

6.5 Multi-band operations

To enhance or extract features from satellite images which cannot be clearly detected in a single band, you can use the spectral information of the object recorded in multiple bands. These images may be separate spectral bands from a single multi spectral data set, or they may be individual bands from data sets that have been recorded at different dates or using different sensors.

The operations of addition, subtraction, multiplication and division, are performed on two or more co-registered images (see previous exercise on image to image registration) of the same geographical area. This section deals with multi-band operations. The following operations will be treated:

- The use of ratio images to reduce *topographic effects*.
- *Vegetation indexes*, some of which are more complex than ratio's only.
- *Multi-band statistics*.
- *Principal components analysis*.
- *Image algebra*, and;
- *Image fusion*.

6.5.1 Image ratios: Brightness variations

When a satellite passes over an area with relief, it records both shaded and sunlit areas. These variations in scene illumination conditions are illustrated in figure 6.14. A red silt stone bed shows outcrops on both the sunlit and the shadowed side of a ridge. The observed DN's are substantially lower on the shaded side compared to the sunlit areas. This makes it difficult to follow the silt stone bed around the ridge.

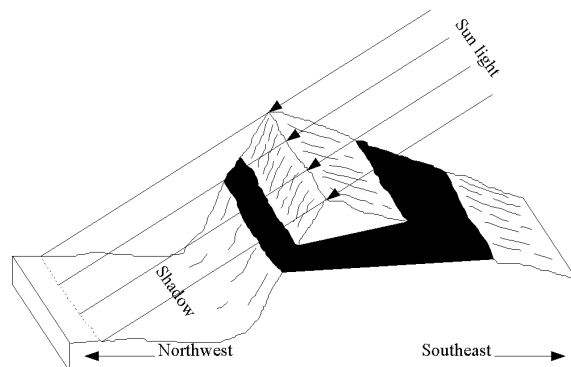


Figure 6.14: Shadow effects

In the individual Landsat-TM bands 3 and 4, the DN values of the silt stone are lower in the shaded than in the sunlit areas. However, the ratio values are nearly identical, irrespective of illumination conditions. Hence, a ratioed image of the scene effectively compensates for the brightness variation, caused by the differences in the topography and emphasizes by the color content of the data (table 6.10).

Table 6.10: Differences in DN values of selected bands and the ratio values

	TM Band 3	TM Band 4	Ratio: Band3/Band4
Sunlit slope	94	42	2.24
Shaded slope	76	34	2.23

In this section, ratioed images are created in order to minimize the effects of differences in illumination. To show the effect of band ratios for suppressing topographic effects on illumination, Landsat TM bands 4 and 5 are used. The northern part of the image displays mountainous areas, where variation in illumination due to the effect of topography are obvious.



- Display the images Tmb4 and Tmb5.
- Visually inspect the two displayed bands on the effect of illumination conditions. Use the mouse to view the DN values in the mountain areas.

The creation of the ratio of the two bands is done with the Map calculator. In chapters 7 to 9 the various functions of the Map Calculator will be treated in detail.



- Double-click the MapCalc item in the Operations-list. The Map Calculation dialog box is opened.
- Under Expression type the following map calculation formula: $Tmb5 / Tmb4$
- Enter Shadow for Output Raster map, select as domain Value and click on the Default button. Select the option Show. Click OK. The map Shadow is calculated, and the Display Options dialog box is opened. Accept the defaults and click OK.
- Zoom in on a sunlit-shaded part of the image.
- Open the pixel information window. Drag-and-drop raster maps Tmb4, Tmb5 and Shadow.
- Evaluate the effect of shadow suppression by means of this band ratio. Select pixels on the sunlit and the shadow side of a water divide.
- Close the map windows and the pixel information window.

6.5.2 Normalized Difference Vegetation Index

Ratio images are often useful for discriminating subtle differences in spectral variations, in a scene that is masked by brightness variations. Different band ratios are possible given the number of spectral bands of the satellite image. The utility of any given spectral ratio, depends upon the particular reflectance characteristics of the features involved and the application at hand. For example a near-infrared / red ratio image might be useful for differentiating between areas of stressed and non stressed vegetation.

Various mathematical combinations of satellite bands, have been found to be sensitive indicators of the presence and condition of green vegetation. These band combinations are thus referred to as vegetation indices. Two such indices are the simple *vegetation index* (VI) and the *normalized difference vegetation index* (NDVI). Both are based on the reflectance properties of vegetated areas as compared to clouds, water and snow on the one hand, and rocks and bare soil on the other. Vegetated areas have a relatively high reflection in the near-infrared and a low reflection in the visible range of the spectrum. Clouds, water and snow have larger visual than near-infrared reflectance. Rock and bare soil have similar reflectance in both spectral regions. The effect of calculating VI or the NDVI is clearly demonstrated in table 6.11.

Table 6.11: Reflectance versus ratio values

	TM Band 3	TM Band 4	VI	NDVI
Green vegetation	21	142	121	0.74
Water	21	12	-9	-0.27
Bare soil	123	125	2	0.01

It is clearly shown that the discrimination between the 3 land cover types is greatly enhanced by the creation of a vegetation index. Green vegetation yields high values for the index. In contrast, water yield negative values and bare soil gives indices near zero. The NDVI, as a normalized index, is preferred over the VI because the NDVI is also compensating changes in illumination conditions, surface slopes and aspect. To create a Normalized Difference Vegetation Index map, Landsat TM imagery of Cochabamba, Bolivia, is used. The following bands are used: Tmb3 and Tmb4. The creation of the NDVI is done with the map calculator.



- Double-click the MapCalc item in the Operations-list. The Map Calculation dialog box is opened.
- Under Expression type the following map calculation formula:

$$(Tmb4 - Tmb3) / (Tmb4 + Tmb3)$$
- Enter NDVI for Output Raster map, select as domain Value and change the Value Range to -1 and +1, and the Precision to 0.01.

- Select the option **Show**. Click **OK**. The map NDVI is calculated and the Display Options dialog box is opened.
- In the Display Options dialog box select **Pseudo** as representation. In this representation the colors range from blue (for the low DN's) through green (for the medium DN's) to red (for the high DN's). Click **OK**. The map NDVI is displayed.
- Open the pixel information window and add the maps Tmb3, Tmb4 and NDVI to it.
- Move through the image with the mouse pointer and study the DN values of the input maps and how they are combined in the Normalized Difference Vegetation Index.
- Calculate also a NDVI image using the images of the Flevo Polder, The Netherlands. As these are SPOT images, select the appropriate bands. Repeat the procedure as described above. Before you create the NDVI image, first make sure that all three bands (Spotb1, Spotb2 and Spotb3) are georeferenced (link them to georeference Flevo3, see exercise 6.4.2).
- Close all open windows and the pixel information window.

