Introduction Geo-Information Science

Practical Manual

Module 9
‘Surface analysis’
9. SURFACE ANALYSIS

INTRODUCTION ......................................................... 9-1

CREATING A DEM FROM POINT OBSERVATIONS ............... 9-2
  Spatial interpolation ........................................... 9-2
    Inverse Distance Weighted (IDW) ....................... 9-3
    Spline .......................................................... 9-4
    Spatial interpolation in ArcMap ......................... 9-4

ANALYZING SURFACES .............................................. 9-8
  Slope analysis .................................................. 9-8
    Slope gradient calculation in ArcMap .................... 9-8
    Slope aspect calculation in ArcMap ....................... 9-9
  Contour mapping ............................................... 9-10
9. SURFACE ANALYSIS

Introduction

This last module of the ArcGIS part of the course ‘Introduction to Geo-information Science’ focuses on operations involving surfaces.

A surface can be defined as a geographic phenomenon represented as a set of continuous data, for example rainfall, temperature, ice thickness of a glacier or organic matter content of a soil. A continually varying surface can be represented by isolines (contour lines), and these contours can be effectively regarded as sets of closed and nested polygons. Although contours are very suitable presentation form of a continually varying surface, they are not particularly suitable for numerical analysis (or modelling). So other data formats were developed in order to be able to represent and to use effectively in spatial analysis where a continuous phenomenon is involved.

A surface model is an approximation of a surface. Surface models are stored and displayed as rasters or TINs (Triangular Irregular Networks; vector format). Because a surface contains an infinite number of points, it is impossible to measure and record the value at every point. A surface model approximates a surface by taking a sample of the values at different points on the surface and interpolating the values between these points.

A widely used surface model in GIS is the Digital Terrain Model (DTM). This is a digital representation of the continuous variation of topography over space. A well known example of a DTM is the Digital Elevation Model (DEM): a digital model of a topographic surface using information on elevation of the land’s surface. Other examples of DTMs are models of slope or aspect. Note that these terrain models are derived from a DEM.

Digital elevation models have many uses. Among the most important are the following:
1. For hydrological analysis.
2. Three-dimensional display of landforms for landscape design and planning.
3. For planning routes of roads, location of dams, etc.
4. For statistical analysis and comparison of different kinds of terrain.
5. For computing slope maps, aspect maps, and slope profiles that can be used to prepare shaded relief maps, assist geomorphological studies, or estimate erosion and run-off.
6. Provide data for image simulation models of landscapes and landscape processes.

ArcMap’s Spatial Analyst offers the user a wide range of functions to analyze surfaces in the Surface toolset.

In this module:
- Interpolation of height points.
- Deriving slope and aspect from a DEM.

Objectives
After having completed this module you will be capable:
- to understand different interpolation methods;
- to apply an interpolation method to derive a elevation surface from observation points;
- to derive other terrain models from a DEM.

ArcMap document: Surface analysis.mxd
Literature: Chapter 14 Terrain Mapping and Analysis
Creating a DEM from point observations

A common data structure of a DEM is a **point elevation raster**. These height points form a mesh of square areas. The DEM is obtained through different sources of height measurements. These sources used to be stereoscopic measurements from aerial photographs using digital stereo-plotters or stereo image correlation using aerial photographs or digital images, land surveying measurements and maps with spot heights and/or contours. Nowadays DEMs are frequently obtained by digital aerial or satellite images rather than from a direct survey. Powerful techniques include **radar interferometry** (RADARSAT–1, Shuttle Radar Topography Mission) and **airborne laser altimetry** ([www.wikipedia.org](http://www.wikipedia.org)). The Dutch AHN (Actual Height Model) was derived from laser altimetry measurements. Note that the contour data or any other sampled elevation datasets (by GPS or ground survey) are not DEMs. A DEM implies that elevation is available **continuously at each location in the study area**. Measured elevation data are often irregularly spaced point observations. By means of an interpolation model a **regular spaced elevation surface** is computed.

Spatial interpolation

Visiting every location in a study area to measure a phenomenon is usually nearly impossible and very expensive. Instead, you can measure the phenomenon at strategically dispersed sample locations, and **predicted** values can be assigned to all other locations by means of an interpolation technique (Figure 1). Input points can be either randomly or regularly spaced or based on some sampling scheme.

Spatial interpolation functions create a **continuous (or prediction) surface from observation point values** (Figure 1). They make predictions from observed values for all locations in a raster dataset, whether a measurement has been taken at the location or not.

