Geographic Information Technology Training Alliance (GITTA) presents:

Accessibility

Responsible persons: Helmut Flitter, Philipp Weckenbrock, Robert Weibel

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1. 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**). The calculation of the distance relations is discussed in unit 2 (unit: **Unlimited Analysis of Distance Relations**). Another lesson about accessibility illustrates methods for the characterization and analysis of networks (**Intermediate Accessibility**).

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.

1.1. Space, object and distance relation

The *space* [1] 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".

Map extract of Manhattan

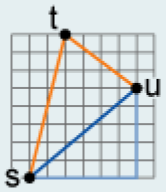
In the following the three fundamental factors for the calculation of distances between spatial objects, in practical GIS application, will be discussed:

- Metric
- Discretization of the space
- Spatial restrictions

1.1.1. 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?

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



$$\text{distanz}(s,t) = \sqrt{(x_s - x_t)^2 + (y_s - y_t)^2}$$

Example Euclidean Distance

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

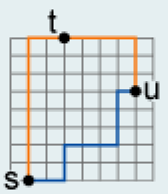
Metric Room

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:



$$\text{distanz}(s,t) = |x_s - x_t| + |y_s - y_t|$$

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**". The following animation illustrates the influence of the metric space on the calculation of distance.

Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed. [link]

Time as distance function

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

1. *Isochrones maps* [2] (maps showing lines of equivalent travel distance)
2. *Time maps* [3] (transformation of the geographic space to the time space)

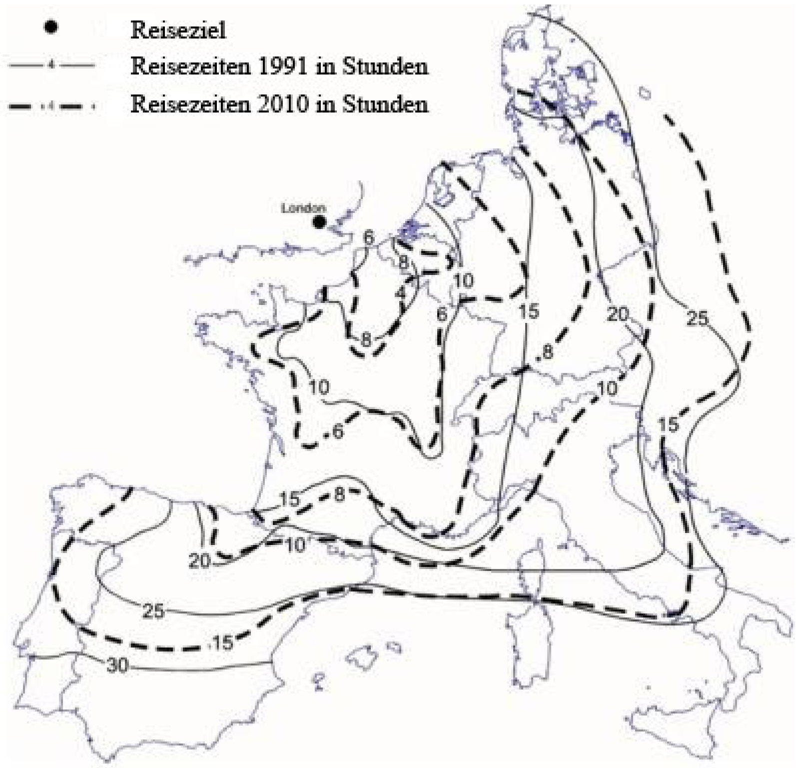
Isochrones maps:

The figure shows the isochrones maps of travel time by train from London for the years 1991 to 2010 (Spiekermann 1999). 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

[2] 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 .

[3] 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.

