CHAPTER 10

Using Digital Elevation Models

Digital Elevation Models (*DEM's*) store continuously varying variables such as elevation, groundwater depth or soil thickness. *Digital Terrain Models* (*DTM's*) are digital representations of altitude and are frequently used in hydrological, erosion and engineering geological studies.

Digital Elevation Models are made via the following techniques:
- Photogrammetrical techniques. These methods use stereoscopic aerial photographs or satellite images to sample a large number of points, with X, Y and Z values, by means of advanced photogrammetrical equipment. After this, the points are interpolated into a regular grid (raster). Unfortunately, the method is rather time consuming (each sampling point has to be measured by an expert through the lowering of a floating mark on the stereo model) and requires photogrammetrical experts, and a set of detailed control points. At present, photogrammetrical software packages are on the market which can automatically generate a DTM from stereoscopic scanned aerial photographs or satellite images in combination with a number of control points for which (x,y, z) coordinates are known. In general, it can be said that photogrammetrical methods, whether analogue or digital, are mainly used by mapping agencies and certain companies specialized in photogrammetry and map production.
- Point interpolation techniques. When point data is available for an area, obtained via ground surveys using theodolites and/or *Global Positioning Systems* (*GPS*), point interpolation can be used to generate a DEM. For complex terrain, the interpolation techniques are also rather complex, taking into account breaklines of slope. Point interpolation techniques will be treated in chapter 11.
- Interpolation of contour lines digitized from existing maps. When neither existing DEMs derived from photogrammetric techniques nor detailed point data is available, the contour information on existing topographic maps is the only source from which you can generate a DEM. In that case the contour lines are digitized and interpolated. The interpolation of contour lines is a standard procedure in ILWIS to generate a DEM. This is what we will discuss in the next section.

Digital Elevation Models can either be stored in vector or in raster format. DEMs in vector format are often in the form of *Triangulated Irregular Networks* (*TIN*), which can be seen as a set of polygons in the form of triangles where the 3 corners of each triangle are known height values. Each triangle has a uniform slope steepness and slope direction. When the terrain is more complex, the number of triangles needed to represent the terrain increases.

In ILWIS, the TIN structure is not used. DEMs are always in the form of raster maps, with a value domain. Each pixel in the raster map contains the altitude of the center of the pixel. Using a large pixel size will therefore result in more general DEMs (a smoother topography). Especially when the mapped changes in topography occur at distances smaller than the pixel size, the slope angles derived from the DEM may lead to an underestimation of the actual slope angles in the field. When the pixel size is chosen too large, ridges and small streams may be missed. The accuracy of a DEM depends very much on the detail of the contour lines, that were used for the interpolation, and the scale of the original topographic map from which the contour lines were digitized. The larger the scale of the map, and the smaller the contour interval, the more accurate the DEM will be.

> **!** In the Properties of a DEM raster map, you can switch on the Interpolation check box. This will calculate height on the fly within pixels. This is extremely important when using a georeference Direct Linear or a georeference Orthophoto (see section 6.4.1.).

Digital Elevation Models have a very wide range of applications. They form one of most frequently used spatial data sources in GIS projects. They are also the basis for a large number of derivative information. The most important application areas of DEMs are:

- Slope steepness maps, showing the steepness of slopes in degrees, percentages, or radians for each location (pixel).
- Slope direction maps (also called slope aspect maps), showing the orientation or compass direction of slopes (between 0˚-360˚).
- Slope convexity/concavity maps, showing the change of slope angles within a short distance. From these maps you can see if slopes are straight, concave or convex in form.
- Hill shading maps (or shadow maps), showing the terrain under an artificial illumination, with bright sides and shadows. Hill shading is used to portray relief difference and terrain morphology in hilly and mountainous areas. The gray tones in a hill shading map represent the amount of reflected light, depending on the relative orientation of a certain location towards the illumination source. The illumination source is usually chosen at an angle of 45˚ above the horizon in the northwest.
- Three dimensional views showing a bird's eye view of the terrain from a user defined position above the terrain.
- Cross-sections indicating the altitude of the terrain along a line and represented in a graph (distance against altitude).
- Volume maps (or cut-and-fill maps), generated by overlaying two DEMs from different periods. This allows you to quantify the changes in elevation that took place as a result of slope flattening, road construction, landslides etc.
- Creation of Ortho-images from aerial photographs or satellite images. With the help of DEMs, aerial photographs and satellite images can be corrected for tilt distortion and relief displacement.

In this chapter, first the method for generating a DEM will be explained, followed by a series of exercises dealing with the derivative maps.

Before you can start with the exercises, you should start up ILWIS and change to the subdirectory C:\ILWIS 3.0 Data\Users Guide\Chapter10, where the data files for this chapter are stored.

☞
- Double-click the ILWIS icon on the desktop.
- Use the Navigator to go to the directory: C:\ILWIS 3.0 Data\Users Guide\ Chapter10.

10.1 Creating a Digital Elevation Model: contour interpolation

In this section, you will create a DEM for the Cochabamba study area from digitized contour lines. The contour lines were digitized manually. See section 3.4 for information on how to digitize contour lines.

You should make sure to have digitized the contour lines a little bit outside of the study area where interpolation should take place, because at the borders of the interpolated area, artifacts may occur.

The creation of a Digital Elevation Model from a segment map is done with the Contour interpolation operation. This operation works in two steps:
- Segment to raster conversion. First the segment map is converted to raster, using a georeference in which the pixel size, the number of lines and columns, and the minimum and maximum X and Y coordinates of the map are defined. It is important to make sure that the pixel size is not too large, in relation to the maximum spacing of the contour lines. Otherwise it may happen that two contour lines may have to be located in the same pixel, which is of course not possible. In this case the program will select one of the two values of the contour lines and will omit the other, which may lead to problems in the interpolation. The input segment map should be a value map. The raster map resulting from the segment to raster conversion will contain values for those pixels covered by a contour line. All other pixels in the map remain undefined.
- Contour interpolation. A linear interpolation is made between the pixels with altitude values, to obtain the elevations of the undefined values in between the rasterized contour lines. The output of the contour interpolation is a raster map in which every pixel has a value. The interpolation method is based on the *Borgefors distance* method. The operation calculates, for each undefined pixel in between two rasterized segments (outcome of the first step), the shortest distance towards the two nearest isolines (see Figure 10.1). The height value (H_p) for a pixel (p), between two contour lines is calculated as:

$$H_p = H_2 + (d_2 / (d_1 + d_2) * (H_1 - H_2))$$

where: H_p is the calculated height value for an output pixel, H_1 and H_2 are the height values of the higher and lower contour lines and d_1 and d_2 are the distances from the pixel to the higher and lower contour lines (see Figure 10.1).
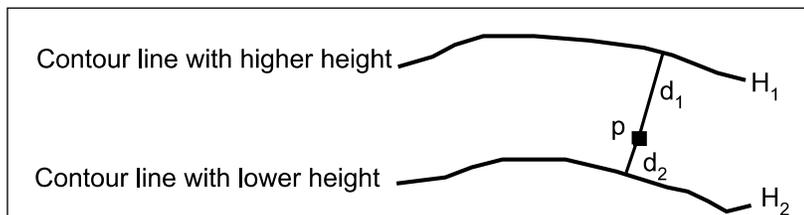

Figure 10.1: Two contour lines (H1 and H2) and the shortest distances (d1 and d2) towards an output pixel (p).