! You can also use the NDVI function in MapCalc:
NDVI_{map} := NDVI (Tm4 , Tm3)
See also chapter 12.

6.5.3 Multi-band statistics

The distribution of data values in a single band could be represented graphically using a histogram and mathematically by the variance statistics, which summarizes the differences between all the pixel values and the mean value of the channel (the range of data values in a channel is an indication of channel variability, it does not indicate the way the values are distributed between the minimum and maximum values). The correlation between two (or more) channels can be shown graphically by a scatter plot and mathematically by the covariance statistics. A scatter plot is a two dimensional graph, with on the horizontal axis the values of one channel, and on the vertical axis the values of the second channel. The points in the graph indicate the data or pixel values. The values in a covariance matrix indicate also the correlation: Large negative values indicate a strong negative correlation, large positive values show a clear positive relation and covariance values near to zero indicate a weak or no correlation.

In figure 6.15 an example is given using scatter plots showing a strong positive covariance (a) and zero covariance (b).

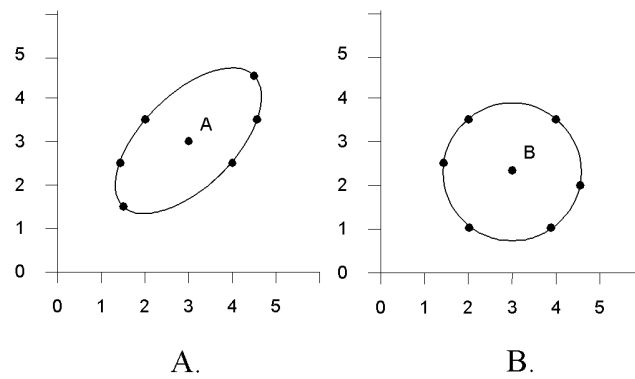


Figure 6.15: Scatter plots showing a strong positive covariance (a) and zero covariance (b). Mean: 3.0, 3.0 (a) and 3.0, 2.3 (b)

Looking at the scatter plot, one could say in other words, that the covariance values indicate the degree of scatter or shape of the spectral cluster and the major direction(s). From figure A, an ellipse like clustering can be deduced, indicating a strong positive correlation (an increase in a value in one channel relates to an increase in a value of the other channel) and figure B shows a circle shaped cluster having zero correlation.

The individual bands of a multi-spectral image are often highly correlated, which implies that there is a redundancy in the data and information is being repeated. To evaluate the degree of correlation between the individual bands a correlation matrix can be used. This matrix (a normalized form of the covariance matrix) has values in the range of -1 to 1, representing a strong negative correlation to a strong positive correlation respectively, where values close to zero represent little correlation. Using the correlation coefficients of the matrix, bands can be selected showing the least correlation and therefore the largest amount of image variation/information to be included in a multi-band composite.

In this exercise variance/covariance and correlation matrices are calculated for Landsat TM, including all bands.



- Double-click the Correlation Matrix item (CorrMat) in the Operations-list.

The Correlation Matrix dialog box is opened and gives the option to select or create a Map List. The Map List to be created consists of all the TM bands.



- Click the **Create** button next to the **Maplist** option.
- Type **Tma11** in the list box **Maplist name**.
- Press the **Ctrl Key** and select the images **Tmb1**, **Tmb2**, **Tmb3**, **Tmb4**, **Tmb5**, **Tmb6** and **Tmb7**. Click **OK**.
- Click **OK** in the **Show Correlation matrix** dialog box.

The correlation, mean and standard deviation for these three bands are calculated and presented in the **Matrix** dialog box. Study the correlation matrix and answer the following questions:

1. Which band(s) in general show the least correlation and why?
2. Are the visible and the infra red bands highly correlated?
3. Select a band combination using three bands, showing most of the information or in other words, those bands having the least correlation.



- Display the three band with the least correlation and combine them by constructing a color composite.
- Close all the dialog boxes and map windows when you finish the exercise.

6.5.4 Principal components analysis

Another method, called principal components analysis (PCA), can be applied to compact the redundant data into fewer layers. Principal component analysis can be used to transform a set of image bands, as that the new layers (also called components) are not correlated with one another. Because of this, each component carries new information. The components are ordered in terms of the amount of variance explained, the first two or three components will carry most of the real information of the original data set, while the later components describe only the minor variations (sometimes only noise). Therefore, only by keeping the first few components most of the information is kept. These components can be used to generate an RGB color composite, in which component 1 is displayed in red, component 2 and 3 in green and blue respectively. Such an image contains more information than any combination of the three original spectral bands.

To perform PCA, the axis of the spectral space are rotated, the new axis are parallel to the axis of the ellipse (figure 6.16). The length and the direction of the widest transect of the ellipse are calculated. The transect which corresponds to the major (longest) axis of the ellipse, is called the first principal component of the data. The direction of the first principal component is the first eigenvector, and the variance is given by the first eigenvalue. A new axis of the spectral space is defined by the

first principal component. The points in the scatter plot are now given new coordinates, which correspond to this new axis. Since in spectral space, the coordinates of the points are the pixel values, new pixel values are derived and stored in the newly created first principal component.

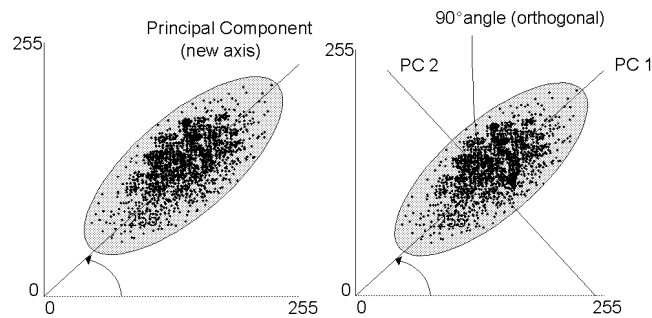


Figure 6.16: First (left) and second (right) principal components

The second principal component is the widest transect of the ellipse that is orthogonal (perpendicular) to the first principal component. As such, PC2 describes the largest amount of variance that has not yet been described by PC1. In a two dimensional space, PC2 corresponds to the minor axis of the ellipse. In n-dimensions there are n principal components and each new component is consisting of the widest transect which is orthogonal to the previous components.