![Figure 1. Observation points (dark dots) with interpolated surface DEM and from the DEM computed contour lines.](image)

**Why interpolation?** The assumption that makes interpolation a viable option is that spatially distributed objects are **spatially correlated**: in other words, things that are close together tend to have similar characteristics: the values of points close to sampled points are more likely to be similar than those that are farther apart. This is the basis of spatial interpolation.

There are a variety of ways to derive a prediction for each location; each method is referred to as a model. With each model, there are different assumptions made of the data, and certain models are more applicable for specific data, for example, one model may account for local variation better than another. Each model produces predictions using different calculations. Based on how the sample points are distributed, each interpolation method will compute a **different result**. No matter which interpolation method is used, the more input points and the greater their distribution, the more reliable the end result.
Spatial interpolation functions can be divided into two groups:

1. **Deterministic models**: Inversed Distance Weighted (IDW) and Spline. These functions assign values to locations based on the surrounding measured values (IDW) and on specified mathematical formulas that determine the smoothness of the resulting surface (Spline).

2. **Geostatistical models**: Kriging. Kriging models use the statistical relationship (autocorrelation) among the observation points.

In this module we focus on the deterministic functions. Kriging is beyond the scope of this course. Feel free to consult ArcGIS Desktop Help to learn more about Kriging.

**Note**: the distribution of the observation points is very important when applying an interpolation. Depending upon the interpolation when making a DEM, observation points must be well distributed over the whole surface according to the relief of the terrain. Sharp changes in height over a short distance requires more observation points than relatively flat areas.

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**Inverse Distance Weighted (IDW)**

**Inverse Distance Weighted (IDW)** is a method of interpolation that estimates cell values by averaging the values of observation data points in the neighborhood of each processing cell. This method assumes that the variable being mapped decreases in influence with distance from its sampled location. The closer a point is to the center of the cell being estimated, the more influence, or weight, it has in the averaging process.

![IDW diagram](image)

*Figure 2: Inverse distance weighted interpolation method (IDW): the values of points closer to the observation point (points in the circle) are more similar to the value of the observation point than the points further away.*

IDW allows you to control the influence of the observation points upon the interpolated values, based upon their weight and their distance from the output point:

- **The power** parameter in the IDW interpolation controls the significance of the surrounding points upon the interpolated value. Power is the exponent of distance. A higher power results in less influence from distant points: distant points receive lower weights. However, lower powers tend to treat all the sample points equally resulting in a smoother surface. When the power is 0 there is no decrease in weight with distance which means that all observation points get the same weight. The prediction will be the mean of the measured values.

- A **specified number** of points or all points within a **specified radius** can be used to determine the output value for each location.
The IDW interpolation method can be accessed using the **Spatial Analyst toolbar** or the **IDW tool** in the **Interpolation toolset** of the Spatial Analyst toolbox.

**Spline**

The **Spline interpolation method** is a general purpose interpolation method that fits a 2-dimensional minimum-curvature surface through the input points. A spline passes exactly through the input data points, to minimise certain aspects of curvature. Conceptually, it is like bending a sheet of rubber to pass through the points, while minimising the total curvature of the surface. It fits a mathematical function to a specified number of nearest input points while passing through the sample points. This method is best for generating gently varying surfaces such as elevation, water table heights, or pollution concentrations.

There are two Spline methods: **Regularized** and **Tension**. The **Regularized** method creates a smooth, gradually changing surface with values that may lie outside the sample data range. The **Tension** method controls the stiffness of the surface according to the character of the modeled phenomenon. It creates a less smooth surface with values more closely constrained by the sample data range.

Further control of the output surface is accomplished through two additional parameters: weight and number of points. Consult ArcGIS Desktop Help to learn how these two parameters influence Spline interpolation (use keyword ‘Spline interpolation’, subsequently choose the described subentry).

![Figure 3: Spline interpolation method.](image)

In Figure 3, Spline estimates the value of the selected cell at 23. Spline tries to fit a curve using the selected subset of samples, in this case 6 samples. The curve would start at one of the cells with a value of 10, start up to a cell with a 20, continue up or overshooting, then come back down to another 20 and back down to a 10. The estimate cell, 23, may have been on the upswing of the curve.

**Spatial interpolation in ArcMap**

The interpolation methods in ArcGIS can only use **point observations** as input. Height profiles, terrain structure lines such as a river drainage pattern and contour lines cannot be used.