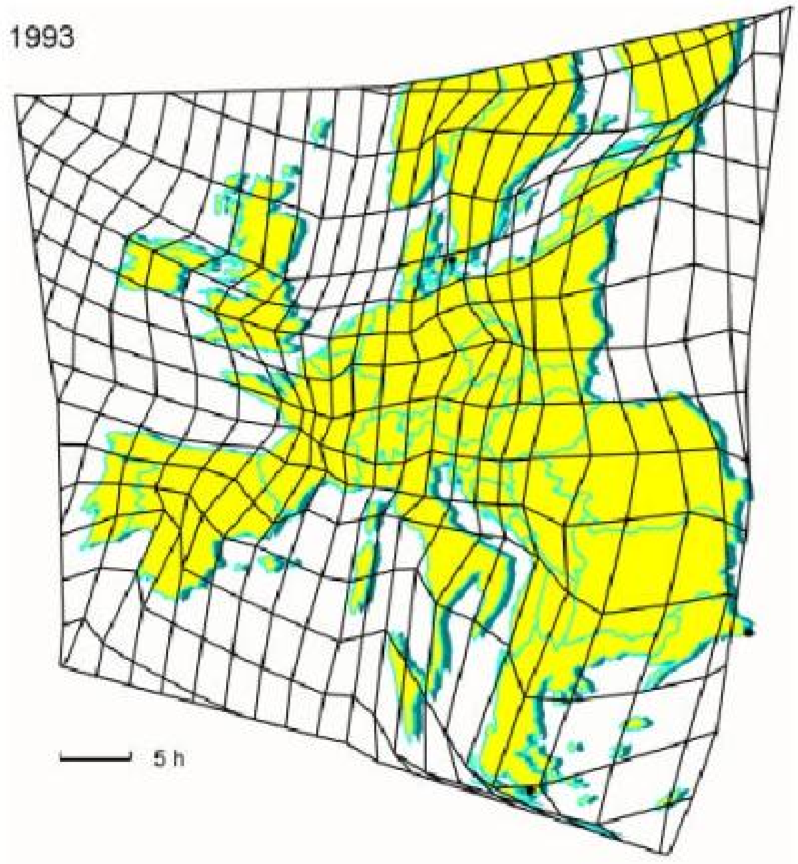
in France between Lyon and Paris. The disadvantage of such isochrones maps is that the temporal distance can be represented just for one starting point. Furthermore, the illustration of the development over several years is confusing.



Example of an isochrome map (Spiekermann 1999)

Time maps:

The following figure shows a time map for the railway traffic in 1993 (Spiekermann 1999). Time maps are transformed from the Euclidean space to the "time space", 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.



Zeitkarte am Beispiel von Reisezeiten (Spiekermann 1999)

1.1.2. Discretization of space

Discretization of space and accuracy

In a GIS, phenomena can be modeled in two main ways: *Raster data model* [4] and *vector data model* [5].

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.).

[4] 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.

[5] 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.

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**).

1.1.3. Spatial constraints

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.

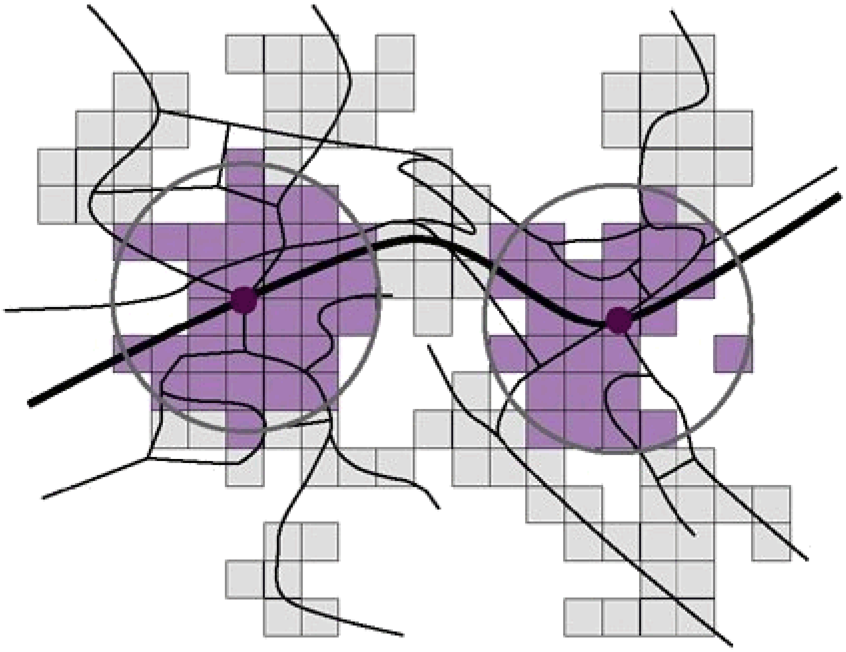
Eisenbahnlinien trennen den Raum und können als räumliche Einschränkung aufgefasst werden. (Photo: Joël Fisler)

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

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.