Figure 6.17 shows graphically the result of a PC transform in which the data are presented without correlation.

Through this type of image transform the relationship with raw image data is lost. The basis is the covariance matrix from which the eigenvectors and eigenvalues are mathematically derived. It should be noted that the covariance values computed are strongly depending on the actual data set or subset used.

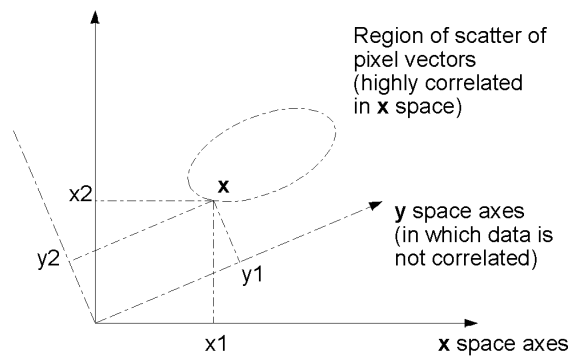


Figure 6.17: Result of a PC transform

In this exercise, a principal components analysis is done using seven TM images in the data set Tmb1, Tmb2, Tmb3, Tmb4, Tmb5, Tmb6 and Tmb7.



- Double-click the Principal Components operation (PrincCmp) in the Operations-list.

The Principal Components dialog box is opened. In this dialog box you can select or create a map list.



- Select the Map List Tma11 (which you created in the previous exercise). It consists of the seven TM bands: Tmb1, Tmb2, Tmb3, Tmb4, Tmb5, Tmb6 and Tmb7.
- Type Tmpc in the text box Output Matrix.
- Click check box Show.
- Click OK.

The Matrix dialog box is opened. The principal component coefficients and the variance for each band can be viewed in this table. Since the number of principal components equals the number of input bands, seven new images named Tmpc1 to Tmpc7 are also created. These output images have a domain type value as default. Write down the eigenvalues of the principal components in table 6.12.

Table 6.12: Eigenvalues

	Tmb1	Tmb2	Tmb3	Tmb4	Tmb5	Tmb6	Tmb7
TmPC1							
TmPC2							
TmPC3							
TmPC4							
TmPC5							
TmPC6							
TmPC7							

All TM bands have a positive eigenvalue in principal component 1, therefore this PC mainly explains the intensity difference of the input bands.

Explain the contribution of the TM bands in principal components 2 and 3?

Note in the table below (table 6.13) the variance explained per component.

Table 6.13: Variance explained

PC	Variance %
TmPC1	
TmPC2	
TmPC3	
TmPC4	
TmPC5	
TmPC6	
TmPC7	

Now you can calculate Principal Component 1 using a Map Calculation formula.



- By opening the Properties of the map Tmpc1 you can check the expression:

$$\text{Tmpc1} := \text{Tmb1} * 0.27 + \text{Tmb2} * 0.19 + \text{Tmb3} * 0.33 + \text{Tmb4} * 0.3 + \text{Tmb5} * 0.72 + \text{Tmb6} * 0.21 + \text{Tmb7} * 0.37$$
- Double-click raster map Tmpc1 in the Catalog for the calculation of the first principal component.
- In the Display Options dialog box select Gray as representation. Keep in mind the % of variance that is explained in this single image.
- Open image Tmpc2 and use again the Gray representation. Open the Edit menu in the map window and choose Properties, select map Tmpc2 and check the expression.

Compare the values in the expression with the eigenvalues noted in the table above. Check whether your answer given to the question: “*Explain the contribution of the TM bands in principal components 2 and 3 ?*” is correct?



- Repeat the procedure to display `Tmpc3`.

A color composite can be created of the images produced by the principal components analysis. To create such a color composite, the domain type of the images should be changed from `Value` to `Image`.



- Stretch image `Tmpc1` as described in the exercise on linear stretching, accept the default domain `Image`, name the output image `Pc1`.
- Repeat these steps for image `Tmpc2` and `Tmpc3` and name the output images `Pc2` and `Pc3` respectively.
- Create a color composite named `Tmpcc` using images `Pc1`, `Pc2` and `Pc3` for the red, green and blue bands respectively and display the image.
- Compare this color composite map with map `Tmcc432`; the color composite created in the exercise 6.3.
- Close the map windows when you have finished the exercise.

6.5.5 Image arithmetics

Below, some examples of common used arithmetic operations are included. Images recording the microwave portion of the electromagnetic spectrum are used. The `Ers1` and `Ers2` images are also from the Flevo Polder, The Netherlands.



- Display raster maps `Ers1` and `Ers2`, using the default display options. Position the map windows next to each other. Check the values of these two images, and compare them. Close the map windows again.
- Link both maps to the georeference `Flevo4` (by changing the properties of the maps).
- Type the following Map calculation formula on the command line of the Main window:

```
Ersavg:=(Ers1+Ers2)/2 ↵
```

- Accept the defaults in the Raster map definition dialog box and click OK.
- Double-click raster map `Ersavg`. In the Display Options dialog box select the representation `Gray` and click OK. The map is displayed.
- Use the pixel information window to check the result. Add maps `Ers1`, `Ers2` and `Ersavg`. Move the cursor over some of the pixels.

Explain what the effect is of the formula $Ersavg := (Ers1 + Ers2) / 2$?



- Type the following Map calculation formula on the command line of the Main window:
`Ersdiff := Ers1 - Ers2 ↵`
- Accept the defaults in the Raster map definition dialog box and click OK.
- Double-click raster map `Ersdiff`. In the Display Options dialog box select the representation `Gray` and click OK. The map is displayed.
- Use the pixel information window to check the result. Add maps `Ers1`, `Ers2` and `Ersavg`. Move the cursor over some of the pixels.

Describe the effect of this operation?



- Close the map windows and the pixel information window when you have finished the exercise.

6.5.6 Image fusion

Image fusion is the process of combining digital images, by modifying the data values, using a certain procedure. Before starting the fusion process the data should be properly co-registered. Combining for example both optical and microwave data, through image fusion techniques, results in a new data set. One of the fusion techniques has already been described: principal component transform. Another commonly used technique is the red-green-blue transform into intensity-hue-saturation, the intensity component is commonly replaced with another image and the modified data set is transformed back into the three primary colors. This technique is used to integrate for example a radar or panchromatic image with a multi spectral data set.