During the interpolation, quite some time is needed to calculate the shortest distance towards two known values, which has to be done for every undefined pixel. This calculation is done iteratively; the program calculates forwards and backwards (from top line to bottom and vice versa) until no more changes occur. Then a linear interpolation is performed using the two distance values. The linear interpolation returns the height values for the undefined pixels. During the calculation, several Megabytes of hard disk are used for storing temporary maps.

In this exercise segment map `Contour`, with a value domain, is used to generate the DEM.

☞
- Click with the right mouse button on segment map `Contour` and select Contour Interpolation from the context-sensitive menu. The Interpolate Contour Map dialog box is opened.
- Type `Dem` as Output Raster Map.
- Select GeoReference `Cochabamba`.
- Type for the Description: `DEM created from the segment map Contour`.
- Accept all other defaults and click Show.

The calculation may take some time, depending on the computer configuration and other programs that are working simultaneously. It is advised to close other programs while performing contour interpolation: this will speed up the process considerably. The Display Options - Raster Map dialog box will be opened after the operation is finished.

The default representation which is indicated in the Display Options dialog box is the same one as was used for the segment map `Contour`: the user-defined Representation `Height`.

☞
- Click OK in the Display Options – Raster Map dialog box. The map is displayed.
- Click several places in the map and read the altitude values.
- Double-click the map `Dem` in the Layer Management pane. The Display Options – Raster Map dialog box is reopened.
- Select Representation `Clrstp12` and click OK. The map is now displayed with a Representation `Clrstp12`.

Now we will show you that even within pixels an interpolation can take place.

☞
- Zoom in on the `Dem`, until you see the pixels clearly.
- Check the value of a pixel by moving the mouse pointer within a pixel. ➡

➡

> - From the File menu, choose Properties, and select the Interpolation check box. Click Apply.
> - Check the height value within a pixel once more and close the map window when finished.

Selecting the Interpolation check box is especially important when you want to use the DEM in a georeference Direct Linear or a georeference Orthophoto. In regular map calculations, however, still 1 value per pixel will be used.

If you wish you can create a new representation to make the Dem appear sliced. A DEM can also be classified or sliced permanently through the operation Slicing. Ranges of values of the input map are grouped together into one or more output classes. The output map resulting from the Slicing operation is a map with the domain type group. A domain group should be created beforehand or during the operation using the Slicing dialog box. The domain group lists the upper boundaries of the groups and the group names. A detailed description of the Slicing procedure was given in the sections 6.6.2 and 7.5.

Use of additional point heights

The interpolation of contour lines will give wrong results for hilltops, which are enclosed on all sides by a contour line. They will appear as flat areas with the same altitude as the contour line surrounding it. To improve this, it is possible to combine the segment map, containing the contour lines, with a point map, containing the altitudes of the hilltops. Both maps should first be converted to raster and then combined into one raster map. This raster map will serve as the basis for the interpolation.

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> - Display segment map Contour with Representation Height.
> - From the Layers menu select Add Layer.
> - The Add Data Layer dialog box appears. Select the Point Map Spotheight and click OK. The Display Options – Point Map dialog box is opened.
> - Press the Symbol button. The Symbol dialog box appears.
> - Select Symbol: + Plus. Clear the check box Stretch. Accept all other defaults and click OK. You are back in the Display Options – Point Map dialog box.
> - Click OK. The point map is displayed on top of the contour lines.

When you zoom in on one of the crosses you will see that it is located within a closed contour line on a hilltop. Of course the same procedure is valid for closed depressions.

☞

> - Close the map window.

Now we have to rasterize the point map and combine it with the rasterized segment map into a single map, which will be the input map for the interpolation. The rasterized segment map ContourRasterized was created already during the previous contour interpolation operation.

☞
- Double-click the Point to Raster operation in the Operation-List. The Rasterize Point Map dialog box is opened.
- Select the Point Map Spotheight. Select GeoReference Cochabamba, accept all other defaults and click Show. The point map is rasterized and the Display Options – Raster Map dialog box is opened.
- Click OK to display the rasterized point map.
- Close the map after you inspected the result.

Now that both the point map and the segment map are rasterized, you can combine them.

☞
- Type the following formula on the Command line of the Main window:
  Combination = IFUNDEF(Spotheight, ContourRasterized,Spotheight) ↵
- The Raster Map Definition dialog box is opened. Click Show to calculate and display the Combination map. After the calculation the Display Options - Raster Map dialog box appears.
- Click OK to display the map.

In the MapCalc formula above, it was tested whether a pixel in the map Spotheight is undefined. If that is so, the map Contour is used in the output map. If not, then the values from the raster map Spotheight are taken.

With the Combination map you can do the actual interpolation. The interpolation expression on the Command line will be used instead of the Contour Interpolation dialog box, since the dialog box only accepts a segment map as input.

☞
- Type the following formula on the Command line of the Main window:
  Dem1 = MapInterpolContour(Combination) ↵

  The Raster Map Definition dialog box appears. Click Show. The map Dem1 is calculated; when the Display Options dialog box appears click OK. The map is now displayed.
- From the Layers menu, select Add Layer. The Add Data Layer dialog box appears
- In the Add Data Layer dialog box select point map Spotheight and click OK. The Display Options - Point Map dialog box is opened.
- Press the Symbol button. The Symbol dialog box appears.

➡️
> - Select Symbol: + Plus. Clear the check box Stretch. Accept all other defaults and click OK. You are back in the Display Options - Point Map dialog box.
>
> - Select the check box Text and click OK. The point map Spotheight is displayed on top of Dem1.
>
> - From the File menu in the map window, select Open Pixel Information. The pixel information window is opened.
>
> - Add map Dem via drag and drop to the pixel information window and check the altitude values of the hilltops with the mouse.
>
> - Close the map window and the pixel information window.

The combination of contour lines with additional point heights is very important for hilly areas, where a lot of isolated hills can occur. Normally the altitude of isolated hilltops is indicated on topographical maps. If they are not available you will have to make an "educated guess", taking into account the value of the enclosing contour line, the contour interval and the overall steepness of the terrain.

