LEOWorks image processing tutorials

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About LEOWorks

LEOWorks is a software product designed and developed for use in educational activities. It is the main tool for demonstrating Earth Observation techniques within the European Earth Observation Web Site for Secondary Schools - EDUSPACE, belonging to the European Space Agency (ESA).

LEOWorks can be used to open, inspect and process data as images coming from various Earth observation satellites.

Initially developed to support teachers teaching geography in the high school, currently LEOWorks is also addressing upper secondary school students and their teachers' needs by providing them a set of tools for processing satellite images and derive information about land and sea, nature and biodiversity, environment and climate change.

Some of the major features of LEOWorks are:

- Read data stored in many file formats;
- Gray scale, RGB or color indexed image display;
- Manipulate 8 bit, 16 bit, float or complex data;
- Radiometric enhancement;
- Geometric transformations;
- Unsupervised and supervised image classification;
- Create, edit and query GIS vector data;
- Image to map and image to image registration;
- Basic radar data processing.

Some of the features, like the "Radar data processing" are available only in the ADVANCED version of the LEOWorks. At the initial installation, LEOWorks is set to the BASIC version. The version can be changed from menu Edit/Preferences and option "LEOWorks level". The changes take effect after restarting the software.

Many software components included in LEOWorks, are imported or derived from existing components used in the ESA BEAM, NEST and SNAP software projects.

LEOWorks is supposed to run on all families of operating systems - Windows, MacOS, Linux. Software and documentation can be downloaded from http://www.esa.int/SPECIALS/Eduspace_EN/

Sample data are embedded in the LEOWorks installer, but also available from the dedicated website at <u>http://leoworks.terrasigna.com/sample-data</u>.

Sentinel data are available for download at Copernicus Open Access Hub (<u>https://scihub.copernicus.eu/dhus/#/home</u>).

1. Accessing files and displaying data

1.1 Opening files

In general, both geospatial data and remote sensing data is stored in files residing on disks either on computers, optical (CD, DVD, BR) or tapes.

A file typically contains a dataset e.g. the bands of a remote sensing scene or the objects (geometry and attributes) belonging to a vector layer.

Opening files in LEOWorks is a very flexible operation. It is possible to open:

- a) one single file as a single dataset;
- b) many single files as a single datasets;
- c) many files as a single dataset;
- d) reopen a previously open file;
- e) import data.

a. Open one single file as a single dataset (applies for both vector and image data)

To open a single file as a single dataset:

- click File/Open/Single File Dataset(s);

🛓 LEOWorks	- Select file(s)	to open	×
Look in:	Venice	👻 🌶 🕫 🖽	
Recent Items		nvisat_ASAR andsat_ETM_multispectral	
Desktop	Menice_La	andsat_ETM_panchromatic	
My Docum			
Computer			
Network	File name:	Venice_Landsat_ETM_multispectral.tif	Open
Network	Files of type:	GeoTIFF data product. (*.tif, *.tiff)	Cancel

- in the *Select file(s) to open* dialog, select the file you want to open (see figure above) and then click the *Open* button;

- choose your options in the *Subset/Resize* dialog (for details about this dialog, please check the 1.3 Subset and resize section) and click the *Open* button;

- The dataset contained in the selected file will be added in the *Available Datasets* window; if not already displayed, it is possible to display this window by selecting *View/Managers/Available Data*.

b. Open many single files as distinct single datasets (applies for both vector and image data)

To open many single files as distinct a single dataset:

- click File/Open /Single File Dataset(s)



- in the *Select file(s) to open* dialog, hold CTRL key pressed and select with the mouse cursor the files you want to open (see figure above for a selection of 5 image files from a Landsat 8 data product) and then click the *Open* button;

- for each selected file choose your options in the *Subset/Resize* dialog and click the *Open* button (for details about this dialog, please check the 1.3 Subset and resize section);

- The dataset contained in each selected file will be added in the *Available Datasets* window; if not already displayed, it is possible to display this window by selecting *View/Managers/Available Data*.

c. Open many single files as a single dataset (applies for image data)

To open many files as a single dataset (typical case of remote sensing data storing each band in a separate file):