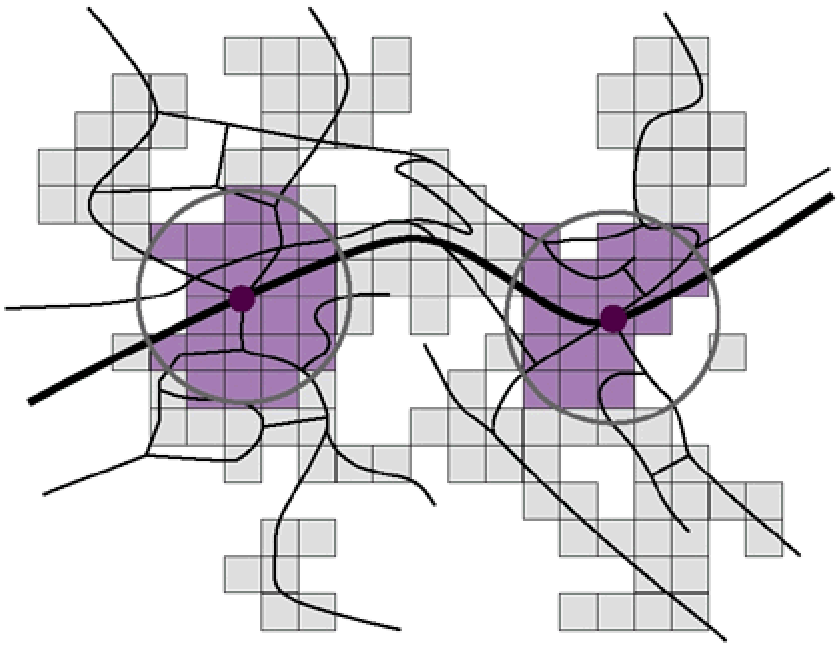
Catchment area of train stations

The following example was composed by Jermann (2002): 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.



Modellierung des Einzugsbereichs über die Luftdistanz (Jermann 2002)

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%.