If you only have elevation data stored as points, the contour interpolation cannot be used for generating a Digital Elevation Model. In that case you will have to use a point interpolation operation, such as Moving Surface or Kriging. This will be demonstrated in chapter 11.

Summary: Contour interpolation

The creation of a Digital Elevation Model from a segment map is done with the Contour Interpolation operation. This operation works in two steps:

- Segment to raster conversion. First a segment map is converted to raster, using a georeference.

- Contour interpolation. A linear interpolation is made between the pixels with known altitude values, to obtain the elevations of the undefined values in between the rasterized contour lines. The output of the contour interpolation is a raster map in which each pixel in the map has a value.

10.2 Filters applied on Digital Elevation Models

Filtering is the calculation of pixel values in an image or a raster map based on the pixel values of the central pixel and its neighbours. In other words, filtering is a process in which, usually a window of 3x3 or 5x5 pixels, is moved over the map, to calculate an output value for the central pixel in the window according to its neighbours.

Filters are commonly used in image processing (see chapter 6) but can also be applied to raster maps (see chapter 9). A special group of filters is used to calculate slope steepness, slope shape (convex, concave) and shadow from Digital Elevation Models. The existing standard filters in ILWIS that can be applied on DEMs are given in Table 10.1.

Table 10.1:   List of standard filters in ILWIS that can be applied on DEMs.

Filter type	Application
DFDX	Detects slope differences in x-direction.
DFDY	Detects slope differences in y-direction.
DFDUP	Calculates slope differences in the upward diagonal direction.
DFDDN	Calculates slope differences in the downward diagonal direction.
D2FDX2	Detects slope shape differences in x-direction.
D2FDY2	Detects slope shape differences in y-direction.
D2FDXDY	Calculates slope shape differences in all diagonal directions
LAPLACE	Calculates slope shape differences in all diagonal directions
SHADOW	Applies artificial illumination (from the northwest) to the DEM.

Creating a hillshading map

In this exercise, the ILWIS standard filter Shadow is applied on the Digital Elevation Model Dem to create a shaded relief image. The shadow filter simulates sun illumination on the surface, with the sun in the northwest. The shaded relief image is merely used for display.

☞
- Double-click the Filter operation in the Operation-list. The Filtering dialog box appears.
- Select Raster Map: Dem
- Select Filter Name: SHADOW.
- Type Hillshading in the text box Output Raster Map.
- Type for the Description: Hill shading map generated from the map Dem.
- Accept all other defaults and click Show. After the map has been calculated, the Display Options - Raster Map dialog box will appear.
- In the Display Options - Raster Map dialog box, select Representation Gray and click OK. The map is now displayed.

When you display the map, you can see the relief coming out of the map. The map shows the representation of the mountains under an artificial illumination, as if the sun is shining from the NW. Steep slopes directed to the SE are dark, and slopes directed to the NW are very bright. You can generate hillshading maps with illumination from other directions by saving a copy of the Shadow filter and then editing the copy.

☞   •   Close the map window.

Using gradient filters

The most important types of filters that can be used on a DEM are called gradient filters. With the help of the gradient filters Dfdx and Dfdy, horizontal and vertical gradients are calculated for each pixel. The gradient maps are used to produce slope steepness maps as well as slope direction maps.

The gradient filter can be seen as a window which moves over the map, starting from the upper left pixel in the map. Each value of the filter is multiplied by the corresponding pixel value in the map. The results, for all the pixels in a filter are added up, and the resulting value is multiplied by the *gain* and stored in the central pixel of the output map. Then, the window moves one pixel to the right, and the procedure is repeated. After finishing with the last pixel of the first line, the window moves to the first pixel of the second line. In this way, a new value is calculated for every pixel in the map. In Figure 10.2, a schematic example is given of a horizontal gradient filter.
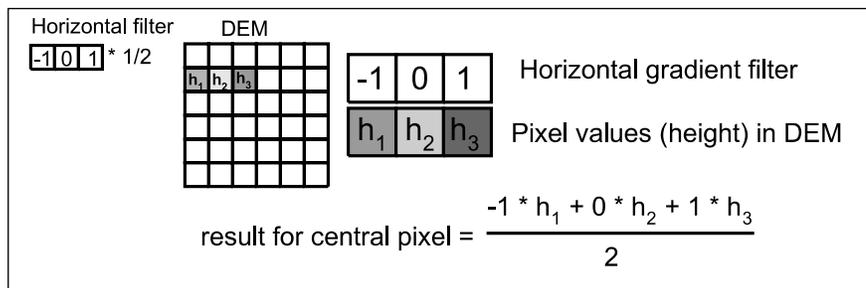

Figure 10.2: The filtering procedure, applying a horizontal gradient filter on a DEM. The direction of the horizontal and vertical filters is not important. Filters -1 0 1 and   1 0 -1 will give the same value but with opposite sign, e.g. in the calculation of slope angles.

The simple horizontal gradient filter shown in Figure 10.2 is not an ILWIS standard filter; it is just an understandable example. The standard gradient filters DFDX and DFDY in ILWIS are a little more complicated and give a better estimation of the first derivative. They are presented in Figure 10.3.
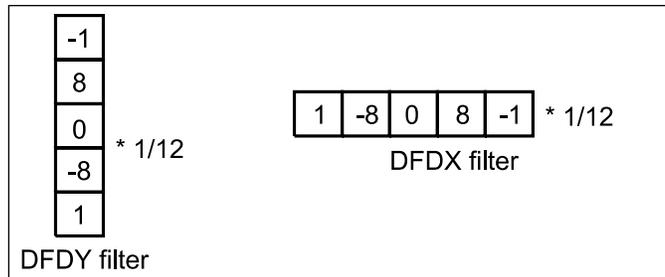
Figure 10.3: The vertical (DFDY) and horizontal (DFDX) gradient filters used in ILWIS.

> To inspect the contents of standard filters, choose Customize Catalog from the View menu in the Main window, and select the Include System Objects check box. You can open the standard filters now by double-clicking them in the Catalog.

☞
- Double-click the Filter operation in the Operation-List. The Filtering dialog box is opened.
- Select Raster Map Dem and Filter Name DFDX.
- Type for Output Raster Map: Dx.
- Accept all other defaults and click Show. The map is calculated, after which the Display Options - Raster Map dialog box is opened.
- Click OK in the Display Options - Raster Map dialog box. The map is now displayed.
- In the map window, open the pixel information window and add the map Dem. Zoom in on the map until you can see individual pixels. Compare the values of the map Dx for a certain pixel, with the difference of the altitude of its left and right neighbours in the map Dem.
- Repeat the procedure to create a gradient map in the y-direction, but select the Filter Name DFDY and type Dy for the Output Raster Map name.
- Close the map window and the pixel information window when you have finished the exercise.