- click File/Open/Multiple Files as Single Dataset

- in the *Select file(s) to open* dialog, select the files you want to open and then click the *Open* button;

- in the *Dataset name* window, type a name for the new dataset as shown below; this name will be used in the *Available Datasets* window;

Dataset name
A name for the merged data:
Landsat_TM1985
OK Cancel

- the datasets contained in the selected files will be merged into a single dataset. The latter will take the name typed in the previous step; choose your options in the *Subset/Resize* dialog and click the *Open* button (for details about this dialog, please check the 1.3 Subset and resize section);

- The new dataset will be added in the *Available Datasets* window; if not already displayed, it is possible to display this window by selecting *View/Managers/Available Datasets*.

d. Reopening files (applies for both vector and image data)

It is possible to re-open a previously open file by selecting *File/Reopen* and selecting the file to be open. LEOWorks keeps a list of the last 10 open files.

e. Importing data

LEOWorks can import data stored in most of the Earth Observation optical or radar data provider file format (e.g. SENTINEL 1, SENTINEL 2, ENVISAT N1, ALOS PALSAR CEOS) or popular image processing software (ENVI). Import functions are also made available for popular DEM formats (e.g. SRTM, GTOPO) and for the GPS observations GPX format.

Once imported and added in the *Available Datasets* window, the imported data is converted in DIMAP format and any modifications can be saved in the same file.

Import functions can be accessed by selecting *File/Import*. The use of any of these requires adequate knowledge of the file format and the content that could be imported depending on further use of the data (see the image below for an Import of a SENTINEL 2 data product).

File	Edit View Inspect	Tools Map	Window Help		
	Open	۱.			
	Session	•			
8	Save	Ctrl+S			
₿	Save Dataset As				
	Save Image As				
	Close	Ctrl+W			
	Import	•	Generic Formats 🕨		
	Export	•	Optical Sensors	Sentinel-2	S2-MSI L1C
	Exit	Alt+F4	SAR Formats	ERS1/2 ATSR (.E1, .E2)	S2-MSI L1B
			SAR Sensors	ENVISAT MERIS, AATSR	S2-MSI L2A
				HICO (ENVI format)	



1.2 Displaying images and vector layers

Once a file is displayed in the *Available Datasets* window (see figure bellow), it is possible to display the data it contains.



In the case of remote sensing data, the digital numbers stored as separate bands can be displayed in grayscale or in color composite images (see figure below).



When dealing with vector data, images can be generated based on object's geometry and attributes (see figure below).



a. One band grayscale image display

Digital numbers in a band of a remote sensing dataset can be displayed as a grayscale image. This can be done by either:

- selecting and double-clicking a band in the Available Datasets window or;

- selecting a band in the *Available Datasets* window and then *View/Show in new view* from the main menu.

b. RGB color image display

Color RGB images can be displayed by using 3 bands of a remote sensing dataset as R, G, and B channels. This can be done by going through the following steps:

- select *View/New RGB* View from the main menu;

🛓 LEON	Norks - Select RGB-Image Channels	X
Profile:		
	• 🗃 [
Red:	band_3	-
Green:	band_2	▼
Blue:	band_1	▼
Stor	e RGB channels as virtual bands in current product	
	OK Cancel	Help

- in the *Select files/bands* window, select the bands to be used as RGB channels as shown in the figure above;

- click the *OK* button.

The most used RGB band combinations (e.g. 3-2-1, 4-3-2 for Landsat 5-7data) can be saved automatically (by pressing the *Save* button) as profiles and restored (by pressing the *Open* button) for a quick display of desired color combinations. Saved profiles can also include band arithmetic expressions edited using the expression editor (see section 4 on band arithmetic) that can be activated by pressing the *...* button.