This exercise makes use of the intensity component of the data sets used. Landsat TM bands 3,4 and 5 and IRS 1C Panchromatic are used of Dhaka City, the capital of Bangladesh. Both images represent the beginning of 1996, the dry season. Landsat TM has a spatial resolution of 30 meters but is resampled to a 10 meter resolution. The IRS 1C image, with an original resolution of 5.8 meter is also resampled to 10 meters. Both images have the same georeference.



- Display raster maps `Irs1C` and `Btm3`, using the default display options. Position the map windows next to each other. Check the values of these two images, and compare them.

What can be concluded looking at the spatial resolution?

As the images have the same georeference, the fusion can be achieved through a combined display of the two data sets in the form of a color composite.



- Double-click the **ColorComp** item from the Operations-list. The **Color Composite** dialog box is opened. Clear the option 24 bit. Select for **Red band**: `Irs1C`, for **Green band**: `Btm3`, and for **Blue band**: `Btm4`. Type `Irstm34` as **Output Raster map name**. Select **Show** and accept the other defaults. Click **OK**.
- Click **OK** in the **Display Options** dialog box. The map is displayed. Check the result and close the map window.

In the next step, the data sets are fused by means of a replacement of the combined intensity of the three TM bands, by the intensity of the panchromatic image. This results in a sharpening of the image due to the higher spatial resolution of the panchromatic image. The results are again displayed as a color composite.



- To calculate the combined intensity, type the following Map Calculation formula on the command line of the Main window:
$$\text{Int} := (\text{Btm3} + \text{Btm4} + \text{Btm5}) / 3 \quad \downarrow$$
- Make sure the domain **Image** is selected in the **Raster map definition** dialog box and click **OK**.
- For the intensity replacement, enter the expressions given below and accept the defaults in the **Raster Map Definition** dialog boxes.

$$It1 := Btm3 / Int * Irs1c \downarrow$$

$$It2 := Btm4 / Int * Irs1c \downarrow$$

$$It3 := Btm5 / Int * Irs1c \downarrow$$

- Stretch, using a linear stretch, the images $It1$, $It2$ and $It3$, select the **Image** domain and use other defaults. Name the output images $It1s$, $It2s$ and $It3s$.
- Double-click the **ColorComp** item from the Operations-list. The **Color Composite** dialog box is opened. Select for **Red band**: $It1s$, for **Green band**: $It2s$, and for **Blue band**: $It3s$. Type $Its123$ as **Output Raster map name**. Select **Dynamic**, 200 colors. Select **Show** and accept the other defaults. Click **OK**.
- Click **OK** in the **Display Options** dialog box.

What can be concluded if this fused image is compared to the image created in the previous exercise?



- Close the map windows and the pixel information window when you have finished the exercise.

Summary: Multi-band operations

- To enhance or extract features from satellite images which cannot be clearly detected in a single band, you can use the spectral information of the object recorded in multiple bands.
- The operations of addition, subtraction, multiplication and division, are performed on two or more co-registered images of the same geographical area.
- **Brightness variations:**
a ratioed image of the scene effectively compensates for the brightness variation, caused by the differences in the topography and emphasizes by the color content of the data.
- **Normalized Difference Vegetation Index.**
Ratio images are often useful for discriminating subtle differences in spectral variations, in a scene that is masked by brightness variations.
The utility of any given spectral ratio, depends upon the particular reflectance characteristics of the features involved and the application at hand.
- Various mathematical combinations of satellite bands, have been found to be sensitive indicators of the presence and condition of green vegetation. These band combinations are thus referred to as vegetation indices. Two such indices

are the simple *vegetation index* (VI) and the *normalized difference vegetation index* (NDVI).

- The NDVI, as a normalized index, is preferred over the VI because the NDVI is also compensating changes in illumination conditions, surface slopes and aspect.
- **Multi-band statistics**
The distribution of data values in a single band could be represented mathematically by the variance statistics, which summarizes the differences between all the pixel values and the mean value of the channel.
The correlation between two (or more) channels can be shown mathematically by the covariance statistics.
The values in a covariance matrix indicate also the correlation: Large negative values indicate a strong negative correlation, large positive values show a clear positive relation and covariance values near to zero indicate a weak or no correlation. The covariance values indicate the degree of scatter or shape of the spectral cluster and the major direction(s).
The individual bands of a multi-spectral image are often highly correlated, which implies that there is a redundancy in the data and information is being repeated. To evaluate the degree of correlation between the individual bands a correlation matrix can be used. This matrix (a normalized form of the covariance matrix) has values in the range of -1 to 1.
- **Principal components analysis**
Principal components analysis (PCA), can be applied to compact the redundant data into fewer layers. Principal component analysis can be used to transform a set of image bands, as that the new layers are not correlated with one another. The first two or three components will carry most of the real information of the original data set. Therefore, only by keeping the first few components most of the information is kept. Through this type of image transform the relationship with raw image data is lost. It should be noted that the covariance values computed are strongly depending on the actual data set or subset used.
- **Image fusion** is the process of combining digital images, by modifying the data values, using a certain procedure. For example data sets are fused by means of a replacement of the combined intensity of the three TM bands, by the intensity of the panchromatic image.

6.6 Image classification

Measured reflection values in an image depend on the local characteristics of the earth surface; in other words there is a relationship between land cover and measured reflection values. In order to extract information from the image data, this relationship must be found. The process to find the relationship is called *classification*. Classification can be done using a single band, in a process called density slicing, or using many bands (multi-spectral classification).

6.6.1 Density slicing

In theory, it is possible to base a classification on a single spectral band of a remote sensing image, by means of single band classification or *density slicing*.

Density slicing is a technique, whereby the DNs distributed along the horizontal axis of an image histogram, are divided into a series of user-specified intervals or slices. The number of slices and the boundaries between the slices depend on the different land covers in the area. All the DNs falling within a given interval in the input image are then displayed using a single class name in the output map.

The image used is a SPOT band 3 of an area in the Flevopolder near Vollenhove in The Netherlands.

Firstly, the ranges of the DN values representing the different land cover types have to be determined. Secondly, a domain Group with the slice boundaries, names and codes has to be created.



- Display the image Spot 3.
- Move through the image and note down the values of water and land. Fill in the data in table 6.14. Zoom in if necessary, select also some mixed pixels along the water / land boundary.

Table 6.14: DN values per cover class of Spot Band 3

Cover class	DN values of Spot XS Band 3
Land	
Water	

By a visual interpretation of the spectral reflectance of the cover classes in band 3, differences are observed with regard to their gray tones. Density slicing will only give reasonable results, if the DN values of the cover classes are not overlapping each other, as indicated in figure 6.18.