Calculating slope shape

Before continuing with the creation of a slope steepness map, you will have a look to another set of filters that are useful for DEMs. A number of filters can be used to investigate which parts of the terrain are convex (showing negative values in the output map) or concave (positive values in output map). Flat areas and uniform slopes obtain the output value 0. The following filters can be used:
- D2FDX2. This 1x5 filter detects slope shape differences in x-direction.
- D2FDY2. This 5x1 filter detects slope shape differences in y-direction.
- LAPLACE. This 3x3 filter can be used to detect slope shape differences in both x and y directions.

- D2FDXDY. This 5x5 filter detects slope differences in both x and y direction (second derivative).

☞
> - Click raster map Dem with the right mouse button and select Image Processing, Filter. The Filtering dialog box is opened.
> - Select Filter Name: D2FDXDY.
> - Type for the Output Raster Map: Shape.
> - Accept all other defaults and click Show. After the map has been calculated, the Display Options - Raster Map dialog box will appear.
> - Click OK in the Display Options - Raster Map dialog box. The map is now displayed.
> - Check some of the pixel values and close the window afterwards.

The map shows many different values, showing the degree of concavity/convexity of the slope. Negative values indicate convex slopes while positive values represent concave slopes. Values close to zero represent straight slopes or flat areas.

It would be better to classify this map into three classes: Convex, Straight and Concave. We can do this by reclassifying the map. We can use the Slicing operation (as was explained in chapter 7) for classifying the value map Shape, but since there are only three units, we can also use a MapCalc formula. The resulting map will be a class map with three classes. The domain will be created semi-automatically after writing the formula.

☞
> - Type the following formula on the Command line of the Main window:
>   Shapeclasses = IFF(Shape<-0.5,"Convex slope", iff(Shape>0.5,"Concave slope","Straight slope")) ↵
>   The Raster Map Definition dialog box appears.
> - Click the Create button next to the drop-down list box of the Domain. The Create Domain dialog box is opened.
> - Enter the Domain Name Shapeclasses and click OK. The Domain Class editor is now opened
> - Close the Domain Class Editor. You are now back in the Raster Map Definition dialog box. Click Show.
> - Answer Yes to the question: Add string 'Concave slope' to domain 'Shapeclasses'.
> - Answer Yes to the question: Add string 'Straight slope' to domain 'Shapeclasses'.
> - Answer Yes to the question: Add string 'Convex slope' to domain 'Shapeclasses'.
> - Open map Shapeclasses and check its contents. Close it when you are finished.

The map `Shapeclasses` shows for each pixel whether the slope is convex, straight or concave. However, since nearly every pixel is having a different class, the result is difficult to read. To improve this we could use a majority filter, which will assign the predominant class name of every 5x5 input pixels into an output pixel.

☞
- Filter the map `Shapeclasses` using the `Majority` filter and generate the result map `Shapeclasses_final`.
- Display this map and compare it with the map `Shapeclasses`.
- After that, close all map windows.

Filters used to calculate internal relief

With the help of filters and digital elevation models, it is also possible to calculate internal relief, which is expressed as the maximum elevation change within 1 hectare, or within 1 square kilometer. The filter type that can be used for this is the *rank order filter*. A rank order filter will place all pixel values that occur within the filter window (in a 3x3 filter that would be 9 values) in an increasing order. The user can then select which rank value should be taken. So, in the case of a 3x3 filter, the first rank value would be the minimum of the 9 pixels, the fifth value would be the median and the ninth value would be the maximum.

For calculating internal relief, we would need the minimum and the maximum value within a sufficiently large area (for example within a hectare) and then calculate the difference.

Georeference `Cochabamba` contains the pixel size of the raster maps (including the DEM) of the data set we are using. This pixel size is 20 meters. So in order to calculate the internal relief per hectare (100x100m), we need to use a filter of 5 rows by 5 columns.

☞
- Select raster map `Dem` in the Catalog, press the right mouse button and select Image Processing, Filter. The Filtering dialog box appears.
- Select Raster Map `Dem` and Filter Type `Rank Order`.
- Clear the check box Predefined because we want to use a user-defined filter.
- We want to use a 5x5 filter so enter 5 for the number of Rows and 5 for the number of Columns.
- Enter the value 1 for the Rank. This will give us the minimum value.
- Type `Demmin` for the Output Raster Map, accept all other defaults and click Define.

The map `Demmin`, giving the minimum altitude within each hectare will be calculated later. Now we also need to define a map for the maximum altitude value per hectare.

☞
- Repeat the procedure as described above but with the following exceptions:
  - The Rank should now be 25 (the maximum value of 5x5 pixels).
  - The Output Raster Map name should be: Demmax.

- Click Define. Type the following formula on the Command line of the Main window:
  Internal_relief = Demmax-Demmin ↵
  The Raster Map Definition dialog box is opened.

- Select Domain Value, change the Value Range to 0-1000 (assume a maximum height difference of 1km in 1 hectare), and the Precision to 1.0.

- Type for the Description: Internal relief in meters per hectare and click Show.

- First the maps Demmin and Demmax will be calculated, then map Internal_relief will be calculated, and the Display Options dialog box of the last map will appear.

- Choose Representation Pseudo and click OK. The map is displayed.

- From the File menu in the map window, select Open Pixel Information. The pixel information window is opened.

- Add maps Demmin and Demmax to the pixel information window and check some values by clicking in the map.

- Close the map and the pixel information window when done.

Summary: filters used on Digital Elevation Models.

The following filters are useful to apply on Digital Elevation Models:

- Shadow filter. The shadow filter simulates sun illumination on the surface, with the sun in the northwest. The shaded relief image is merely used for display purposes.

- Gradient filters. With the help of the gradient filters DFDX and DFDY, horizontal and vertical gradients are calculated for each pixel.

- Slope shape filters. With the help of second derivative filters, such as D2FDXDY, you can detect slope differences in both x and y direction, and calculate if the slope is convex, concave or straight.

- Rank order filters. With the help of rank order filters it is also possible to calculate internal relief in a digital elevation model, expressed for example as the maximum elevation change within 1 hectare, or within 1 square kilometer.

10.3 Creating a slope map

In principal, a slope angle or slope percentage can be calculated for each pixel in a raster map, as shown in Figure 10.4.
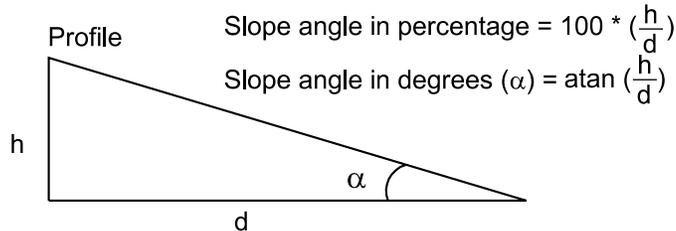

Profile

$$\text{Slope angle in percentage} = 100 * \left(\frac{h}{d}\right)$$

$$\text{Slope angle in degrees } (\alpha) = \text{atan} \left(\frac{h}{d}\right)$$

Figure 10.4: Slope steepness calculation. h is the height difference between two points and d is the distance between them on the map.

