified.

Two objects, A and B, are given. Both of them are represented by their interior (i), boundary (b) and exterior (e). There are nine possible relations of these two geometrical objects. They are shown in the following table.

$$\begin{array}{lll} ObjektA^{b} \cap ObjektB^{b} & ObjektA^{b} \cap ObjektB^{i} & ObjektA^{b} \cap ObjektB^{e} \\ ObjektA^{i} \cap ObjektB^{b} & ObjektA^{i} \cap ObjektB^{i} & ObjektA^{i} \cap ObjektB^{e} \\ ObjektA^{e} \cap ObjektB^{b} & ObjektA^{e} \cap ObjektB^{i} & ObjektA^{e} \cap ObjektB^{e} \end{array}$$

Figure 81: i9schema.jpg

The 4intersectionmatrix is sometimes used as basis for the analysis of topological relations. It is generated by omitting the components of the exterior. It is less powerful than the 9intersectionmatrix.

$$\begin{array}{ll} ObjektA^{b} \cap ObjektB^{b} & ObjektA^{b} \cap ObjektB^{i} \\ ObjektA^{i} \cap ObjektB^{b} & ObjektA^{i} \cap ObjektB^{i} \end{array}$$

Figure 82: i4schema.jpg

The most important topological relations between objects that are used in GIS applications are listed in the following sequence. Note that there are three different geometries (point, line, polygon) on which the topological relations are applied.

Disjoint

There is no intersection area between object A and object B. Test for disjoint.

Meet

Object A and object B meet at the boundary. The boundaries meet, but not the interior. Two geometry objects meet if the boundaries touch. Test for touch.

Overlap

Object A and object B overlap . Test for intersect (inversion of disjoint).

Overlap with disjoint: The interior of an object intersects the boundary and the interior of the other object, but the boundaries do not intersect. That is the case if a line starts outside a polygon (area) and ends in the interior of the polygon.

Overlap with Intersect: The boundaries and the interior of both objects intersect. If a geometry object has to intersect another geometry object the geometry needs to be part of the dimension of the bigger object. That means:

- *Points*

  - Cannot intersect with points, lines or areas.

- *Lines*

  - Cannot intersect with points.

  - Can intersect with other lines ≫intersection = point.

  - Can intersect with polygons ≫intersection = lines (or points).

Contains

Object A contains object B. Test whether the initial geometry object encloses a different geometry object. The interior and the boundary of an object are completely inside of the other object. A geometry object cannot contain a geometry object of higher order. E.g.:

- Points can not contain lines or polygons.
- Lines can not contain polygons.

Inside

Object B lies inside object A. It is the opposite of "contain. If A is inside B, then B contains A.

Covers

Object A covers object B. The interior of an object is completely inside the other object and the boundaries intersect. A geometry object can't include a geometry object of higher dimension. That means:

- Points can not contain lines or polygons.
- Lines can not contain polygons.

Covered by

Object B is covered by object A. It is the opposite of “covers. If A is covered by B, then B covers A.

Equal

Object B and object A match. Test for equality of the initial geometry object and a different geometry object. The interior and the boundary of an object are lying on the boundary of the other object and vice versa. This happens when a line falls exactly on the boundary of a polygon. The coordinates of all components have to be equal. The compared geometry objects must be equal. That means:

- Point = point
- Line = line
- Polygon = polygon

The following table shows the most common topological relations:

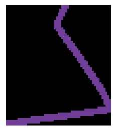
	poly-poly	**line-line**	**point-point**	**poly-line**	**poly-point**	**line-point**
Disjoint						

Table 28: Legend missing

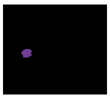
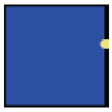
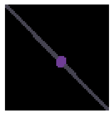
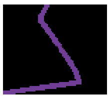
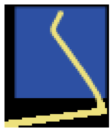
Meet			**Please note:** Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed.			
Overlap			**Please note:** Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed.		**Please note:** Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed.	**Please note:** Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed.

Table 28: Legend missing

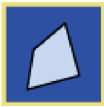
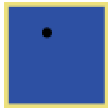
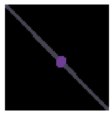
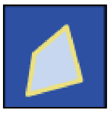
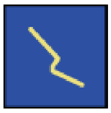
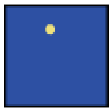
Contains		**Please note:** Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed.	**Please note:** Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed.			
Inside		**Please note:** Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed.	**Please note:** Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed.			**Please note:** Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed.

Table 28: Legend missing

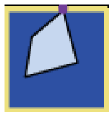
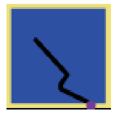
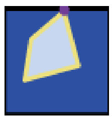
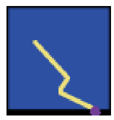
Covers		**Please note:** Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed.	**Please note:** Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed.		**Please note:** Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed.	**Please note:** Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed.
Covered by		**Please note:** Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed.	**Please note:** Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed.		**Please note:** Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed.	**Please note:** Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed.

Table 28: Legend missing

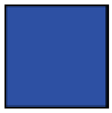
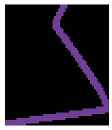
Equal				**Please note:** Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed.	**Please note:** Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed.	**Please note:** Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed.

Table 28: Legend missing

The following table shows the 9intersetionschema and the 4intersection-schema for some typical topological relations between two polygons, proposed by Egenhofer et al. [?] . The relations are given by the values 0 and 1. Every pair has an empty (0) or an occupied (1) intersection.