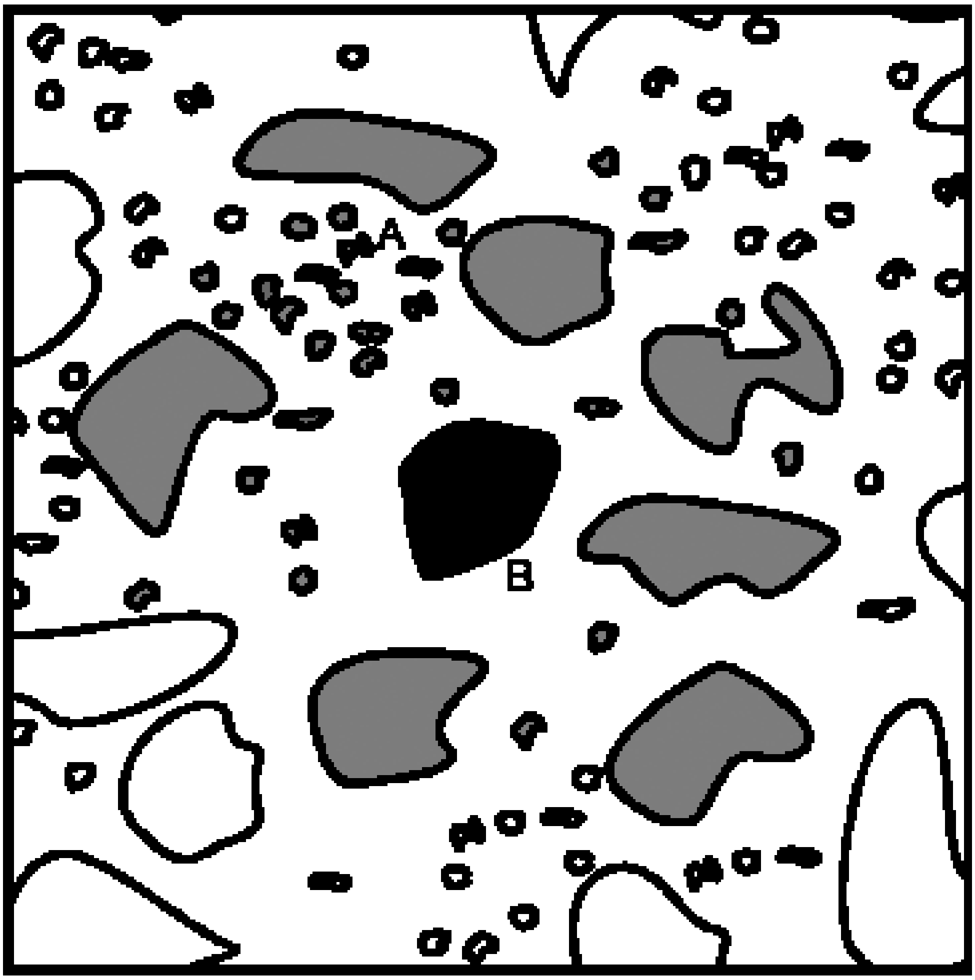


Modellierung des Einzugsbereichs über die Luftdistanz mit Umwegfaktor (Jermann 2002)

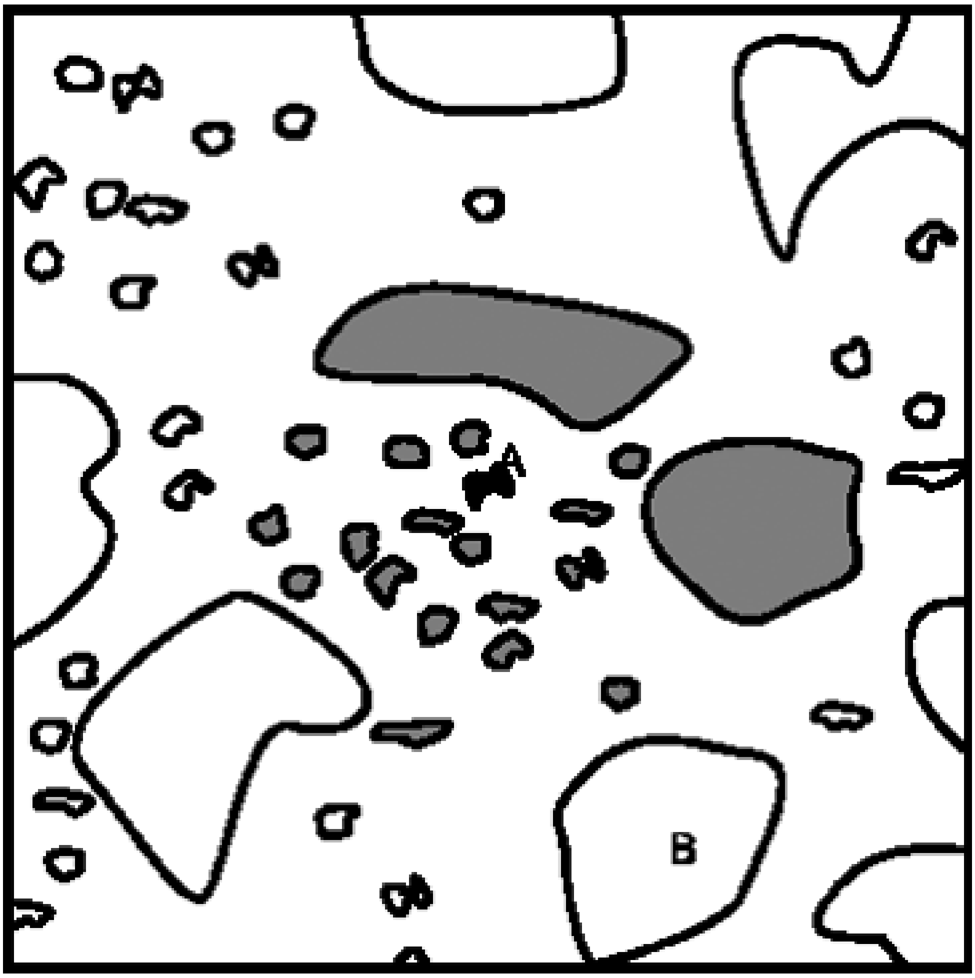
Such models can be further improved. In Jermann (2002) such model extensions for potential models of public transportation are discussed in detail.