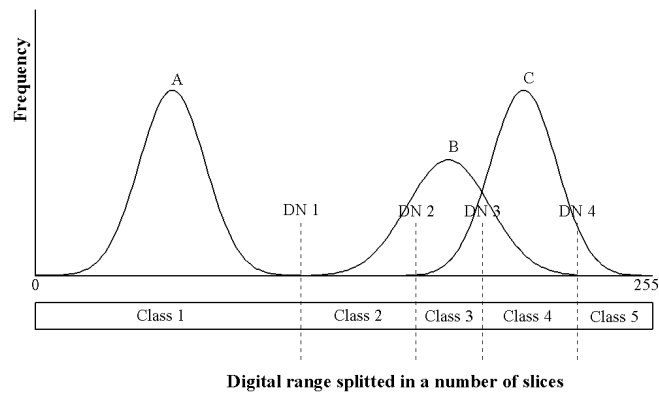


Figure 6.18: Distribution of ground cover classes over the digital range

In figure 6.18, a clear distinction is possible between cover type A and cover types B/C (slice with minimum number at position DN 1), as the distribution of the pixels over the digital range is different from cover type B and C. If the distributions of cover types B and C are studied, an overlap can be observed. To discriminate between B and C several options are possible, but all will result in an improper slice assignment. To classify cover class B, the slice DN 1 to DN 2 will include the lower DN values of C and the higher DN values of B are excluded. To include all the pixels belonging to B, the slice assignment is from DN 1 to DN 4. This slice assignment is including even more pixels that belong to cover class C. When trying to classify C, the same problem occurs.

Before a Slicing operation is performed it is useful to firstly apply a method which shows the map, as if it was classified, by manipulating the representation.



- Create a value domain `Spotb3`, with the value range 0 to 255 and a precision of 1. Change the domain of the map `Spotb3` from `Image` to `Spotb3`.
- Double-click raster map `Spotb3`. The `Display Options` dialog box is opened. Click the `Create` button next to the `Representation` list box. The `Create Representation` dialog box is opened.
- Type for `Representation name`: `Spotb3`. Click `OK`. The `Representation editor` is opened.
- Open the `Edit` menu and select `Insert Limit`. The `Insert Limit` dialog box is opened. Enter the limit you have written in table 6.14 to differentiate land from water, and select the color `Blue`.

- Insert also the other limit shown in the table and select a color (green) for it.
- Open the **Edit** menu and select **Stretch Steps**. Change the stretch steps to 1. Click **OK**.
- Double-click on the word **Stretch** between two limits. It changes now to **Upper**. Double-click again. Now it changes to **Lower**. Do the same for the other.
- Close the Representation editor. You are back in the **Display Options** dialog box. Click **OK**. The map is now displayed as if it was classified.

The representation can be edited, and the result shown on the screen (using the redraw button in the map window, will redraw the map with the updated representation). This allows you to interactively select the best boundaries for the classification. Now you will do the actual classification, using the **Slicing** operation.



- Double-click the **Slicing** operation in the Operation-list.

The Map Slicing dialog box is opened.



- Select **Spotb3** in the **Raster Map** list box.
- Type **Slices** in the **Output Raster Map** text box.
- Select the **Show** check box.
- Type **Classified SPOT** in the **Description** text box.
- Click the **Create Domain** button next to the **Domain** list box. The **Create Domain** dialog box is opened.
- Type **Slices** in the **Domain name** text box.
- Make sure to select the option **Class** and the check box **Group**.
- Accept the defaults by clicking the **OK** button of this dialog box.

The **Domain Editor** is opened. For a **Group** domain, you can enter an upper boundary, a name and a code for each class/group. This domain will be used to slice or classify the raster map **Spotb3**. The upper boundaries and group names, that you have entered in table 6.14, will be used in this exercise.



- Open the Edit menu of the Domain Editor and select Add Item. The Add Domain Item dialog box is opened.
- Type the value from table 6.14 in the Upper Bound text box.
- Type water in the Name text box. The use of a Code is optional. It will not be used now.
- Click OK.
- Press the Insert key of the keyboard to enter the next upper boundary and name.

When you create a domain group, a representation is also created. It is possible to edit the colors of the output groups/classes from the Domain Group Editor, or by opening the representation. To edit the representation:



- Open the Edit menu in the Domain Editor and select Representation.

The Representation Editor is opened, showing the five groups/classes that are present in the domain with different colors.



- Double-click a color Group name and select a pre-defined color, or edit the colors of the selected group by changing the amount of Red, Green and Blue.
- Exit the Representation Editor when you are satisfied with the colors.
- Exit the Domain Editor.
- Click OK in the Map Slicing dialog box.

The Display Options - Raster Map dialog box is opened.



- Select the Legend check box.
- Accept the defaults by clicking OK. The map and the legend are displayed on the screen.
- Use the Pixel Information window to compare the values of the original map with the names in the classified map.
- Close the Pixel information window and the map window.

6.6.2 Multi-spectral image classification

Multi spectral image classification is used to extract thematic information from satellite images in a semi-automatic way. Different methods for image classification exist; some of them are based on the theory about probabilities. Looking at a certain image pixel in M bands simultaneously, M values are observed at the same time. Using multi-spectral SPOT images, where $M=3$, three reflection values per pixel are given. For instance, (34, 25, 117) in one pixel, in another (34,24,119) and in a third (11, 77, 51). These values found for 1 pixel in several bands are called *feature vectors*. It can be recognized that the first two sets of values are quite similar and that the third is different from the other two. The first two probably belong to the same (land cover) class and the third belongs to another one.

In classification jargon it is common to call the three bands *features*. The term features instead of bands is used because it is very usual to apply transformations to the image, prior to classification. They are called *feature transformations*, their results *derived features*. Examples are: Principal components, HSI transformations etc.

In one pixel, the values in the (three) features can be regarded as components of a 3-dimensional vector, the feature vector. Such a vector can be plotted in a 3-dimensional space, called feature space. Pixels belonging to the same (land cover) class and having similar characteristics, end up near to each other in the feature space, regardless of how far they are from each other in the terrain and in the image. All pixels belonging to a certain class will (hopefully) form a cluster in the feature space. Moreover, it is hoped that other pixels, belonging to other classes, fall outside this cluster (but in other clusters, belonging to those other classes).