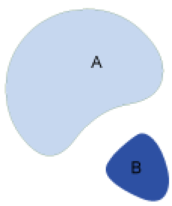
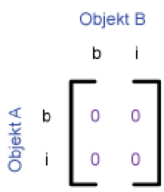
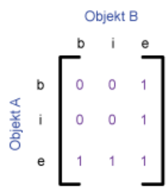
Topological relation	**Graphical description**	**4-intersection-matrix**	**9-intersection-matrix**
Disjoint			

Table 29: Legend missing

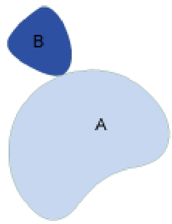
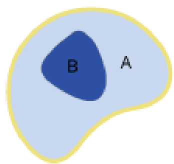
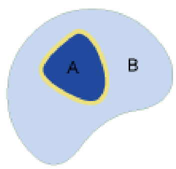
Meet		$\begin{array}{ccc} & & \text{Objekt B} \\ & & \begin{array}{cc} b & i \end{array} \\ \text{Objekt A} & \begin{array}{c} b \\ i \end{array} & \begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix} \end{array}$	$\begin{array}{ccc} & & \text{Objekt B} \\ & & \begin{array}{ccc} b & i & e \end{array} \\ \text{Objekt A} & \begin{array}{c} b \\ i \\ e \end{array} & \begin{bmatrix} 1 & 0 & 1 \\ 0 & 0 & 1 \\ 1 & 1 & 1 \end{bmatrix} \end{array}$
Overlap		$\begin{array}{ccc} & & \text{Objekt B} \\ & & \begin{array}{cc} b & i \end{array} \\ \text{Objekt A} & \begin{array}{c} b \\ i \end{array} & \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix} \end{array}$	$\begin{array}{ccc} & & \text{Objekt B} \\ & & \begin{array}{ccc} b & i & e \end{array} \\ \text{Objekt A} & \begin{array}{c} b \\ i \\ e \end{array} & \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} \end{array}$
Contains		$\begin{array}{ccc} & & \text{Objekt B} \\ & & \begin{array}{cc} b & i \end{array} \\ \text{Objekt A} & \begin{array}{c} b \\ i \end{array} & \begin{bmatrix} 0 & 0 \\ 1 & 1 \end{bmatrix} \end{array}$	$\begin{array}{ccc} & & \text{Objekt B} \\ & & \begin{array}{ccc} b & i & e \end{array} \\ \text{Objekt A} & \begin{array}{c} b \\ i \\ e \end{array} & \begin{bmatrix} 0 & 0 & 1 \\ 1 & 1 & 1 \\ 0 & 0 & 1 \end{bmatrix} \end{array}$
Inside		$\begin{array}{ccc} & & \text{Objekt B} \\ & & \begin{array}{cc} b & i \end{array} \\ \text{Objekt A} & \begin{array}{c} b \\ i \end{array} & \begin{bmatrix} 0 & 1 \\ 0 & 1 \end{bmatrix} \end{array}$	$\begin{array}{ccc} & & \text{Objekt B} \\ & & \begin{array}{ccc} b & i & e \end{array} \\ \text{Objekt A} & \begin{array}{c} b \\ i \\ e \end{array} & \begin{bmatrix} 0 & 1 & 0 \\ 0 & 1 & 0 \\ 1 & 1 & 1 \end{bmatrix} \end{array}$

Table 29: Legend missing

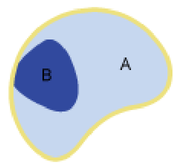
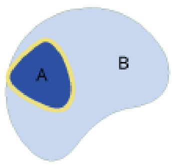
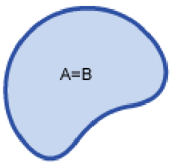
Covers		$\begin{array}{ccc} & & \text{Objekt B} \\ & & \begin{array}{cc} b & i \end{array} \\ \text{Objekt A} & \begin{array}{c} b \\ i \end{array} & \begin{bmatrix} 1 & 1 \\ 0 & 1 \end{bmatrix} \end{array}$	$\begin{array}{ccc} & & \text{Objekt B} \\ & & \begin{array}{ccc} b & i & e \end{array} \\ \text{Objekt A} & \begin{array}{c} b \\ i \\ e \end{array} & \begin{bmatrix} 1 & 0 & 1 \\ 1 & 1 & 1 \\ 0 & 0 & 1 \end{bmatrix} \end{array}$
Covered by		$\begin{array}{ccc} & & \text{Objekt B} \\ & & \begin{array}{cc} b & i \end{array} \\ \text{Objekt A} & \begin{array}{c} b \\ i \end{array} & \begin{bmatrix} 1 & 1 \\ 0 & 1 \end{bmatrix} \end{array}$	$\begin{array}{ccc} & & \text{Objekt B} \\ & & \begin{array}{ccc} b & i & e \end{array} \\ \text{Objekt A} & \begin{array}{c} b \\ i \\ e \end{array} & \begin{bmatrix} 1 & 0 & 1 \\ 1 & 1 & 1 \\ 0 & 0 & 1 \end{bmatrix} \end{array}$
Equal		$\begin{array}{ccc} & & \text{Objekt B} \\ & & \begin{array}{cc} b & i \end{array} \\ \text{Objekt A} & \begin{array}{c} b \\ i \end{array} & \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \end{array}$	$\begin{array}{ccc} & & \text{Objekt B} \\ & & \begin{array}{ccc} b & i & e \end{array} \\ \text{Objekt A} & \begin{array}{c} b \\ i \\ e \end{array} & \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \end{array}$

Table 29: Legend missing

There is at least one disadvantage in this model: there is no possibility to conceptually separate different situations.

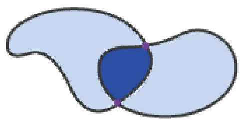
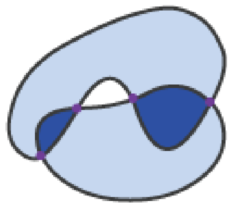
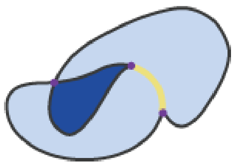
		

Table 30: Legend missing

These three situations presented correspond to the following matrix:

$$
\begin{array}{ccc}
 & & \text{Objekt B} \\
 & & \begin{array}{cc} b & i \end{array} \\
\text{Objekt A} & \begin{array}{c} b \\ i \end{array} & \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}
\end{array}
$$

Figure 83: overlap_I4.png

3.4.2 Topological operators

Topological operators are components of spatial analysis functions of a GIS. These functions are fundamental and therefore implemented in commercial GIS, such as ArcGIS, Geomedia or MapInfo. Each system has its own formulations of spatial queries; some of them allow the user to perform topological queries using SQL. Spatial databases, such as Oracle, have been and continue to be, developed for data management purposes in GIS. Further topological operators, which are adapted to the corresponding data structure, are developed. In the following list some of the functions and the corresponding operators, provided by Geomedia, Oracle Spatial and ArcView, are shown.