1.2. 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.



Distanz und Nähe ist kontextabhängig und nicht symmetrisch (Worboys 1996)



Distanz und Nähe ist kontextabhängig und nicht symmetrisch (Worboys 1996)

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?

1.2.1. 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.

1.2.2. 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,	reclassification of the distance transformation

	• weighted buffer (depending on the attribute value of the object), • form of the buffer (rounded or flat end)	
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

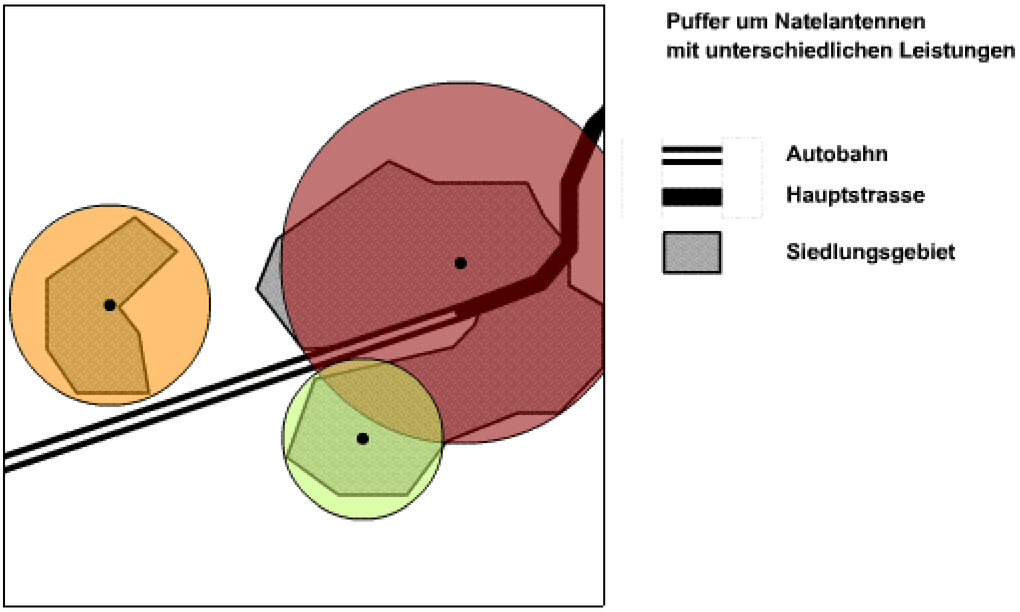
1.2.3. Creating Distance Buffers

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.

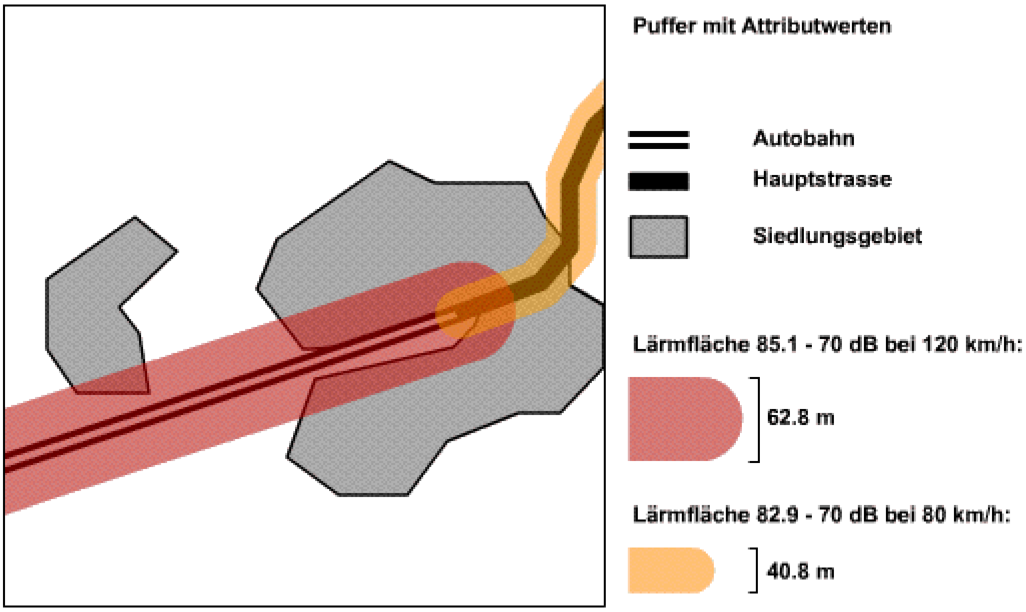
Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed. [link]