**INSTRUCTIONS:**

1. Open ArcToolbox. Click **Spatial Analyst Tools → Interpolation → IDW / Spline**.
2. Choose an input point dataset that contains elevation values.
3. Choose the **Z value field** (field that contains elevation values).
4. Choose name and location of the output raster dataset.
5. Specify the parameters for the chosen interpolation method in parameter type-in boxes.
   - **Inverse Distance Weighted:**
     - Specify the power.
     - Choose a **Variable** or a **Fixed Radius** interpolation. If you choose Variable, enter the number of input points and/or the maximum distance. If you choose Fixed, enter the distance to search for points and/or the minimum number of points.
     - Select a barrier dataset (optional).
• **Spline interpolation:**
  - Choose cell size (optional).
  - Choose the **Regularized** or **Tension** method.
  - Enter a **weight factor**.
  - Specify the **number of points** to use per region.

  6. Click **OK**.

1. Open the ArcMap document ‘**Surface analysis.mxd**’.
   a. How many point observation points are stored in dataset ‘Height_observations’?
   
   b. Is this a vector or raster dataset vector or raster structured? Explain your answer.

2. In this exercise you have to interpolate the elevation point observations using different interpolation methods, types and parameter settings.
   a. Set the Output Extent to ‘Same as Layer lu_raster’ and set the Mask to ‘lu_raster’ (see Module 7 how to set the output extent and mask).
   
   b. Create 5 digital elevation models by interpolation of the elevation points. Use the interpolation parameters as given in Table 1.
   
   c. Display the DEMs you created. The DEMs must be displayed with the same symbology in order to compare. Open the Symbology editor, right-click the box that contains the ranges and labels, choose ‘**Load class breaks**’ from the menu and select ‘**Elevation_classification.xml**’ from the data folder.
   
   d. Fill in Table 2. You cannot open the attribute table of the DEM (because this is a continuous raster dataset). You must use dataset statistics to retrieve minimum, maximum and average elevation. These statistics can be found under the **Source** tab in the **Layer properties** window.
   
   e. How is it possible to get lower and higher elevation values after interpolation than the minimum and maximum values contained in dataset ‘Height_observations’?

<table>
<thead>
<tr>
<th>Name</th>
<th>Interpolation method</th>
<th>Type</th>
<th>No. of neighboring points</th>
<th>Radius</th>
<th>Power / Weight</th>
<th>Cell size</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDW_4_5</td>
<td>IDW</td>
<td>Variable</td>
<td>4</td>
<td>-</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>IDW_4_25</td>
<td>IDW</td>
<td>Variable</td>
<td>4</td>
<td>-</td>
<td>2</td>
<td>25</td>
</tr>
<tr>
<td>IDW_12_5</td>
<td>IDW</td>
<td>Variable</td>
<td>12</td>
<td>-</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>IDW_50_5</td>
<td>IDW</td>
<td>Fixed radius</td>
<td>-</td>
<td>50</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Spline_4_5</td>
<td>Spline</td>
<td>Tension</td>
<td>4</td>
<td>-</td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>
Table 1. Interpolation parameters.

<table>
<thead>
<tr>
<th>Name</th>
<th>Minimum Elevation</th>
<th>Maximum Elevation</th>
<th>Average Elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDW_4_5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
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</tr>
<tr>
<td>IDW_12_5</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>IDW_50_5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spline_4_5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2. DEM statistics.

3.

In this exercise you have to compare the results of exercise 2.

a. Describe in your own words how the Variable IDW-interpolation method works.

b. What is the effect of cell size when using IDW as an interpolation method?

c. What is the effect of increasing the number of nearest points when using IDW as an interpolation method?

d. Describe in your own words the differences between the Fixed Radius IDW-interpolation method and the Variable IDW-interpolation method.

e. Write down the effect of a 50 meter radius on the spatial coverage out the interpolation. What could you do to improve the coverage of the interpolation ‘IDW_50_5’.
f. Write down the advantages of using the Fixed Radius IDW-interpolation method.

g. For which type of terrain is it better to use the Spline interpolation method instead of IDW? Zoom in to different locations of the Wageningen South area.

h. Write down what the differences are between the different interpolation methods IDW and Spline.

Use interpolation Spline_4_5 for the next exercises. Remove the other created datasets from the data frame!