TOPOLOGICAL RELATION	**ORACLE**	**GEOMEDIA**	**ARCVIEW**
Disjoint	disjoint	-	are within a distance of
Meet	touch	meet	-
Overlap	overlap by intersect	overlap	intersect
Contains	contains	entirely contains	completely contains
Inside	covers	are entirely contained by	contains the center of
Covers	inside	contain	have their center in
Coverered by	coveredby	are contained by	are completely within
Equal	equal	are spatially equal	-

Table 31: Legend missing

Relationships between polygons and other objects are the most frequent. Below are some examples of topological queries:

LAYERS		**INPUT**	**QUERY**	**RESULTS**	
N.1	**N. 2**			**Table**	**Graphically**

Table 32: Legend missing

<table>
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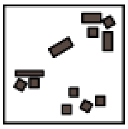
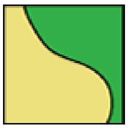
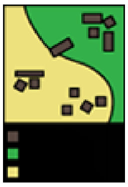
<td></td>
<td></td>
<td></td>
<td>Find the buildings, which lie completely within the forest.</td>
<td>
<table>
<tr><th>Shape</th><th>ID</th><th>AREA</th></tr>
<tr><td>Polygon</td><td>1</td><td>105</td></tr>
<tr><td>Polygon</td><td>2</td><td>50</td></tr>
<tr><td>Polygon</td><td>3</td><td>50</td></tr>
<tr><td>Polygon</td><td>4</td><td>110</td></tr>
<tr><td>Polygon</td><td>5</td><td>110</td></tr>
<tr><td>Polygon</td><td>6</td><td>115</td></tr>
<tr><td>Polygon</td><td>7</td><td>50</td></tr>
<tr><td>Polygon</td><td>8</td><td>50</td></tr>
<tr><td>Polygon</td><td>9</td><td>50</td></tr>
<tr><td>Polygon</td><td>10</td><td>50</td></tr>
<tr><td>Polygon</td><td>11</td><td>50</td></tr>
<tr><td>Polygon</td><td>12</td><td>50</td></tr>
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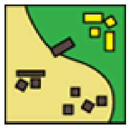
<td></td>
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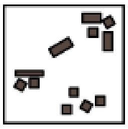
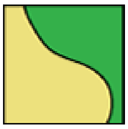
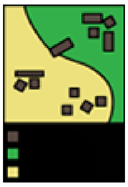
<td></td>
<td></td>
<td></td>
<td>Find the buildings, which intersect the boundary of the forest.</td>
<td>
<table>
<tr><th>Shape</th><th>ID</th><th>AREA</th></tr>
<tr><td>Polygon</td><td>1</td><td>105</td></tr>
<tr><td>Polygon</td><td>2</td><td>50</td></tr>
<tr><td>Polygon</td><td>3</td><td>50</td></tr>
<tr><td>Polygon</td><td>4</td><td>110</td></tr>
<tr><td>Polygon</td><td>5</td><td>110</td></tr>
<tr><td>Polygon</td><td>6</td><td>115</td></tr>
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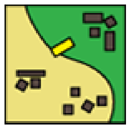
<td></td>
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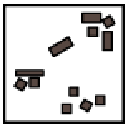
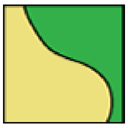
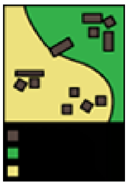
<td></td>
<td></td>
<td></td>
<td>Find the buildings, whose centroid lies within the forest.</td>
<td>
<table>
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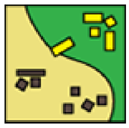
<td></td>
</tr>
</table>

Table 32: Legend missing

Application

As described earlier, topological queries refer to the reciprocal locations of objects in space. The following examples illustrate this concept.

Select the huts that are reached first from the starting point (green point).

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Figure 84: closest.swf

SHAPE	ID	NAME
Point	1	Sillerenbühl
Point	2	Gilbachegge
Point	3	Gilbach
Point	4	Berglàger

Figure 85: tab_act1.jpg

Select the huts that are in the forest (dark green area).

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Figure 86: in_liegen.swf

Select the areas that touch the forest (dark green area).

Which parcels are crossed by the river Allenbach?

SHAPE	ID	NAME
Point	1	Sillerenbühl
Point	2	Gilbachegge
Point	3	Gilbach
Point	4	Bergläger

Figure 87: tab_act2.jpg

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Figure 88: wald_adjacency.swf

SHAPE	ID	OBJECTVALUE
Polygon	1	Geröll in Wald
Polygon	2	Steinbruch
Polygon	3	Feld
Polygon	4	Feld
Polygon	5	Steinbruch
Polygon	6	Feld
Polygon	7	Geröll in Wald
Polygon	8	Wald
Polygon	9	Steinbruch
Polygon	10	Wald
Polygon	11	Feld
Polygon	12	Geröll in Wald
Polygon	13	Geröll in Wald
Polygon	14	Steinbruch
Polygon	15	Feld
Polygon	16	Feld
Polygon	17	Steinbruch
Polygon	18	Geröll in Wald
Polygon	19	Feld

Figure 89: tab_act3.jpg

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Figure 90: by_fluss_intersect.swf

SHAPE	ID	OBJECTVALUE
Polygon	1	Geröll in Wald
Polygon	2	Steinbruch
Polygon	3	Feld
Polygon	4	Feld
Polygon	5	Steinbruch
Polygon	6	Feld
Polygon	7	Geröll in Wald
Polygon	8	Wald
Polygon	9	Steinbruch
Polygon	10	Wald
Polygon	11	Feld
Polygon	12	Geröll in Wald
Polygon	13	Geröll in Wald
Polygon	14	Steinbruch
Polygon	15	Feld
Polygon	16	Feld
Polygon	17	Steinbruch
Polygon	18	Geröll in Wald
Polygon	19	Feld

Figure 91: tab_act4.jpg

3.5 Summary

An information system is a questionresponse system based on a data set. Such systems contain tools for the computational analysis of information. If the stored data have a spatial reference, the system is called geographic information system (GIS). It allows the interrogation and display of attribute values based on spatial criteria and vice versa. Hence the term data analysis, that includes all those analysis, queries, evaluations etc. that can be performed on structured and stored geodata. Queries can be performed according to different approaches: thematic, geometric and topological. Geometry is expressed by the spatial reference, which is assigned to all objects. They fulfill the requirement of location and extension. The topological properties are expressed by the relations of neighborhood, containment, and overlapping etc. Besides geometric characteristics that exist for spatial data, there are also thematic properties. Those properties are stored in tables. A query can be classified in two ways, depending on the result. In a direct query, there is a subset extracted from the database and the original data are not modified by this process. In a manipulation, new space related information elements are generated, which can be used in further analysis operations. The results of data processing and data manipulation in GIS should be represented in a form which is understandable for the user, or in a form which enables data sharing.