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.



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**), 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?



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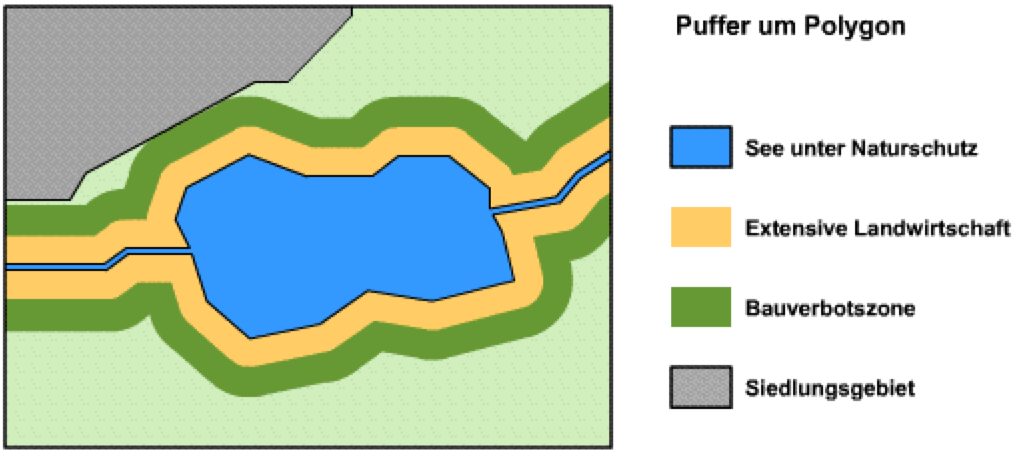
The last example shows one-sided distance buffers. They have been determined based on a law. They define the area around the nature reserve, where only extensive agriculture is allowed and where a construction ban is established.



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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Greater

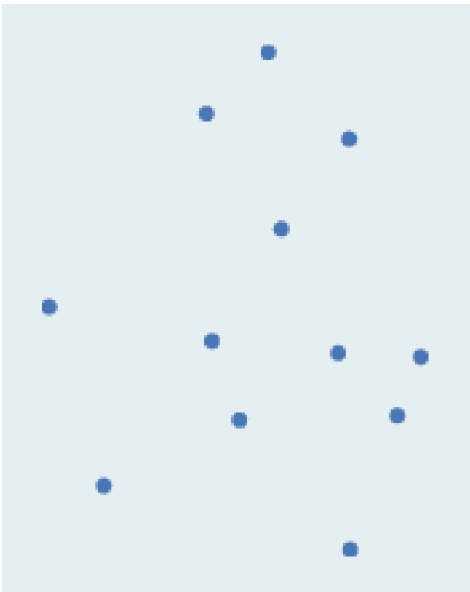
In a raster data model, distance transformation can be performed for areas or any arrangement of "source cells". In the example below, the grid cells are of the same thematic, coded with the value 99, representing a forest. For each cell, the shortest path to the edge of the forest can be calculated (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".