In ILWIS, the slope angle or slope percentage can be calculated in X and Y direction using a digital elevation model (DEM), gradient filters (DFDX and DFDY) and a map calculation formula. The following steps have to be done to calculate a slope map:
- Constructing a DEM (see section 10.1).
- Calculating gradient maps in X and Y direction (see section 10.2).
- Calculating the slope angle or slope percentage using map calculation formulas.

In this exercise the gradient maps Dx and Dy (created in the previous section), are used to generate a slope map. The pixel size in these gradient maps is 20 meters and the domain type is value.

☞
- Type the following formula on the Command line of the Main window:
  `Slope_percentage = ((HYP(Dx,Dy))/pixsize(Dem)) *100 ↵`

In this formula HYP (*hypotenuse*) is an internal MapCalc/TabCalc function to calculate the positive root of the sum of square Dx plus square Dy (Pythagoras rule), Dx is the horizontal gradient map, and Dy the vertical gradient map. In this formula, the numerator is divided by the pixel size, using the internal function `pixsize(map)`, since the gradient is expressed in meters difference per pixel and the result should be in meters difference per meter. The value 100 in the formula gives the slope in percentages

☞
- The Raster Map Definition dialog box is opened.
- Type for the Description: `Slope map in percentages` and click Show. The map is calculated and after that the Display Options - Raster Map dialog box is opened.
- Click OK. The map is now displayed.

As you will see, slope values in this map may well rise above 100%. Note: the following slope values are the same: 30° = 58%, 45° = 100%, 60° = 173%, 80° = 567%. Now you will calculate a slope map in degrees.

☞
- Close the map `Slope_percentage`.
- Type the following formula on the `Command line`:
  `Slope_degrees = RADDEG(ATAN((HYP(Dx, Dy))/pixsize(Dem)))`↵

`ATAN` and `RADDEG` are internal MapCalc/TabCalc functions. The `ATAN` function calculates the arctan (tan^{-1}), and returns real values in radians in the range $-\frac{1}{2}\pi$ to $\frac{1}{2}\pi$. The function `RADDEG` is used to convert the radians to degrees.

☞
- The Raster Map Definition dialog box is opened.
- Select a Value Range from 0 to 90 and a Precision of 1.0.
- Click Show. The map is calculated and after that the Display Options – Raster Map dialog box is opened.
- Click OK. The map is now displayed.
- From within the map window, open the pixel information window and add the map `Slope_ percentage` to it. Compare the values and calculate if both maps are correct in respect to each other.
- Close the map and pixel information window when finished.

10.4 Slope direction (aspect)

The slope direction (or slope aspect) can also be calculated by combining gradient maps which result from applying horizontal and vertical filters on a digital elevation model (DEM).

In this exercise, a slope direction map is calculated for the Cochabamba area. The two maps with the horizontal and vertical gradients (`Dx` and `Dy`) have already been created in section 10.3.

☞
- Type the following formula on the `Command` line in the Main window:
  `Aspect = RADDEG(ATAN2(Dx,Dy)+pi) ↵`

`RADDEG` and `ATAN2` are internal MapCalc/TabCalc functions. `ATAN2(y,x)` returns the angle in radians of two input values; `x` is horizontal, `y` is vertical. The function `RADDEG` is used to convert from radians to degrees. The value for `pi` (π) is 3.141592653589.... The map `Dx` is the horizontal gradient map, and `Dy` the vertical gradient map. The formula results in values between 0° and 360°, according to the degrees of the geological compass. For flat areas no slope direction can be calculated. They will obtain an undefined value. In order to be able to display them correctly we need to make a domain `Compass`, for which we will create a special representation later on.

☞
- In the Raster Map Definition dialog box click the Create button next to the drop-down list box of the Domain. The Create Domain dialog box is opened.
- Type the Domain Name: `Compass`.
- Type for the Description: `Compass direction.`
- Enter the Min and Max: `0` and `360`, the Precision: `1.0` and click OK. You are now back in the Raster Map Definition dialog box.
- Click Show to calculate the map.
- In the Display Options - Raster Map dialog box, select Representation `Gray` and click Show. The map will be displayed.

We still need to make a good representation for the map.

☞
- Reopen the map's Display Options dialog box and click the Create representation button. The Create Representation dialog box is opened.
- Type the Representation Name: `Compass`, the Description: `Compass directions` and click OK. The Representation Value editor is now opened, showing the limits `0` in black and `360` in white.

The values 0° and 360° should have the same color (as they represent the same compass direction). Furthermore, you want to see the relief properly (i.e. sun light from the west). We will therefore use the following values and colors (Table 10.2):

Table 10.2: Values and color for representation Compass.

Degrees	Color
360	Gray
270	White
180	Gray
90	Black
0	Gray

☞
- Open the Edit menu and select the Insert Limit command or press the Insert Limit button. The Insert Limit dialog box is opened.
- Insert the limits and edit the colors according to Table 10.2.
- Select from the Edit menu the command Stretch Steps. The Stretch Steps dialog box appears.
- Enter 25 for the number of Stretch Steps and click OK.

Now the representation is ready. It goes from white for western aspects to gray for northern and southern aspects to black for eastern aspects.

☞
- Close the Representation Value editor.
- Representation Compass is now selected in the Display Options dialog box of the map. Click OK. The map is displayed.
- Add the segment map Drainage and/or Contour to the map window. Display the segments in a single color (e.g. Blue or SandyBrown).
- Check the slope directions by clicking on the pixels and close the map window afterwards.

It is also possible with the Slicing operation to classify the aspect map. The procedure how to do this is clearly described in the ILWIS Help topic "How to calculate an aspect map".

10.5 Display 3D

A Digital Elevation Model (DEM) can be visualized in 3 dimensions using a georeference 3D. The DEM or perspective view will initially appear as a line grid. It is possible to superimpose on this DEM/perspective view any map (satellite images, thematic maps) with the same coordinate system. The initial 3D grid lines of the georeference 3D have to be edited so that the user can specify the view parameters (altitude, rotation, distance, vertical exaggeration, etc.). This defines the perspective of the observer in relation to the 3D model.

In the following exercise the Digital Elevation Model Dem created in section 10.1 is displayed as a three dimensional view. A line grid in X and Y directions will be displayed. By modifying the view parameters you can adapt the grid so that the 3D model meets your requirements.

☞
- Double-click the Display 3D operation in the Operation-list. The Display 3D dialog box is opened.
- In the Display 3D dialog box, click the Create button next to the GeoReference drop-down list box. The Create GeoReference dialog box is opened.
- Type Dem3D in the text box GeoReference Name.
- Type 3D view, Cochabamba in the text box Description.
- Select raster map Dem in the list box DTM, accept the number of Rows, Columns, and click OK. Now you are back in the Display 3D dialog box.
- Click OK. The Display Options - 3D Grid dialog box is opened.
- Accept the defaults and click OK.