Glossary

Abfrage: Die Abfrage ermittelt räumliche Beziehungen zwischen Elementen eines oder mehrerer Themen, um auf dieser Basis eine Lokalisierung von Objekten zu erreichen. Die Analyseergebnisse können dann bei konkreten Fragestellungen zur Entscheidungsfindung beitragen.

Konsistent: Gewährleisten der Widerspruchsfreiheit innerhalb einer Datenbank; d. h., dass der Inhalt einer Datenbank alle vordefinierten Konsistenzbedingungen („Constraints“) erfüllt.

Operators: In search algorithms, operators enable the logical conjunction of search items using keywords like AND, OR, and NOT.

SQL: ”Acronym for Structured Query Language. A syntax for retrieving and manipulating data from a relational database. SQL has become an industry standard query language in most relational database management systems” [**?**] , e.g. Oracle, DB2, Access, etc.

Topologie: Die Topologie beschäftigt sich mit den räumlichen und strukturellen Eigenschaften der geometrischen Objekte unabhängig von ihrer Ausdehnung und ihrer Form. Die topologischen Eigenschaften äussern sich in Beziehung der Nachbarschaft, des Enthaltenseins, der Überschneidung und Ähnlichem. [**?**]

4 Accessibility

In spatial analysis, more than just properties of the analyzed objects are of interest. Especially the relations between them are of interest. As discussed in the lesson "Spatial Query", various relations between objects can be analyzed. There are thematic (or semantic), spatial and temporal relations established. The spatial relations can be divided into topological relations, directional relations and distance relations. In this lesson, the distance relations are of interest. Using methods to detect distances and proximities, answers to the following questions can be given:

- Which is the nearest railway station?
- How many pharmacies are within a radius of 300m from a specific location?
- Which is the best residential area, in the case that the distance to the kindergarten, the school and the shopping centers should be minimal?
- How many people live in the catchment area of the shopping center?

In a GIS the spatial objects are generally (in the two dimensional case) represented by the geometric primitives such as points, lines and polygons and can also exhibit descriptive properties (attributes). In the first unit the basics of distance relations are introduced (unit: Space-Object-Distance Relation (Page 120)). The calculation of the distance relations is discussed in unit 2 (unit: Unlimited Analysis of Distance Relations (Page 132)). Another lesson about accessibility illustrates methods for the characterization and analysis of networks (Intermediate Accessibility (www.gitta.info/Accessibiliti/en/)).

Learning Objectives

- You know the possible distance relations between the different geometric primitives (points, lines and polygons).
- You are able to explain the principle of distance formations for raster and vector data models and know the advantages and disadvantages of both models.
- You understand the principle of Thiessen-polygons as expression of proximity and as concept of "catchment" and regions of proximity around points. You are also able to draw them on paper.
- You know simple applications of distance transformation, of distance buffer and Thiessen-polygons.

4.1 Space, object and distance relation

The *space*[6] can be seen as a relation between a set of objects. Due to different possible relations, different types of space can be generated. The focus is on the distance as relation between objects. The Euclidian Distance is possibly the simplest example for a distance relation. All kind of things which can be of interest, are objects, e.g. tourist sites in Manhattan. The relation that links this tourists sits is the "distance".

Figure 92: Map extract of Manhattan

In the following the three fundamental factors for the calculation of distances between spatial objects, in practical GIS application, will be discussed:

- Metric
- Discretization of the space
- Spatial restrictions

[6]Space is given by a set of objects with associated attributes and the relations between them.

4.1.1 Metric

The metric defines the location, the direction and the distance of objects in space. E.g. it is used to calculate the distance between objects, to detect the shortest path or to identify the nearest neighbor.

The Euclidean Distance is an example of a mathematical metric space. It gives the distance between two points as the length of a straight line segment between them. A metric space can be a simple distance function. Remember the Pythagorean Theorem from school?

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Figure 93: Example Euclidean Distance

The following three conditions must be satisfied to make a space a metric space:

Metric Room

A set of points S is called metric space, if a distance function distance() exists, which returns for each pair (s , t) of elements in S the distance (s , t) between them. The distance value is returned as real number and satisfies the following conditions:

1. For each pair s , t in S , distance(s , t) $>$ 0, if s and t are disjoint points and

   distance(s , t) $=$ 0, if s and t are identical.

2. For each pair s , t in S , distance(s , t)$=$ distance(t , s

3. For all triples s , t , u in S distance(s , t) $+$ distance(t , u) $>=$ distance(s , u), also known as triangle inequality (for points which are not lying on a straight line).

The first condition defines that the distance between two points always has to be a positive number, unless the points are identical, so the distance would be 0. The second condition ensures that the distance is independent of the direction in which it is measured. And it defines as well that the distance is symmetric. And the third condition means that a direct journey between two points is maximal as long as the trip over a third point.

There are various types of metric spaces. They are mainly used in digital image processing, such as in remote sensing. In GIS, the metric space used generally is the Euclidean metric. To demonstrate the influence of the metric on the distance calculation, the Manhattan metric, also called Cityblock metric or Taxidriver metric, is introduced. In most of the cases, beelines are not suitable to detect distances that are physically feasible. As an example have a look at the map of Manhattan. The region of Manhattan is neither flat nor empty, but structured by its road system. The Manhattan metric follows the same logic as the taxi driver in Manhattan: He would drive two blocks north and subsequently three blocks east. Thus, only trips along the four cardinal directions are possible. The Manhattan metric is defined as follows:

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Figure 94: Example Manhattan Metric

The Manhattan metric meets all three conditions. But it is variable regarding the orientation of the coordinate system. The distance changes in the case that the axes of the coordinate system are reoriented. It is reasonable to apply the Manhattan distance only in cities with a grid like structure and a coordinate system that follows the road axes.