Only pictures can be viewed in this version! For Flash, animations, movies etc. see online version. Only screenshots of animations will be displayed. [link]

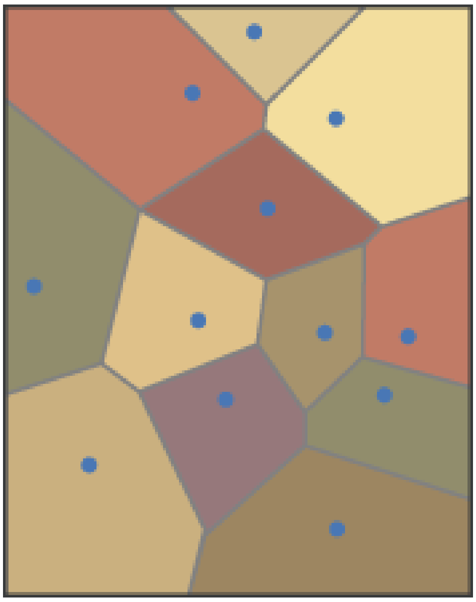
Greater

1.2.4. 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.

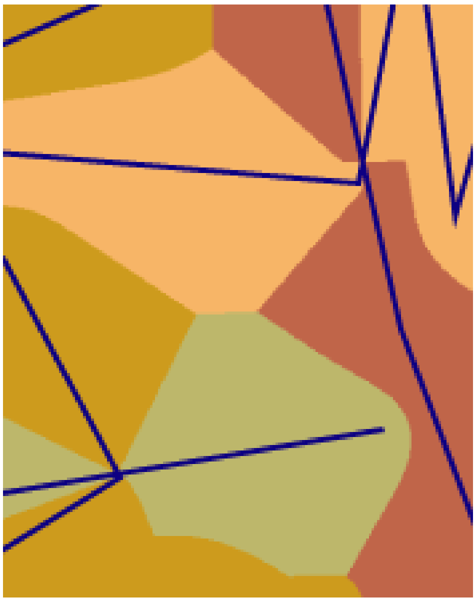


Unregelmässig verteilte Punkte oder Stichproben



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 (1999).



Rasterzellen Thiessen-Polygone konstruiert um Linienzüge

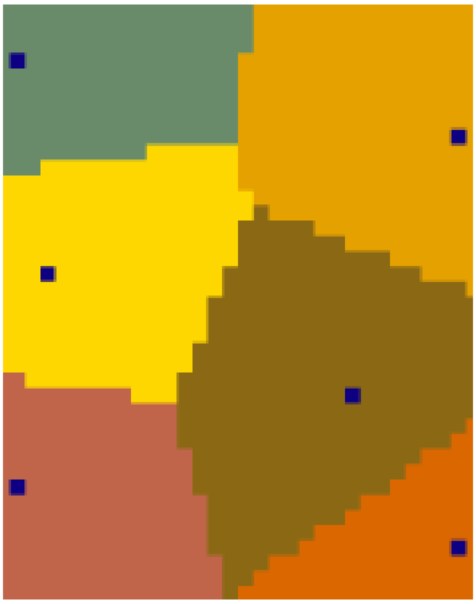
There are various applications possible for Thiessen polygons, due to their organization that is similar to many phenomena observed in nature (plant cells, soap bubbles bumping together) and in geosciences. Jones (1997, p. 48) provided the following example: Thiessen polygons are used to generate soil 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.

Konstruktion von Thiessen-Polygonen (Haggett et al. 1977)

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.



Thiessen-Polygone in einem Raster mit kleiner Auflösung

1.2.5. Self Assessment

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

1.3. 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.

1.4. Recommended Reading

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- **Spiekermann, K.**, 1999. Visualisierung von Eisenbahnreisezeiten – Ein interaktives Computerprogramm. *Berichte aus dem Institut für Raumplanug*, 45, Dortmund: Institut für Raumplanung, Universität Dortmund.
  Download: http://www.raumplanung.uni-dortmund.de/irpud/pro/visual/ber45.pdf
- **Worboys, M.F.**, 1996. Metrics and topologies for geographic space. *In:* **Kraak, M.J., Molenaar, M.**, ed. *Advances in Geographical Information Systems Research II: Proceedings of the International Symposium on Spatial Data Handling*. Delft: International Geographical Union.
  Download: http://www.spatial.maine.edu/~worboys/mywebpapers/sdh1996.pdf

1.5. 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 (Hake et al. 2002).

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.

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