The 3-D view is now displayed with default values. These default view parameters can be modified by *editing* the *georeference 3D*.

☞
- From the Edit menu, select the command GeoReference. The GeoReference 3D editor is opened.
- Maximize the window so that the whole 3D view (grid lines) and all parameters in the 3D View Parameter pane are visible.

By changing the values in this editor you can change the view direction, altitude, etc. This is explained in Figures 10.5 and 10.6.

You can imagine a 3D view as the view that you would have from an area when you are in a helicopter, which is at a fixed position. This position is called the *view point*. The view point is at a certain height (i.e. *view height)* in meters and at a certain X and Y coordinate in the map. From the view point you are looking at the study area. The point in the center of your study area is called the *focal point*, which also has a

certain X and Y coordinate. You can draw an imaginary line between the focal point and the view point, which is called the *view axis* (see Figure 10.5).
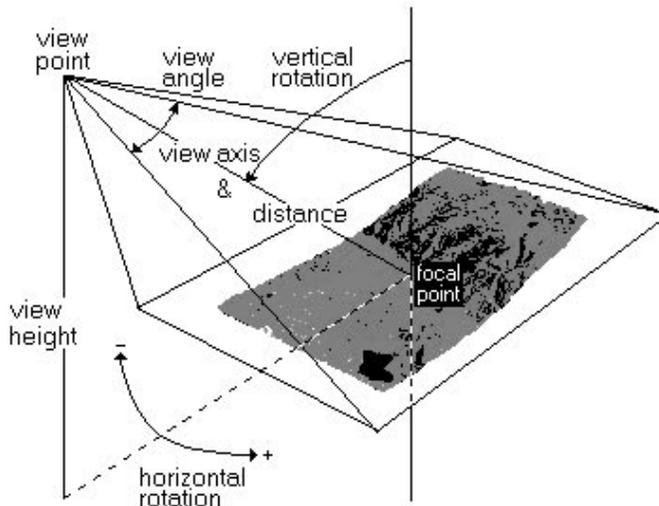

Figure 10.5: The parameters used to define a 3D view. The *view point* is the point from which you look, and the *focal point* is the center of the area to which you look. The view point is at a certain height *(view height)*, and at a certain *horizontal rotation* with respect to the N-S line. The line between the view point and the focal point is called the *view axis* and has a certain *distance* and a certain angle with respect to a vertical line through the focal point *(vertical rotation)*.

The focal point is at a certain *distance* from the view point. This distance is the real distance between the view point and the focal point.

The viewing axis also has a certain horizontal rotation with respect to a line in N-S direction. This is called the *horizontal rotation (angle)*. The horizontal rotation angle is taken as a negative value when the viewing axis is rotated in western direction and positive when rotated in eastern direction. For example: when you are looking from the SW, the horizontal angle is -45°, and when you are looking from the NE, the horizontal angle is +135°.

The viewing axis also makes an angle with respect to a vertical line. This is called the *vertical rotation (angle)*. The vertical rotation angle is 0° when you are exactly above the focal point, and it is 90° when your helicopter is at the same level as the focal point (i.e. as if you were standing on the ground at a certain distance).

The *viewing angle* is defining the opening angle with which you are looking to the focal point. You can imagine it as a cone, with the viewing axis as the center, starting at the view point. When the viewing angle is 180° degrees, it is as if you are looking at the terrain with a fish eye lens.

The last parameter to explain is the *scale height*. With the scale height, you can exaggerate the height differences in Z (as compared to X and Y).
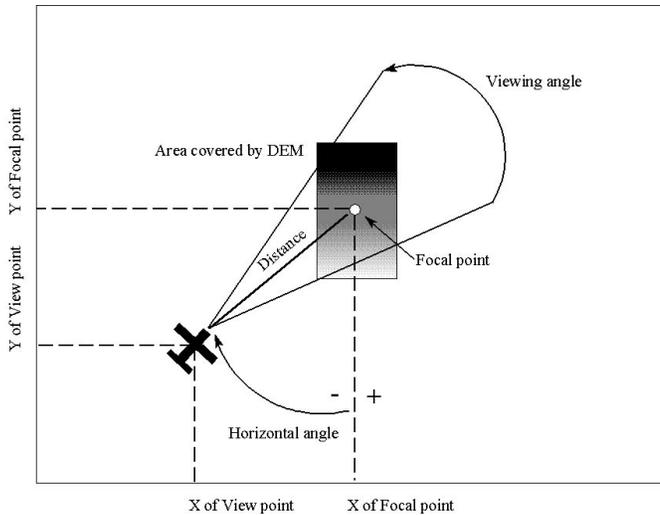
Figure 10.6: Parameters used to define the 3D view. The *coordinates* of the view point and the focal point can be entered, as well as the *distance* between the two (real distance). The horizontal rotation angle is the angle between the line connecting the focal point and the view point with respect to a N-S oriented line. The viewing angle is the angle with which you look to the focal point (it is the sum of the two angles at both sides of the view axis which connects the view point and the focal point).

In the following exercise you will learn how to work with the different parameters, in order to get an optimal 3D view. The first impression is that it is quite complicated to enter so many parameters manually. However, many of these are interrelated, and there are a few which are crucial: Horizontal Rotation, Vertical Rotation, Distance, Viewing Angle and Scale Height.

First, we will adapt the 3D view to simulate that you are looking from the south to the terrain and from a position close to the ground surface (high vertical rotation).

☞
- In the GeoReference 3D Parameter pane, change the Horizontal Rotation to 0 and the Vertical Rotation to 82, and press Enter.
- Accept all other defaults and press the Redraw button 🖵 in the map window.

For your information, the Focal Point is located approximately at (801850, 8081200), the Distance to the Focal Point is approximately 20400 m and the View Point Height is approximately 5700 m. The values above are just an indication. You will probably not get exactly the same values yourself.

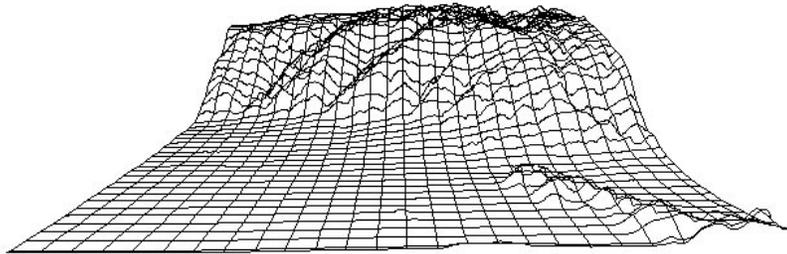The 3D view should now be similar to the one shown in Figure 10.7.