The form of the glob is a real constraint for the use of metric for the distance calculation. The goal of the map production is to represent the spherical shape on a plane surface. For small scale maps, the geographical coordinate system can be imaged in the plane. The resulting coordinate grid is curvilinear. For many applications, and to simplify the calculation, it is reasonable to take a Cartesian (rectangular) coordinate system. This system is mostly used for large scale maps: e.g. 1:25'000 and 1:50'000, such as the maps of Switzerland. In the case, that a limited space is mapped, the curvature of the earth can be neglected. For maps with small scales, less than 1:50'000, the curvature has to be taken into account, the distances are calculated using spherical distances.

Catchment areas of shopping centers

There are four shopping centers indicated on the map. The catchment area is not known. For the analysis, the following points are assumed: Clients prefer the shopping center which is the closest to their place of residence. For this purpose, the distance between two shopping centers is divided in half, according to the metric space chosen. The resulting limits build the shopping centers' catchment areas, including all the corresponding domiciles. The resulting polygons are called Thiessen polygons. For further information have a look at unit "Analyse von Distanzbeziehungen (Page 132)". The following animation illustrates the influence of the metric space on the calculation of distance.

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Figure 95: Thiessen-polygons with a comparison of Manhattan metric and Euclidean metric

Time as distance function

Another description of distance is the time. This concept is illustrated by means of two maps:

1. *Isochrones maps*[7] (maps showing lines of equivalent travel distance)
2. *Time maps*[8] (transformation of the geographic space to the time space)

Isochrones maps:

The figure shows the isochrones maps of travel time by train from London for the years 1991 to 2010 [**?**] . Isochrones maps provide spatially the temporal distance from a given location (e.g. London) to all the other locations on the map. A big distance between the isochrones indicates a lot of space that is overcome per time unit. That means e.g. that the public transport network is well developed, such as in France between Lyon and Paris. The disadvantage of such isochrones maps is that the temporal distance can be represented just for one starting point. Furthermore, the illustration of the development over several years is confusing.

Time maps:

The following figure shows a time map for the railway traffic in 1993 [**?**] . Time maps are transformed from the Euclidean space to the "time space",

[7] Isochrones maps represent the travel time to or from a location by displaying isochrones to indicate regions, which are, for example, easy accessible or less easy accessible by public transport .

[8] Time maps display the elements in a way, that the distances between the points is not proportional to the spatial distance anymore, but proportional to travel time between them. The scale is not given by the metric space but by the time unit.

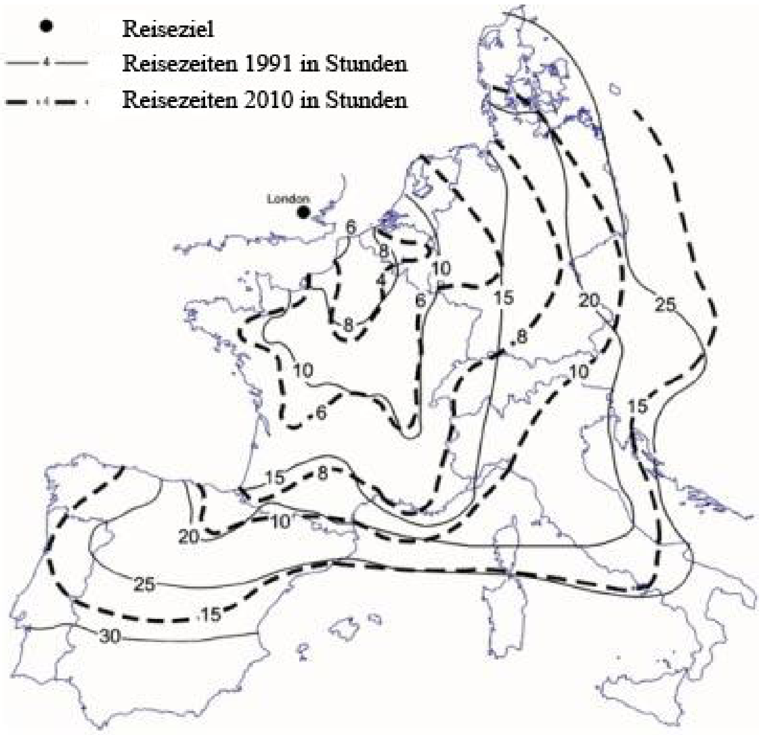

Figure 96: Example of an isochrome map [?]

using a mathematical method. The faster the transportation is, the more shrunken is the space. The distances on the maps are no longer proportional to physical distances, but proportional to the traveling time between them. The measuring unit is given by the time. The TGV railway, existing since 1993, makes France shrinking. In contrast to France, the railways infrastructures in southeast Europe is relatively sparse, which makes this region expand.

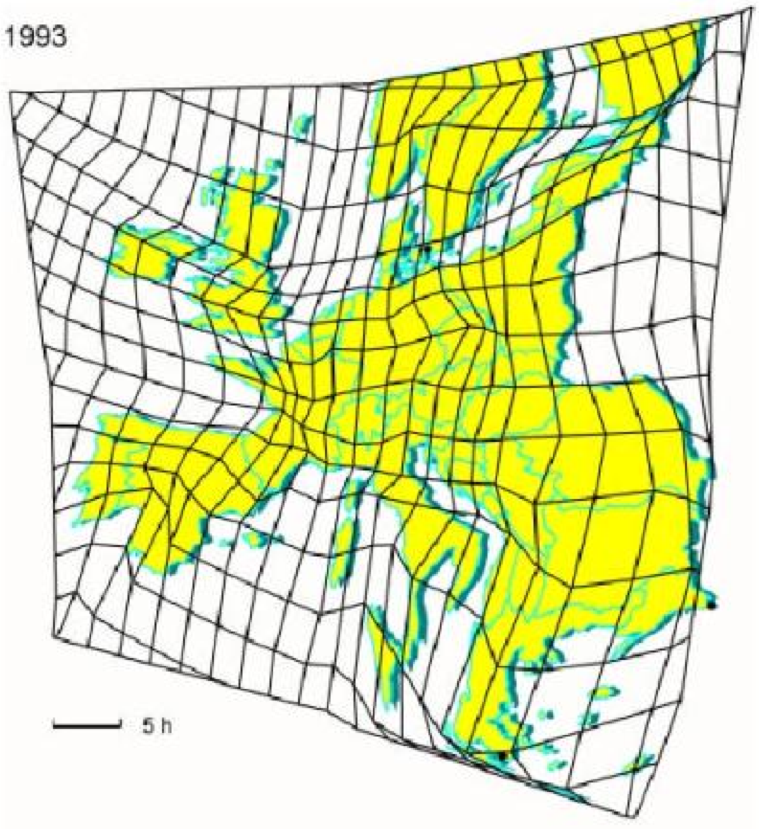

Figure 97: Zeitkarte am Beispiel von Reisezeiten [?]