IDW and Spline interpolations are basic methods. The more advanced interpolation method ‘Topo to Raster’ is discussed in the follow-up course Geo-information Tools (GRS 20806).
Analyzing surfaces

Before digital elevation models were available, geomorphologists applied a wide variety of qualitative and semi-quantitative techniques to describe and compare terrain. Quantitative analysis was difficult due to the amount of work collecting data, either in the field or from aerial photographs. Once a DEM is produced, several standard computations allow the production of digital terrain models showing slope and other terrain features.

When analyzing surfaces, you perform a specified calculation that results in different representations of a surface or that derives patterns not readily apparent in the original surface, using a continuous raster dataset. With surface-analysis operations, you can derive additional information by producing new data and identifying patterns in existing surfaces.

Slope analysis

Slope is defined by a plane tangent to the surface as modelled by the DEM at any given point and comprises two components:
- Gradient: the maximum rate of change of elevation from each cell to its neighbors;
- Aspect: the compass direction of this maximum rate of change.

Slope gradient calculation in ArcMap

The Slope function calculates the maximum rate of change between each cell and its neighbors, for example, the steepest downhill descent for the cell (the maximum change in elevation over the distance between the cell and its eight neighbors). Every cell in the output raster has a slope value. The slope gradient can be calculated in percentage or degrees.

INSTRUCTIONS:

1. Open ArcToolbox. Click Spatial Analyst Tools → Surface → Slope.
2. Select the Input raster.
3. Specify a name and location for the output raster.
4. Specify whether you want the output slope raster in degrees or in percentages.
5. Enter the Z-factor if the horizontal unit differs from the vertical unit. For example when the horizontal unit is meter and the vertical unit centimeter, then the Z-factor is 0.01.
6. Click OK.

Derive the slope gradient from the DEM you have created. Improve the display; change the number of classes to 15.

a. What type of raster operation (module 6) is the calculation of slope gradient? Why?

b. Write down the maximum, minimum and mean of the slope gradient dataset.

Maximum:
Minimum:
Mean:
**Slope aspect calculation in ArcMap**

Aspect identifies the steepest downslope direction from each cell to its neighbors. It can be thought of as slope direction or the compass direction a hill faces. Aspect is usually measured in degrees from the north: 0 is north; 90 degrees is east.

**INSTRUCTIONS:**

1. Open ArcToolbox. Click **Spatial Analyst Tools** ➤ **Surface** ➤ **Aspect**.
2. Select the **Input raster**.
3. Specify a name and location for the **output raster**.
4. Click **OK**.

Cells with a zero slope (flat) receive the value ‘-1’. The slope aspect in the output raster is represented in 8 cardinal directions, e.g. East [67.5 - 112.5 degrees], Southeast [112.5 - 157.5 degrees].

5.

Derive the slope aspect from the DEM.

a. What is the slope aspect of the Rhine facing side of the Wageningen hill?
Contour mapping

Contours are lines, also referred to as isolines that connect points of equal value, such as elevation, temperature, precipitation, pollution, or atmospheric pressure. The distribution of the lines shows how values change across a surface. Where there is little change in a value, the lines are spaced farther apart. Where the values rise or fall rapidly, the polylines are closer together. Elevation contour lines are derived from a DEM.

You can access the contour function in ArcToolbox and in the Spatial Analyst toolbar. The latter is the most convenient for mapping contour lines. The contour function does not connect cell centres; it interpolates a line that represents the most likely location with the same height. Since the lines are smoothed, an idealistic representation of the surface is produced. You can also create an individual contour line by clicking the Contour tool, and then selecting a location in the view. The function traces the contour of the value that the chosen point represents.

INSTRUCTIONS:

1. Open ArcToolbox. Click Spatial Analyst Tools ➔ Surface ➔ Contour.
2. Select the Input raster.
3. Specify a name and location for the Output polylines features.
4. Type a Contour interval.
5. Type a Base contour. Contours are generated above and below the base contour.
6. Optionally, type a value for the Z factor.
7. Click OK.

Smaller contour intervals create more contours. The optimum contour interval is a matter of the realistic elevation change in the DEM, the size of the area covered by the DEM, the analyses to follow, and the desired aesthetics of the contour line dataset.

6.

Derive 3 contour datasets from the DEM. Use the following contour parameter combinations.

<table>
<thead>
<tr>
<th>Contour dataset</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contour interval</td>
<td>2</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>Base contour</td>
<td>0</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

a. Which contour parameter combination do you prefer? Explain why?

b. What is the meaning of the Base contour?