Figure 10.7: A 3D view from the south with a high vertical rotation.

To evaluate the effect of using a higher view point (i.e. a smaller vertical angle), you will now change the 3D view again.

☞
- Change the Vertical Rotation to 40, and press Enter. Note that the View Point and the View Point Height change automatically.

The view should now be similar to the one shown in Figure 10.8. Note that you now see a larger part of the area but less height differences.
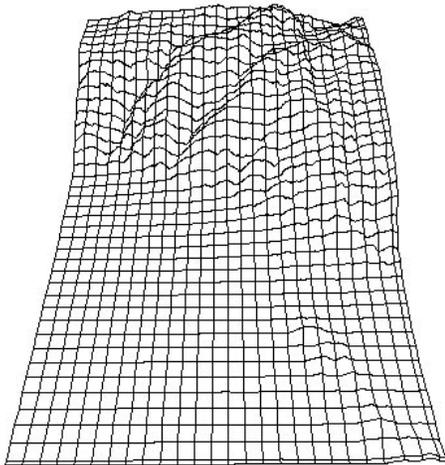

Figure 10.8: A 3D view showing the effect of a smaller vertical rotation.

Now you will see the effect of changing the horizontal rotation. We will change the vertical rotation back to the original value.

☞
- Change the Vertical Rotation to 82.
- Change the Horizontal Rotation to 30. This means you are now looking from the south-southeast towards the north-northwest.
- Click the Redraw button, or press Enter.

The view should now be similar to the one shown in Figure 10.9. Note that the 3D view is now rotated.
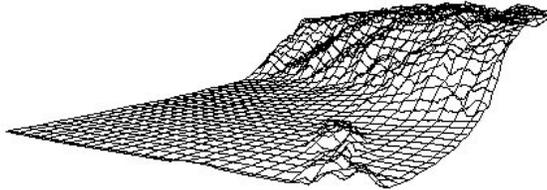

Figure 10.9: A 3D view from the south-southeast (30° rotation from the south).

The next parameter that we will change is the Viewing Angle. Decreasing the viewing angle is similar to zooming in with a camera. You will see a smaller area, but in more detail.

☞ | • Change the Viewing Angle to 60 and press Enter.

The view should now be similar to the one shown in Figure 10.10. Note that you will see a smaller area than before.
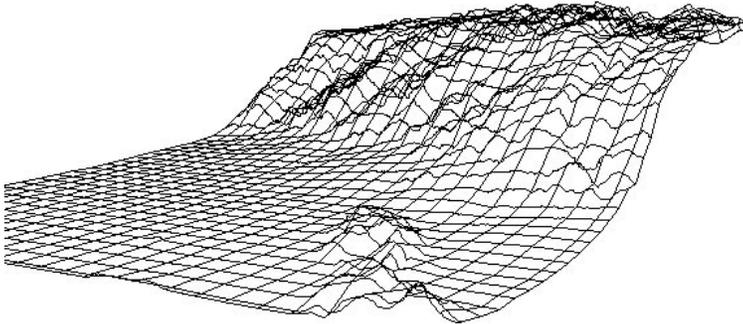

Figure 10.10: A 3D view showing the effect of a larger viewing angle.

Finally, you will look how you can change the position of the focal point. The focal point is always in the exact center of the 3D view in the window. It is the point to which you are looking and this point will be displayed at the center of the window. You could change the focal point location by typing the coordinates, but this is rather tedious. There are much faster methods to change the focal point location and the other interrelated parameters. You can also set the focal point interactively by clicking in the grid line window.

☞ | • Open the Edit menu and select the Focal Point command and click with the mouse pointer somewhere in the grid line map (e.g. near the small mountains at the foreground) to set the new focal point.

Now we will use the small DEM window which appears above the 3D view parameters. This window can be used to interactively specify the View Point and the Focal Point by drawing a line.

☞
- First, click the Extend Boundaries button. The Extend Window by Percentage dialog box appears.
- In the Extend Window by Percentage dialog box extend all four sides of the window with 50%.
- Now, click the Set View Point button.
- Click somewhere in the white space in the small DEM window, e.g. somewhere at the bottom left; keep the left mouse button down and move the pointer to the center of the map; then release the mouse button. The 3D view will change immediately.
- If you like, adapt the Viewing Angle to a somewhat larger value, e.g. 95.
- Practice some more until the grid lines nicely fill the area of the georeference 3D window.

Selecting the best parameters for defining a 3D view seems quite difficult when you are doing it for the first time. However, if you practice some more with the editor, you will see that a number of parameters are interrelated.

When you have finished editing the parameters of the GeoReference 3D, you can leave the editor by pressing the Exit Editor button ➡ on the Toolbar in the GeoReference 3D editor.

☞
- Click the Exit Editor button in the Toolbar of the GeoReference 3D editor or open the File menu and choose Exit Editor.

3D view with raster draping

In the previous exercise you have created and edited a 3D view using only grid lines for the 3D display. It is also possible to drape a raster map on top of the 3D view. In this exercise you will create a 3D view using a hillshading map.

☞
- Double-click georeference Dem3D in the Layer Management pane or click the right mouse button in the window and select Display Options. The Display Options - 3D Grid dialog box appears.
- Clear the check box Grid, select the check box Raster Drape and select raster map Shadows from the drop-down list box.
- Click OK. The Shadows map is now draped over the 3D view.

As you can see the display is still rather course. This is because you accepted the default pixel size of 3. With the pixel steps, you can define the number of rows and

columns from the raster map that should be used to drape the raster map over the 3D model. The best result is obtained by selecting a pixel step of 1. This will, however, lead to a much slower display. Therefore, use larger pixel steps to edit the initial 3D view, and use a pixel step of 1 for the final view.

☞
- In the Layer Management pane double-click Dem3D. The Display Options - 3D Grid dialog box appears.
- Change the Pixel steps to 1 and click OK. The 3D view is redisplayed slowly, but more accurately.
- In the map window, press the right mouse button and select Display Options. The Display Options – 3D Grid dialog box appears.
- In the Display Options – 3D Grid dialog box, select the Grid check box, change the Grid Distance to 1000 m and click OK.
- Close the map window when you have seen the result.

Once you finished creating and editing the georeference 3D, you can display any existing raster map as a 3D view by using the Display 3D operation.

☞
- Double-click the Display 3D operation in the Operation-list. The Display 3D dialog box is opened.
- In the Display 3D dialog box, select Dem3D1 from the GeoReference drop-down list box and click OK. The Display Options - 3D Grid dialog box is opened.
- Clear the Grid check box, select the check box Raster Drape and select raster map Landuse.
- Accept the default Representation and click OK. The Landuse map is now draped over the 3D view.

The result of this exercise can be saved as a map view.