In the case the bands to be used are in different datasets, the Combine in RGB function can be used to generate a color image. This can be accessed by clicking *View/Combine in RGB* ... The following dialog is displayed:

🧟 Select files	; / bands	
Red band:	Venice_Landsat_ETM_multispectral:band_1 \bullet]
Green band:	Venice_Landsat_ETM_multispectral:band_1 👻	1
Blue band:	Venice_Landsat_ETM_multispectral:band_1 Venice_Landsat_ETM_multispectral:band_2 Venice_Landsat_ETM_multispectral:band_3	
	Venice_Landsat_ETM_multispectral:band_5 Venice_Landsat_ETM_multispectral:band_5 Venice_Landsat_ETM_panchromatic:band_1	

In this dialog, the data to be used as R,G or B channels can be selected among all the bands attached to all datasets displayed in the *Available Datasets* window. However, this procedure can be applied only for geocoded data so that the common geographical area covered by all bands can be computed.

c. GIS vector data display

GIS vector data can be displayed by double clicking the name of the feature layer of a vector dataset (under the *Feature* node).

By default, the symbol (type of line, color etc.) used to display vector data is chosen randomly. It is also possible to change the way a vector layer is displayed by

clicking the *Layer Style Editor* button in the *Layer Manager* window or in the *GIS Manager* window. The *GIS Manager* window can be opened by selecting *Tools/GIS/GIS Tools* from the main menu. The controls on the *Layer Style Editor* window are enabled or disabled, according to the selected layer's feature type. If the feature type is polygon or polyline, the point symbols are disabled.

For polygon layers, the polygon boundary line and the interior can be customized in different ways, by choosing representation values in Line and Fill areas. The boundary line properties that can be customized are line color and line width. The interior fill properties that can be customized are fill color and opacity level.

For polyline layers, the line color and line width can be customized.

For point layers, there are three elements that can be customized: symbol, symbol size and symbol color.

Colors can be chosen by using the color chooser dialog, a dialog being activate after clicking the Color... button.

○ ○ ○	UTM_Venice.shp
Feature type railways_UTM_Venice (line) Line Color Width 1 ‡	
Fill	J
rm	
Color % opacity	20 40 60 80 100
Point	
Size 5 \$ Symbol Circl	e 🛔
Labels	
☐ Field osm_id ‡	
Font	
Color	
Apply Reset	OK Help

The layer style editor allows feature labeling. Labeling is activated by checking the tick box in the *Labels* area. To be able to label a layer, the vector data must contain at least one field that can be used as a label. When *Label* feature is activated, fields suitable to be selected as labels are shown in the *Field list* box.

Layer's labels can be customized by choosing font and color. The font can be changed pressing the *Font...* button. The label font chooser dialog is shown. The user can select font family, style, weight and size. The changes are done by pressing the *Apply* button.

Choose label font			×
Family Serif	▼ Style Normal ▼ Weight Normal ▼ Size 1	arstuvwxyz 0123456789 The quick brown fox jumped over ▼	Cancel

1.3 Subset and resize

When opening files, either remote sensing (raster) or GIS vector data, it is possible to subset and/or resize the datasets contained in a selected file or in a group of files (see previous section 1.1.c).

This operation can be performed in two ways, by choosing the appropriate option in the menu *Tools/Subset*:

- Subset from View;
- Subset from Shapefile

1.3.1 Subset from view

It is possible to spatially subset an image by adjusting the blue rectangle in the *Spatial* tab (see figures below), by specifying pixel coordinates or by specifying geographical coordinates.



In the case of multi-band remote sensing datasets, it is possible to select among the existing bands and keep one or more bands to work with. The selection can be done by clicking one or more bands listed on the *Band* tab.



It is also possible to resize an image dataset by changing the size of the pixels. This can be done by specifying a scaling factor for both X and Y directions and a resampling method in the *Resize* tab (see figure above). See 4.4 for more details about resampling methods.

When dealing with vector data, it is also possible to subset spatially or by defining a query based on attribute values.



In the case of vector data, only the objects falling inside the rectangle will be kept. Alternatively, only the objects meeting the defined criteria will be kept.

1.3.2 Subset form Shapefile

This option allows the subset of an image datasets, using single or multipart polygons stored in shape files (.shp).

The subsetting works on a Source image dataset that is already loaded and is visible in the Available Datasets window. Alternatively, an image dataset can be selected from the local disk after clicking the "three points" button at the right side of the Name field.

The Vector Dataset can also be selected from the available datasets or from the local disk, by clicking the "three points" button at the right side of the Name field.