A large number of classification methods exist. To make some order, the first distinction is between *unsupervised* and *supervised classification*. For satellite image applications, the second is generally considered more important.

In order to make the classifier work with thematic (instead of spectral) classes, some *knowledge* about the relationship between classes and feature vectors must be given.

Theoretically, this could be done from a database in which the relationships between (thematic) classes and feature vectors is stored. It is tempting to assume that in the past, enough images of each kind of sensor have been analyzed, as to know the spectral characteristics of all relevant classes. This would mean, for example, that a pixel with feature vector (44, 32, 81) in a multi spectral SPOT image always means: Grass, whereas (12, 56, 49) is always a forest pixel.

Unfortunately, the observed feature vectors in a particular image are influenced by a large amount of other factors than land cover, such as: Atmospheric conditions, sun angle (as function of latitude/time of day/date and as a function of terrain relief), soil types, soil humidity, growing stage (vegetation), wind (affecting orientation of leafs), etc. The problems we meet when trying to take all these influences into account vary from *quite easy* to *practically impossible*; at least, vast amounts of additional data (DEM's, soil maps, etc.) would be required.

6.6.3 Sampling

Therefore, classification methods are much more widely used, where the process is divided into two phases: a training phase, where the user *trains* the computer, by assigning for a limited number of pixels to what classes they belong in this particular image, followed by the decision making phase, where the computer assigns a class label to all (other) image pixels, by looking for each pixel to which of the trained classes this pixel is most similar.

During the training phase, the classes to be used are previously defined. About each class some *ground truth* is needed: A number of places in the image area that are known to belong to that class. This knowledge must have been acquired beforehand, for instance as a result of fieldwork, or from an existing map (assuming that in some areas the class membership has not changed since the map was produced). If the ground truth is available, training samples (small areas or individual pixels) are indicated in the image and the corresponding class names are entered.

A sample set has to be created in which the relevant data regarding input bands (map list), cover classes (domain codes) and background image for selecting the training areas is stored. The map presented below is giving the ground truth information, as well as the cover classes to be used. The images used in this exercise are SPOT images from the area of the Flevo Polder, The Netherlands:

SPOT XS band 1: Spotb1

SPOT XS band 2: Spotb2

SPOT XS band 3: Spotb3

As the selection of the training areas is done on a color composite, it has to be created beforehand.



- Create a false color composite using the following color assignment: Spotb3-Red, Spotb2-Green, Spotb1-Blue. Make sure to clear the option 24 bit. Type as output map name Spotfcc and use the defaults.

In the following steps a sample set will be created. This will be used for the actual sampling procedure.



- Double-click **Sample Map** in the Operations-list. The Sampling dialog box is opened.
- As no sample set has yet been created, a new one has to be created: Click the **Create Sample Set** button. The **Create Sample Set**

dialog box is displayed.

- Enter `Spotclas` for the **Sample Set name**.
- Create a domain for the classes to be sampled by selecting the **Create Domain** button. The **Create Domain** dialog box is displayed.
- Enter `Spotclas` for the **Domain name**. Click on **OK** and the **Domain Editor** is opened.
- In the **Domain Editor**, from the **Edit** menu, select **Add Item**. The **Add Domain Item** dialog box is displayed. Enter the **Name: Forest**, and the **Code: f**. Click **OK**. Repeat this for all classes to be sampled. A list is given in table 6.15. New classes can always be added later on.

Table 6.15: The land-cover classes in the sample set for a supervised image classification

Class name	Code
water	w
forest	f
grass land	gl
crop1	c1
crop2	c2
crop3	c3



- After having entered all classes, open the **Representation Editor** by selecting **Representation** from the **Edit** menu (in the **Domain Editor**). Select each class by double-clicking and select a color from the color list or define a color by mixing red, green and blue.
- After you have finished, close the **Representation Editor** and the **Domain Editor**, to return to the **Create Sample Set** dialog box.
- Create a **Maplist** which contains all the input bands by clicking the **Create Map List** button. The **Create Maplist** dialog box is displayed.
- Enter `Spotlist` for the **Maplist name**. Select the three input bands (`Spotb1`, `Spotb2`, `Spotb3`). Use the **Ctrl**-key to select all three bands. Accept the selection and return to the **Create Sample Set** dialog box.
- Select `Spotfcc` as the **Background image**.
- Click **OK** in the **Create Sample Set** dialog box and click **OK** in the **Sample** dialog box.
- The false color composite is displayed as background map. The actual sampling procedure can start.

The `Spotfcc` color composite will be displayed in a map window. In order to select training pixels and assign a class name to them, you have to zoom in.



- Click OK in the Pixel Editor message box showing the message “Please zoom in to edit”.

Two windows are displayed: A map window showing the background map (window title: `Sample Set Editor: Spotclas`) and a window showing the sample statistics (window title: `Sample Statistics`). During the sampling procedure, consult also the topographic map of the Flevoland region, shown in figure 6.8.



- Zoom in on an area with water. To select pixels press the left mouse button and drag the cursor. When the mouse button is released, the statistics of the current selection of pixels are shown in the `Sample Statistics` window, `Current Selection` (figure 6.19).
- Click the right mouse button to reveal the context-sensitive menu and select `Edit`. Select the appropriate class from the class list (`Dw: Deep water`). Once this selection is added to the class, the total class statistics are shown in the upper part of the table.
- One can always compare the statistics of a sample with the statistics of a class, by selecting the class in the class list.
- Repeat the sampling procedure for a number of water samples and then continue with sampling the other land cover classes.
- If a land cover class has not yet been defined and, therefore, does not appear in the class list, a new class can be created by selecting `<new>`.
- Add a new class (`Name: Urban`, `Code: u`). Take samples of this class.

The `Sample Statistics` window contains the code and name of the selected class as well as the number of bands. The following statistics are shown for a selected class:

- Mean value of pixels (`Mean`).
- Standard deviation of pixels (`StDev`).
- The number of pixels having the predominant value (`Nr`).
- The predominant pixel value (`Pred.`).
- The total number of the selected pixels (`Total`).

Sample Statistics						
1: water						
Band	Mean	StDev	Nr	Pred	Total	
1:	9.3	1.0	245	9	518	
2:	7.5	1.5	176	8	518	
3:	2.6	1.3	205	3	518	
Current Selection:						
1:	9.4	1.3	51	9	132	
2:	8.8	2.0	43	8	132	
3:	5.4	3.1	30	3	132	

Figure 6.19: The sample statistics window

Displaying Feature Spaces

The classes can be plotted in distinct colors in the *feature space*, which enables a judgment of whether the classes can really be spectrally distinguished and whether each class corresponds to only one spectral cluster (if not, it is advisable to create sub-classes, which must be joined after the classification is finished). After training is done, the feature space with training samples looks like figure 6.20, which shows a 2-dimensional example. The number of training samples should be between 30 and some hundreds of samples per class, depending on the number of features and on the decision making that is going to be applied.