☞
- In the map window open the File menu and select the Save View command. The Save View As dialog box appears.
- In the Save View As dialog box type 3Dmapview for the Map View Name and click OK. The map is saved as a map view.

Adding vector layers to a 3D view

One of the major advantages of the 3D views in ILWIS is that they remain georeferenced, so that you can display other data layers on top. You can also use the pixel information window to retrieve information of raster and vector maps, combined with attribute tables, while moving the mouse pointer through the 3-D view.

☞
- Drag-and-drop polygon map `Cityblock` to the map window in which the 3D view `3Dmapview` is displayed. The Display Options -Polygon Map dialog box is opened.

- Change the Boundary Width to `0`. In this way only the polygons are shown in color, without boundary lines.

- Change the amount of Multiple Colors to `31` and click OK. The polygon map is drawn in the perspective view.

- Also add segment map `Drainage` to the map window.

- Zoom in if you like and save the result as a map view.

It is also possible to use the pixel information window in combination with a 3D view.

☞
- In the map window, open the File menu and select the Open Pixel Information command. The pixel information window is opened. You may have to add raster map `Landuse` yourself to the pixel info window.

- Move with the mouse pointer to one of the city blocks displayed in the 3D view, and read the information from the pixel information window.

- Close the map window and the pixel information window.

To obtain a new raster map in 3D, you can use the Apply 3D operation.

☞
- Double-click the operation Apply 3D in the Operation-list. The Apply 3D dialog box is opened.

- Select Raster Map `Landuse`, GeoReference `Dem3D1` and type for the Output Raster Map name `3DLanduse`.

- Click Show. The new map is now created. This will take a while.

- After that the Display Options - Raster Map dialog box is opened. Click OK to display the 3D view and close it after you have seen the result.

The resolution of the output raster map may be rather course. The resolution is determined by the size of your georeference 3D (default 300 lines x 400 columns) when the georeference 3D was created, and how well you made the initial 3D grid lines fit into this when you edited the georeference 3D.

Summary: 3D-display

- A Digital Elevation Model (DEM) can be visualized in three dimensions by creating and editing a Georeference 3D.

- A georeference 3D can be created with the Display 3D operation.

- Once the initial georeference 3D is displayed, you have to edit the georeference and make the 3D view according to your wishes. This can be done in the Georeference 3D editor. The user can specify the view parameters (altitude, rotation, distance, vertical exaggeration, etc.) to define the perspective of the observer in relation to the 3D model.

- A georeference 3D or 3D view can be displayed as grid lines but you may also use a raster drape (i.e. any satellite image or thematic map). When you use a raster drape, the raster map should use a georeference that has the same coordinate system as the georeference of the 3D view.

- Once you finished editing the georeference 3D, you can display any raster map in 3D by using the Display 3D operation and optionally combine this with one or more vector layers. The results can be stored as a map view.

- To produce an output raster map in 3D, you can use the Apply 3D operation. On the output, you can overlay again any vector map(s), and the result can be stored as a map view.

- The main advantage of the 3D views as obtained from either Display 3D or Apply 3D is thus that the 3D maps remain georeferenced. You can thus display other vector layers on top of the 3D views, and you may use pixel information to retrieve information of raster and vector maps, combined with attribute tables, while moving the mouse pointer through the 3D view.

10.6 Creating cross-sections from a DEM

In this last exercise, dealing with the use of Digital Elevation Models, a simple method is presented to generate altitude information from a DEM along profiles. The profiles are segments, which can be digitized with the mouse or the digitizer. The objective is to display in a graph the distance from the starting point of the profile along the X-axis and the altitude along the Y-axis.

In order to do so we have to make the following steps:
- Digitize a line along which you want to create a cross-section.
- Use the operation Segment to Points, to convert the digitized line to regularly spaced points.
- Open the point map as a table, and calculate the column Distance, which is the distance from the starting point of the profile.
- Read the values of the altitude from the DEM for the coordinates specified in the table.
- Plot the distance against the altitude in a graph.

For this exercise you will use a predefined segment map Profile. If you want digitize profiles yourself, you should make sure that each profile consists of one single segment, with a unique code. It is possible to have several profiles in the same file, but then they should be coded differently (e.g. Profile1, Profile2, etc.). For the conversion from segments to points, only one segment should be present in the file. If you have more profiles, the process should be done for each profile individually and the conversion from segment to point should be preceded by the Mask Segments operation, which you use to copy one single profile segment into another file.

☞
- Click with the right mouse on the segment map Profile, and select Vectorize, Segment to Point from the context-sensitive menu. The Segments to Points dialog box is opened.

- Select the option button Distance and enter 50 for the Distance. This means that along the segment, points will be stored at every 50 meters.

- Type for the Output Point Map Profile and click Show. A point map is made containing points at every 50 meters along the profile line. The Display Options - Point Map dialog box is opened.

- Click OK to display the point map.

- Zoom in on a section to verify that the map contains individual points.

- Close the point map.

Now that the point map is generated, we can open it as a table, and read the altitude values from the DEM for each point.

☞
> - Click with the right mouse on the point map Profile, and select the command Open as Table from the context-sensitive menu. The point map is now shown as a table with two columns: Coordinate and Name.
> - Open the View menu in the table window and select the Command Line. The table window should now give you a Command line.
> - Type the following formula on the Command line of the table window:
>   Distance =(%R-1) * 50 ↵
> - Click OK in the Column Properties dialog box.

The objective of this formula is to use the record indexes (the values shown in the left gray column). The predefined variable %R refers to these record indexes. The formula results in distances in meters from the start of the profile.

Now we will read for all the points, the values of the Digital Elevation Model, from the pixels with the same coordinates as shown in the table. This can be done with the MapValue function.

☞
> - Type the following formula on the Command line of the table window:
>   Altitude = MapValue(Dem,Coordinate) ↵
> - Click OK in the Column Properties dialog box.

Now we have the distance as well as the altitude, and the profile can be drawn.

☞
> - From the Graph menu, select the command New Graph Window or press the New Graph Window button in the Toolbar of the table window. The Graph dialog box is opened.
> - In the Graph dialog box select the column Distance for the X-column and the column Altitude for the Y-column and click OK. The Graph Options sheet is opened.
> - Accept the default settings and click OK. The profile is now shown.
> - If you like, you can adapt the descriptions for the X and Y-axis in the Graph Options sheet; on the X-axis tab and the Y-axis (left) tab. On the X-axis tab, you can also rotate the values along the X-axis (e.g. 90°).
> - Close the graph and the table window.

In the previous exercise vector data (a segment map) is used to create a cross-section through the terrain. It is also possible to use raster data as basis for the selection and creation of a cross section e.g. using a particular line or column from a raster map. How to do this is clearly described in the ILWIS Help topic How to calculate a cross-section through the terrain (Advanced).