Subset from Shapefile	Subset from Shapefile
I/O Parameters Subset preview	I/O Parameters Subset preview
Source dataset (image) Name:	
[1] landuse_UTM_Venice_subset.tif	
Vector dataset	
Name:	· · Just
landuse_UTM_Venice	8 and a
Target dataset	and si ha
Name:	A Company of the second
landuse_UTM_Venice_subset.tif	
Save as: GeoTIFF 👻	O TANG O AND .
Directory:	
C:\Users\adrian.stoica\leoworks.data	
Open in LEOWorks	0.00
Run Close Help	Run Close Help

In the Target dataset area it can be selected the name, the format and the location of the file in which the result will be stored. In the Save As field, a format for the output image subset can be selected. By default, the GeoTiff format is selected. A result of a subset from shapefile can be observed in the image bellow.



1.4 Saving and exporting data

Once a desired result is obtained, there is the possibility to save it as a separate file by:

- saving the entire dataset, including all bands displayed in the *Available Datasets* window (including e.g. NDVIs or filtered band added to the dataset); this can be done by selecting *File/Save* or *File/Save Dataset As* depending on whether your dataset was previously converted in BEAM DIMAP format or not;

- saving an image displayed either in gray scale or colors in a viewer in a separate file (TIFF, GeoTIFF or other generic image file format e.g. JPEG); the same result can be achieved by selecting *File/Save image as* or *File/Export View as Image*.

Other functions given in *File/Export* allow exporting a dataset displayed in the Available Datasets window as one of the GeoTiff, BEAM DIMAP or ENVI file formats compatible dataset.

Using the *Export* function, the content of a viewer can also be exported as KMZ file and displayed in the Google Earth Application.

2. Inspecting data

Inspecting data is in almost all cases a pre-requisite when doing remote sensing data analysis (more words about data inspection goals). The objective of inspecting data is to assess the quality and potential of the data. To do so, statistics are usually extracted and visual analysis is performed.

2.1 General information on image data

It is possible to get information about a dataset by pressing the *Information* button or by selecting *Inspect/Information* from the main menu. This will display the *Information* dialog for the dataset selected in the *Available Datasets* window.

9				×
Information ×				
File name:	Venice_La	andsat_ETM_	multispectral	
File format:	GeoTIFF		and and the second s	
File location:	C:\Users	LW4build\De	esktop\LW_Test_Data\Venice\Venice_Landsat_ETM_multispectral.tif	
Product scene width:		791	pixels	
Product scene height:		655	pixels	
Data type:	uint8			
Geographic extent:				
Upper left latitude:	45°35'09	*N		
Upper left longitude:	12°10'12	*E		
Lower right latitude:	45°24'02	"N		
Lower right longitude:	12°27'45	"Е		
Map coordinates extent:				
Upper left X	747293.0)6 m		
Upper left Y	5052917.	.12 m		
Lower right X	770993.0)6 m		
Lower right Y	5033297.	. 12 m		
Coordinate Reference S	ystem: EPS(G:WGS 84 / L	JTM zone 32N	
Pixel size X:30.00000 m				
Pixel size Y:30.00000 m				
				-
				1

Information X			
Information ×			_
-1			
File name: File format:	landuse_UTM_Venice		
File format: File location:	.shp	Attack M. Test Data Wasias (CIC Theorem) and the UTM Vasias she	
Product scene width:	C: Users LW 40010 Ues 23730	ktop\LW_Test_Data\Venice\GIS_Themes\Janduse_UTM_Venice.shp pixels	
Product scene width: Product scene height:	18640	pixels	
Vector product attribute		pixels	
Name:	Type:		
the_geom	MultiPolygon		
osm id	Long		
name	String		
type	String		
cype	Juliy		
Geographic extent:			
Upper left latitude:	45°35'09" N		
Upper left longitude:			
Lower right latitude:	45°24'34" N		
Lower right longitude:	12°27'49" E		
Map coordinates extent	:		
Upper left X	747293.56 m		
Upper left Y	5052916.62 m		
Lower right X	771022.56 m		
Lower right Y	5034277.62 m		
Coordinate Reference S	ystem: WGS_1984_UTM_	Zone_32N	
Pixel size X:1.00000 m		1. 100	
Pixel size Y:1.00000 m			
			1

The information provided on the *Information* dialog consist of the File name, format and location, product dimension, data type, vector product attribute fields (only for vector data), as well as the geographical extent of a dataset and the Coordinate Reference System (CRS) for geo-coded data (see figure above).