4.1.2 Discretization of space

Discretization of space and accuracy

In a GIS, phenomena can be modeled in two main ways: *Raster data model*[9] and *vector data model*[10].

Raster data model:

In raster data models, spatial objects are divided into regular grid cells. In this model, the discretization of space is evident. It is particular suitable to model continuous physical phenomena. In Switzerland, the meteorological stations are distributed irregularly in space. To convert this point samples to raster, the values of the missing locations can be calculated depending on the distance to the meteorological stations. The accuracy depends on the mesh size of the raster model (10m, 20m etc.).

Vector data model:

In vector data models, discretization is not obvious. Objects are represented as exact entities. Especially manmade objects are represented, such as parcels and streets. The discretization depends on the precision with which the data is stored in a GIS. The two most important data types are integers and floating point numbers. Both types provide positive and negative values. Floating point numbers are subdivided into single precision and double precision.

Further information about raster data models and vector data models is provided in the module "Spatial Modeling" (Lesson: Digital Models (`www.gitta.info/DigitModel/fr/html/index.html`)).

[9] A raster data model is a data structure which divides spatial objects into regular grid cells. It is very appropriate to model continuous physical phenomena.

[10] A vector data model is a data structure which is based on vectors in a coordinate system. Points, lines and polygons are the geometric primitives. Every single object is described by a list of x-, y-coordinates. The semantics are assigned to the geometric elements through explicit links.

4.1.3 Spatial constraints

Figure 98: Eine Strasse kann beispielsweise für kleine Tiere eine räumliche Einschränkung sein. (Photo: Joël Fisler)

There is a fundamental difference between the geographical space and the metric space. The metric space is adequate for many applications of spatial analysis, such as distance calculations. In the geographical space, relations between objects are not only determined by the metric distance that can be calculated based on the given coordinate system. In order to explain the spatial objects, restrictions and conditions have to be considered. Up to now, we assumed space to be homogeneous and isotropic.

The distance was determined only by the underlying metric. Nothing has affected the calculation of distance, except the metric space. But homogeneous and Isotropic space is rare. Let's illustrate this with the following example: The diagonal is the shortest path in a rectangle, if you want to path from a vertex to its nonconsecutive vertex. If your rectangle is a corn field, more effort is required to cross it than in the case it was a freshly cut meadow. Imagine a bull standing on the meadow, it could be reasonable to go around it. The effort made to overcome the field (friction) is called cost. The obstacle that has to be overcame (in this case the field), is called friction. If, in a given space unit, the cost, that is needed to overcome an obstacle, is known and displayed, the surface is called cost surface. Cost surfaces are used for weighting purposes.

Until now we calculated the distances in Manhattan or the Euclidean space. But there can be obstacles on the roads, such as railways, or the road can be composed of different road classes with different speed limits. All these attributes have to be included into the calculation, if you want to calculate fastest route between a starting point and the final destination. In the case that someone is interested to get a cheap flight ticket, e.g. to get from Zürich to Havana, he might take an indirect flight and change plain in Paris. Thus, in a monetary view, the indirect connection is shorter than the direct connection. In practice, distances are in general not symmetric and the triangle inequality doesn't make sense. Thus, space can't be defined only by metric space.

Catchment area of train stations

The following example was composed by Jermann [**?**] : In a small town, there are two train stations. Bus lines serve as feeder busses. There is a raster of 1ha cell size underlying the route network. There is a raster layer of 1ha cell size underlying the route network. For each grid cell, the number of inhabitants and the number of employees is given. It is of interest, how many people potentially use those train stations. The drawing power of train stations, expressed in m, is known. It has been detected empirically. This drawing power is modeled based on the beelines, and displayed as circle around the train stations (illustration 1). The residents and the employees within these circles are potential clients of the train stations. The friction (or costs to overcome the distance) was not included in this calculation.

The model is improved in a second step. In addition, the average approaching time and a general detour factor are included into the model. This time, the catchment area is specified by the time. The catchment area is defined by a given approach time to the train station. From the literature it is known, that the average pedestrian speed is 4.5km/h. Thus, the radius of the circle can be calculated. Compared to beelines, approach routes exhibit detours. A common empirical value for the detour factor is 1.23. Thus, the radius decreases by 20%.

Such models can be further improved. In Jermann [**?**] such model extensions for potential models of public transportation are discussed in detail.

Figure 99: Eisenbahnlinien trennen den Raum und können als räumliche Einschränkung aufgefasst werden. (Photo: Joël Fisler)

Figure 100: Für gewisse Menschen stellen auch Check-Points eine räumliche Einschränkung dar. (Photo: Joël Fisler)

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Figure 101: Modellierung des Einzugsbereichs über die Luftdistanz [?]

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Figure 102: Modellierung des Einzugsbereichs über die Luftdistanz mit Umwegfaktor [**?**]

4.2 Unlimited analysis of distance relations

This unit is dedicated to the analysis of distances between spatial objects. Unrestricted means that no spatial restraints (such as transport network, topography or settlement area, which could constrain the spatial distance between objects) are taken into account. If information is missing, it can be very useful to perform the analysis without predefined conditions.