The feature space is a graph in which DN values of one band are plotted against the values of another. To view a feature space:

- Click the Feature Space button in the button bar of the map window. The Feature Space dialog box is opened.
- Select two bands for which a feature space should be created. Select `Spotb1` for the horizontal axis and `Spotb2` for the vertical axis. Click OK. A feature space is displayed.
- Try also other band combinations for the feature space display.

You will probably see some overlapping classes in the feature space.

What can be said about the standard deviation for the urban area and how can this be explained?

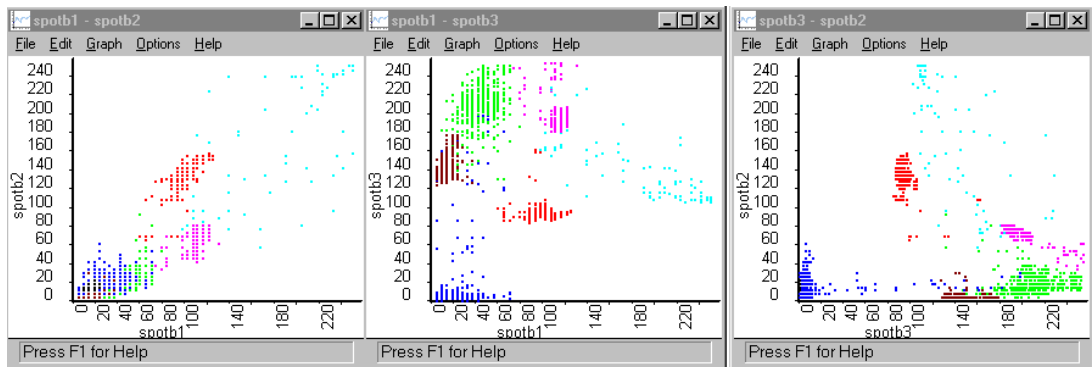


Figure 6.20: Three examples of ILWIS Feature Space Windows



- After you have finished the sampling, close all windows and return to the ILWIS main window.

6.6.4 Classification

It is the task of the decision making algorithm to make a partitioning of the feature space, according to our training samples. For every possible feature vector in the feature space, the program must decide to which of the sets of training pixels this feature vector is most similar. After that, the program makes an output map where each image pixel is assigned a class label, according to the feature space partitioning. Some algorithms are able to decide that feature vectors in certain parts of the feature space are not similar to any of the trained classes. They assign to those image pixels the class label 'unknown'. In case the area indeed contains classes that were not included in the training phase, the result 'unknown' is probably more realistic than to make a 'wild' guess.

To find the relationship between classes and feature vectors is not as trivial as it may seem. Therefore, various decision making algorithms are being used; they are different in the way they partition the feature space. Three of them are:

- *The Box classifier* is the simplest classification method: In 2-D space, rectangles are created around the training feature vector for each class; in 3-D they are actually boxes (blocks). The position and sizes of the boxes can be 'exactly around' the feature vectors (Min-Max method), or according to the mean vector (this will be at the center of a box) and the standard deviations of the feature vector, calculated separately per feature (this determines the size of the box in that dimension). In both cases, the user is allowed to change the sizes by entering a 'multiplication factor'.

where boxes overlap, it is usual to give priority to the smallest box. Feature vectors in the image that fall outside all boxes will be 'unknown'.

- *The Minimum Distance-to-mean classifier*, first calculates for each class the mean vector of the training feature vectors. Then, the feature space is partitioned by giving to each feature vector the class label of the nearest mean vector, according to Euclidean metric. Usually it is possible to specify a maximum distance threshold: If the nearest mean is still further away than that threshold, it is assumed that none of the classes is similar enough and the result will be 'unknown'.
- *Gaussian Maximum Likelihood classifiers* assume that the feature vectors of each class are (statistically) distributed according to a 'multivariate normal probability density function'. The training samples are used to estimate the parameters of the distributions. The boundaries between the different partitions in the feature space are placed where the decision changes from one class to another. They are called decision boundaries.

In this exercise, different types of land-cover in the area will be detected by implementing a supervised classification, using the sample set prepared in the previous exercise on sampling. The output will be a map with domain type class representing land-cover units in the area.

Four standard techniques for classifying an image are:

- 1) The Box classifier.
- 2) The Minimum Distance classifier.
- 3) The Mahalanobis Distance classifier, and;
- 4) The Maximum Likelihood classifier.

Each classifier uses a sample set, only the procedure to classify an image is different.

Box classification

This classifier uses class ranges determined by the DN values observed in the training set. These intervals result in rectangular spaces or boxes; hence, the name Box classifier.

Having sampled a representative amount of pixels per class, the mean DN values of the class are used, together with the standard deviation of the sample and a multiplication factor, to determine the extent of the box. The boundaries of the box are defined by the product of the standard deviation and the multiplication factor.

A pixel not falling within a box, is not classified. If a pixel lies within two or more overlapping boxes, the pixel is classified according to the smallest box.

The bands used in this exercise are from a SPOT image of the Flevo Polder, The Netherlands:

SPOT XS band 1: Spotb1

SPOT XS band 1: Spotb2

SPOT XS band 1: Spotb3

When performing an automated Box classification, the different land cover classes in the area will be detected by implementing a programmed classification rule, using a specified sample set. The output map will be a map with classes representing the land cover units in the area. The sample set, to be used, has been created in the exercise Sampling.



- Double-click the **Classify** operation in the Operations-list. The **Classification** dialog box is opened.
- Select `Spotclas` for the **Sample Set** and select **Box Classifier** as **Classification method**. Accept the default **Multiplication Factor**. Give an appropriate **Type Boxclas** for **Output Raster Map name**. Select **Show** and click **OK**. The classification will take place.
- After performing the classification, display the result.
- Repeat the same procedure using a larger multiplication factor.
- Visually compare the results with the classified map using the default multiplication factor.

Other classifiers can be used:



- Perform another classification using the **Minimum Distance** method. Compare the results with the box classified map.
- Close the map window when you have finished the exercise.