The term proximity is quite imprecise. It can be replaced with more qualitative terms such as "near", "far" or "in the neighborhood of". The term "proximity" has to be objectified and operationalized in order to use it in a GIS. For this reason, a distance concept is needed, such as the Euclidean distance or the travel time (cf. unit 1 Space, Object and Distance Relation). In the second step, the unit for "proximity" has to be defined interpretatively. There exist more appropriate and less appropriate units, but none of them is right or wrong. It is therefore important that the neighborhood relations are well and reasonably defined. Illustration 1 object B is large, and its neighborhood is mainly determinate by large objects. Object A (illustration 2) is smaller and located in a different neighborhood, mainly determined by local and small objects. It is evident, that A belongs to the local environment of B, B be is not necessarily part of A's environment.

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Figure 103: Distanz und Nähe ist kontextabhängig und nicht symmetrisch [?]

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Figure 104: Distanz und Nähe ist kontextabhängig und nicht symmetrisch [?]

In the proximity analysis and the analysis of neighborhood, the catchment areas and areas of influence related to supply and demand are of interest. Frequent questions in this context:

- Which and how many pharmacies are located within a radius of 300m from a specific location?

- Which are the catchment areas of shopping centers?
- How many households are reached by the transmission power of a mobile phone antenna?
- Is a certain district located within the noise zone of the highway?

4.2.1 Distance relations: Distance analysis methods

In the following several methods for distance calculations between spatial objects are discussed. Due to the different types of discretization of space, it is necessary to differentiate between vector data models and raster data models.

4.2.2 Distance zones: Distance buffer and distance transformation

Besides the calculation of the shortest path between two objects, there is another important application performed in a GIS: The determination of distance zones. This function can be used to assign for all the objects in space the corresponding distance between it and the nearest object. The calculation of the distance zones is different for vector data models and raster data models.

Vector data model

Vector data models are often used to model exact phenomena. Distance zones are again exact entities. Therefore, distance zones are called distance buffer. The calculation of a buffer always results in a polygon, independent of the original geometric primitive (point, line, and polygon). The boundary line of those polygons is of interest. They surround the objects in a certain distance (cf. animation below). The calculation of distance buffers is based on the Euclidean distance. Further methods, e.g. those which can be easily implemented in raster data models, are complex and need a lot of effort to be realized in vector data models. Distance zones (e.g. 0-500m, 501-1000m, 1001-2000m) which are nested inside each other, can only be realized by repeated calculation and subsequent application of polygon overlay. The possibilities of buffering in the vector data model are more limited than those in the raster data model. Nevertheless, there are a few possibilities to vary the distance buffer (cf. animation below):

- The shape of a buffer can be varied. A line buffer's end can be rounded or flat.
- Buffering distances can be calculated depending on the attribute value of the object. E.g.: The transmission power of a mobile phone antenna determines its range.
- Buffer can also be formed on one side only, e.g. a building ban zone around a lake.

Raster data model

Also single grid cells in raster data models can be buffered. In raster data models distance zones assign a distance value to each grid cell according to their distance to the nearest source cell. This results in a quasi continuous result. Since space is transformed according to the distance to a certain object, we can speak about distance transformation. In raster data models an appropriate metric space can be chosen for the distance transformation: Euclidean metric, Manhattan metric or other metrics what include in addition also the diagonal neighbors. In addition, path costs and travel time are included are considered, e.g. as cost surfaces. Cost surfaces contain information about the effort needed to overcome a distance per cell. A quasi continuous raster distance transformation can be converted elegantly into a simple classification of distance zones (e.g. distance zone up to 250m, up to 550m etc.). The accuracy of the results depends on the raster resolution (cell size).

	Vector data model	**Raster data model**
Denomination	Distance buffer	Distance transformation
Metric space	Euclidean distance	different metric spaces possible
Modeling	Clear defined phenomena	Phenomena that vary continuously over space
Distance zones	Intersection of the distance buffer using polygon overlay. Additional possibilities: • unilateral buffer, • weighted buffer (depending on the attribute value of the object), • form of the buffer (rounded or flat end)	reclassification of the distance transformation
Variable costs	impossible	Inclusion of cost surfaces as effort for distance overcoming
Accuracy	Depending on the data accuracy and precision of the calculation	Depending on the raster resolution

Table 33: Legend missing

4.2.3 Creating Distance Buffers

Vector data model

Distance buffers around lines or polygons are not simply parallel lines or parallel polygons around the object at a certain distance. To create buffers additional circular arcs with radius l are required. The following animation shows the construction of a distance buffer a line.

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Figure 105: Construction of a distance buffer

Distance buffers around points are circles. The points presented in the following illustration, represent the location of mobile phone antennas with different transmission power. Thereby, the furthermost line is the maximal range at a given transmission power. The distance buffers are weighted with attribute values of the object. On the map, the regions of the settlement area that are within the transmission range and which are outside of the transmission range, are indicated.

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Figure 106: Distance buffers around points are circles

The next two examples deal with distance buffers around lines. In these two cases, the lines represent roads of different classes. Due to the classification of the roads, the speed limits are known: Highway 120km/h and main road 80km/h. According to an immission / emission model for street noise (cf. Laermorama (www.laermorama.ch/)), the distance buffers were calculated for a limit value of 70dB depending on the speed limit. There are mainly three parameters integrated in the model: Average speed, average number of vehicles per hour and the percentage of trucks. Obstacles were not considered. It is assumed that the sound propagates unimpeded in space. The resulting area covers the region of 85.1dB at the major artery and 70dB at the outline of the distance buffer (respectively 82.9dB to 70dB). This means that the buffered area is not homogeneous with respect to the immission value. Often, the boundary respectively the limits are of interest. The resulting buffered area is useful to answer to questions such as: How big are the affected areas and how many inhabitants are influenced by the noise?

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Figure 107: Distance buffers around lines

If you want to represent the immission values gradually, various distance buffers with the respective immission values have to be calculated. To avoid, that the areas always start at 85.1dB, the buffer polygons have to be overlaid. You can learn more about polygon overlay in the lesson "Suitability Analysis".

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Figure 108: Distanzpuffer um einen Linienzug mit Polygon overlay

The last example shows one-sided distance buffers. They have been determined based on a law. They define the area around the nature reserve, where only extensive agriculture is allowed and where a construction ban is established.

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Figure 109: Einseitiger Distanzpuffer um Fläche

Raster data set

Have a look at the following animation. In the first illustration, the cells of the tram stop are indicated with the value 7. Starting at these two "source cells", for each cell in the grid the distance to the nearest "source cell" is calculated. The result of this calculation is a "distance raster". In this resulting raster, the distance assigned to the "source cells" is 0. The transformation is based on the Euclidean distance. In the animation, the values can be reclassified. Thus, a quasi continuous surface, containing noise values, could be generated. The accuracy and the continuity of the raster depend on the raster resolution. Noise zones could be established by reclassifying the immission values.

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Figure 110: Calculating of distance and reclassification

Greater: www.gitta.info/Accessibilit/en/multimedia/disttrans_reclassify.swf

In a raster data model, distance transformation can be performed for areas or any arrangement of "source cells". In the example below, the grid cells are of the same thematic, coded with the value 99, representing a forest. For each cell, the shortest path to the edge of the forest can be calculated (depending on the metric). The results are entered in a new raster. In this new raster, the values assigned to the cells represent the distance to the edge of the forest. At the edge of the forest, the values are smaller and increase to the center. In our example, the Manhattan metric was chosen. Consequently, only the direct neighbors of a cell (4 neighbors) are included to the calculation. Thus, the region is transformed stepwise, one cell width after the other. The results of each calculation step are joined and added to a common raster. You can learn more about the combination of raster in the lesson "Suitability Analysis".

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Figure 111: Distance transformation of a woodland area

Greater: www.gitta.info/Accessibilit/en/multimedia/disttrans_zone.swf

4.2.4 Thiessen Polygon

Thiessen polygons (otherwise known as Voronoi polygons or Voronoi diagrams), are an essential method for the analysis of proximity and neighborhood. Thiessen polygons (cf. figure below on the right side) are used to allocate space to the nearest point feature. It defines an area around a point, where every location is nearer to this point than to all the others (2D). Such kind of structures can be generated also in higher dimensions, whereupon they are called Thiessen polyhedron or Voronoi polyhedron.

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Figure 112: Unregelmässig verteilte Punkte oder Stichproben

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Figure 113: Punkte mit den dazugehörenden Thiessen-Polygonen

Voronoi polygons can also be created around lines, which then lead to more complex structures (cf. illustration below). In this unit, the thematic is restricted to the Thiessen polygons for points, the simplest and most common ones. An advanced discussion is provided by Boots [**?**] .

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Figure 114: Rasterzellen Thiessen-Polygone konstruiert um Linienzüge

There are various applications possible for Thiessen polygons, due to their organization that is similar to many phenomena observed in nature (plant cells, soap bubbles bumping together) and in geosciences. Jones [**?**, p. 48] provided the following example: Thiessen polygons are used to generate soil maps based on irregular distributed sample points. The border between two soil types is assumed to be at the half of the distance between two sample points that exhibit different soil types. It is assumed that there is no further information about the space. Another application of Thiessen polygons is the attempt to model the catchment area of stores.

Construction of Thiessen polygons

How can Thiessen polygons be built? The solution is a geometrical approach. A Thiessen polygon encloses all the space which is closer to the associated center than to any other point. It is obvious, that the borders of Thiessen polygons are the geometric places, which have the same distance to two centers. In order to construct Thiessen polygons, all the points are triangulated into a triangulated irregular network. For each triangle edge, the perpendicular bisectors are generated, which form the edges of the Thiessen polygons. The perpendicular bisectors are constructed by drawing circles with radius d around the corresponding points. The vertices of the Thiessen polygon are at the location, at which the bisectors intersect.

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Figure 115: Konstruktion von Thiessen-Polygonen [**?**]

In raster data model, polygon raster zones are created. These zones show the locations that are closest to a given point (in this case points are represented by raster cells). There is the advantage that compared to vector data models, in raster data models the metric space can be chosen and weighting factors etc. can be included to the calculation. This subject is discussed more in detail in the lesson "Accessibility" of the intermediate level.

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Figure 116: Thiessen-Polygone in einem Raster mit kleiner Auflösung

4.2.5 Self Assessment

Construct the Thiessen polygons on a point data set, which you draw on a paper. Which metric (Page 121) space did you choose?

4.3 Summary

Space can be considered from different points of view. Space is defined as the relations between the spatial objects. Distance relations are the basis of the concept of accessibility. Distances on the other hand depend on three conditions: a) the metric space, b) the discretization of space (vector data model or raster data model) and c) the spatial constraints. There is more than the metric space defining distance concepts. Distances can also be expressed by costs or time. In this lesson, the focus is mainly on unrestrained distance relations respectively on the accessibility of objects (there is assumed to be no objects constraining the way between location A and location B.

Different forms of distance calculations are related to the three geometric primitives in the 2D case: Points, lines and polygons. There are several options to calculate the distances between these primitives. It has been shown, that there is no clear solution for the distance calculation between two lines. The construction of distance zone is an extension of the distance calculation. This function allocates distance values, according to the distance to the next associated object. In raster data models, such functions are called distance transformation, in vector data models, they are called distance buffers. In the proximity analysis, Thiessen polygons are used. Within such polygons, all the locations are nearer to the associated center than to any other point. The edges of the polygons are the perpendicular bisectors on the connecting line between two centers. The intersections of these bisectors build the vertices of the Thiessen polygons.

4.4 Recommended Reading

- JERMANN, J., 2002 *Potenzialanalyse von ÖV-Haltestellen - Ein Vergleich verschiedener Ansätze* [?]
- SPIEKERMANN, K., 1999 *Visualisierung von Eisenbahnreisezeiten - Ein interaktives Computerprogramm* [?]
- WORBOYS, M.F., 1996 *Metrics and topologies for geographic space* [?]

Glossary

Isochrones maps: Isochrones maps represent the travel time to or from a location by displaying isochrones to indicate regions, which are, for example, easy accessible or less easy accessible by public transport [**?**]
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Raster data model: A raster data model is a data structure which divides spatial objects into regular grid cells. It is very appropriate to model continuous physical phenomena.

Space: Space is given by a set of objects with associated attributes and the relations between them.

Time maps: Time maps display the elements in a way, that the distances between the points is not proportional to the spatial distance anymore, but proportional to travel time between them. The scale is not given by the metric space but by the time unit.

Vector data model: A vector data model is a data structure which is based on vectors in a coordinate system. Points, lines and polygons are the geometric primitives. Every single object is described by a list of x-, y-coordinates. The semantics are assigned to the geometric elements through explicit links.