Evaluate the reclassified results

The final result is compared with the original values in the bands 1,2 and 3 of the SPOT image. For the complex and more homogenous land covers the results can be compared with the original bands.



- Display the topographic map `Polder`. Make sure that it is georeferenced. Check this also for the SPOT bands.
- Open the ILWIS pixel information window and add the maps `Spotb1`, `Spotb2`, `Spotb3` and `Boxclas`.

- Evaluate for pixels the different cover classes defined and the result of your classification.
- Close the map window and the pixel information window.

To get a better idea of the overall accuracy of the classification, use has to be made of the test set which contains additional ground truth data, which have not been used to train the classifier. Crossing the test set with the classified image and creation of a *confusion matrix*, is an establish method to assess the accuracy of a classification.

It is not recommended to use the same sample map for both the classification and the accuracy assessment, because this will produce figures that are too optimistic.

Post classification operations

The final classification may not meet the expected results. This can be due to spectral overlap in the sample set, or because the classifier has not been trained properly. If this is the case the classification process should be repeated, incorporating for example more spectral classes. Defining sub-classes, when a bi-modal distribution or large standard deviation/variance exists in a class, will improve the classification results. After the classification process these classes can be merged again. If the obtained results are still not according to expectations, incorporation of ancillary non spectral information might be considered, for example elevation information might be useful to distinguish certain forest types.

In a classified image small areas occur, consisting of one or a few pixels, to which another class label has been assigned, compared to the larger homogeneous classified surrounding areas. Individual non-classified pixels may also occur throughout the classified image. If there is, for example, a need to integrate the results with other data sets, a large number of small individual units will occur which can not be properly represented on a map. To circumvent these problems the classified image may be generalized in order to remove these small individual areas. Spatial filters are a mean to achieve this objective, e.g. individual pixels may be assigned to the majority of the surrounding pixels.

Majority and Zero majority filter

A standard filter which can be applied is the majority filter. The majority filter selects the predominant (most frequently occurring) value of a pixel and its 8 neighbors. The zero majority filter selects only the predominant value if the central pixel is zero, which thus removes isolated unclassified pixels and assigns the pixel to the surrounding class.



- Double-click the Filter operation in the Operations-list. The Filtering dialog box is opened.

- Select the classified image `Boxclas` as the input Raster Map. Select the filter type: **Majority** and the filter name: **Majority**. Enter `Major` as **Output Raster map** name and use the default domain. Select **Show** and click **OK**. The map `Major` will be created. Accept the defaults in the **Display Options** dialog box.
- Display also the original classified image (`Boxclas`) and compare both images.

These post classifier operations should be used with care: Small areas are of high relevance for some applications. A further generalization can be achieved if the majority filter is applied several times.



- Close the **Map window** when you have finished the exercise.

In chapter 9 more examples of map filters will be given.

6.6.5 Unsupervised classification (clustering)

One way to perform a classification is to plot all pixels (all feature vectors) of the image in a feature space, and then to analyze the feature space and to group the feature vectors into clusters. The name of this process is unsupervised classification. In this process there is no knowledge about thematic land cover class names, such as town, road, potatoes etc. All it can do, is to find out that there appears to be (for example) 16 different things in the image and give them numbers (1 to 16). Each of these things are called spectral classes. The result can be a raster map, in which each pixel has a class (from 1 to 16), according to the cluster to which the image feature vector of the corresponding pixel belongs.

After the process is finished, it is up to the user to find the relationship between spectral and thematic classes. It is very well possible, that it is discovered that one thematic class is split into several spectral ones, or, worse, that several thematic classes ended up in the same cluster.

Various unsupervised classification (clustering) algorithms exist. Usually, they are not completely automatic; the user must specify some parameters such as the number of clusters (approximately) you want to obtain, the maximum cluster size (in the feature space), the minimum distance (also in the feature space), that is allowed between different clusters etc. The process builds clusters as it is scanning through the image. Typically, when a cluster becomes larger than the maximum size, it is split into two clusters; on the other hand, when two clusters get nearer to each other than the minimum distance, they are merged into one.



- Double-click the **Cluster** operation in the Operations-list. The **Clustering** dialog box is opened. Select `Spotb1`, `Spotb2` and `Spotb3`. Use the same number of classes as when performing the supervised classification (see table 6.15).
- Type `Clust` for the **Output Raster map** name. Select **Show** and click **OK**.
- Accept the defaults in the **Display Options** dialog box. The map is displayed.
- Display the map produced using the supervised classification method (`Boxclas`) and compare the results.
- Close the map windows when you have finished the exercise.

Summary: Image classification

- In order to extract information from the satellite images, the relationship between pixel values and land cover types must be found. The process to find the relationship is called *classification*.
- **Density slicing** is a technique, whereby the DNs distributed along the horizontal axis of an image histogram, are divided into a series of user-specified intervals or slices. Density slicing will only give reasonable results, if the DN values of the cover classes are not overlapping each other.
- **Multi spectral image classification** is used to extract thematic information from satellite images in a semi-automatic way. The values of the various bands found for 1 pixel in several bands are called *feature vectors*. Such a vector can be plotted in a 3-dimensional space, called feature space. Pixels belonging to the same (land cover) class and having similar characteristics, end up near to each other in the feature space. In order to make the classifier work with thematic (instead of spectral) classes, some *knowledge* about the relationship between classes and feature vectors must be given.
- The classification process is divided into two phases: a **training phase**, where the user *trains* the computer, by assigning for a limited number of pixels to what classes they belong in this particular image, followed by the **decision making phase**, where the computer assigns a class label to all (other) image pixels, by looking for each pixel to which of the trained classes this pixel is most similar.
- About each class some *ground truth* is needed: A number of places in the image area that are known to belong to that class. It is the task of the decision making algorithm to make a partitioning of the feature space, according to our training samples. For every possible feature vector in the feature space, the

program must decide to which of the sets of training pixels this feature vector is most similar. After that, the program makes an output map where each image pixel is assigned a class label, according to the feature space partitioning.

- Various decision making algorithms are used: **box classifier**, **minimum distance to mean classifier**, and **Gaussian maximum likelihood classifier**
- **Unsupervised classification.** One way to perform a classification is to plot all pixels (all feature vectors) of the image in a feature space, and then to analyze the feature space and to group the feature vectors into clusters. In this process there is no knowledge about thematic land cover class names. The user must specify some parameters such as the number of clusters (approximately) you want to obtain, the maximum cluster size (in the feature space), the minimum distance (also in the feature space), that is allowed between different clusters etc.