2.2 Pixel information

It is often useful to inspect the values of the pixels in different bands of a remote sensing dataset.

🔁 Pixel Info V			ωx
🔘 Geo-locati	on		đ×
Coordinate	Value	Unit	
Image-X	51	pixel	
Image-Y	184	pixel	
Longitude	8°29'04" E		
Latitude	55°09'02" N		
Map-X	467225.0	m	
Map-Y	6111859.0	m	
Bands			ے ×ت
Band	Original	Displayed	
band_1	126	154	
band_2	66	139	
band_3	82	147	

To do so:

- display a gray scale image of a band or a color RGB image combination of three bands;

- click the *Pixel Info* button i or select *Inspect/Pixel Info* from the main menu; the *Pixel Info View* window will be displayed (see figure above);

- move the mouse over the displayed image and watch the *Pixel Info View*. The image coordinates (row and column), geographical coordinates, rectangular (map) coordinates, as well as the pixel values of each band are shown. It can be noted that both, *Original* and *Displayed* values are provided.

Displayed values are the pixel values depicted on the screen (the R,G and B channels). Original and Displayed values usually differ after applying Histogram stretching (see sections 2.4 and 3.2)

2.3 Statistics for remote sensing data

When selecting *Inspect/Statistics* or clicking the *Statistics* button Σ it is possible to get some statistical parameters computed and displayed for a band being part of a remote sensing dataset (see figure below) or for a GIS vector dataset attribute field.

∑ Statistics - Veni	ce_Landsat_ETM_m	ultispectral	
band_1 Statistics			Compute
Total number of pi Number of conside Ratio of considere	red pixels:	518105 518105 100.0	
Minimum: Maximum:	61 250		
Mean: Median: Std-Dev: Variation:	85.43 122.17 9.95 0.12		
			?

2.4 Histogram

Given an image dataset, it is possible to compute and display the histogram of a band or of the three bands composing an RGB image (see figure below). This can be done by following the next steps:



- select *Inspect/Histogram* or click the *Histogram* button
- select the band of an image dataset for which you want the histogram to be computed in the *Available Datasets* window;
- set the number of bins (number of points displayed on the graph). The number is related to the displayed image. If you want to see les points on the graph, just decrease the number of Bins;
- set the *Min* and *Max* values if appropriate.;
- click the Re-Compute button.

You can zoom in the histogram, change the way the histogram looks like, or export the histogram as an image using the tools available in the bottom-right side of the window. You can also choose to display the histogram using a Logarithmic Scale, or to display only one or two bands in the case of RGB images.

2.5 Profile plots and spectra

Profile plots

Using profile plots it is possible to check the digital numbers associated to the pixels crossed by a line in a color image or a gray scale image (see figure below).



To use the *Profile Plot* tool, you need to:

- display the image of a band or an RGB color combination using 3 bands of a remote sensing dataset;

- draw a line on the image by clicking the intermediary points; end the line with a double-click.

After having the profile plot displayed, you can access and choose different options for displaying the profile by right-clicking in the plot area or by changing the way the profile is displayed by clicking the *Edit Properties* button in the *Plot* toolbar (right-down side of the window).

It is also possible to export as image or to print the plot by clicking the appropriate buttons in the *Plot* Toolbar.

Pixel spectra

Using the *Pixel Spectrum View*, spectra can be displayed for pixels in the image. The *Spectrum View* can be activated by selecting *Inspect/Spectrum* from the main menu.



The pixel spectrum view displays the pixel values in all the spectral bands or the selected bands associated with an image dataset.

Spectra are displayed for the mouse position and dynamically update as the mouse is moved over the image.

Alternatively, spectra can be displayed for any Pin placed in the image (see picture above). Pins can be placed on the image after pressing the *Pin Placing Tool* button available on the right side of the *Spectrum Tool View*.

Spectra associated to pins can be exported and further analyzed (e.g. using a Microsoft Excel-like program).

2.6 Features and feature attributes

When working with GIS vector data, it is useful to inspect the values of different feature attributes.

To do so, the following steps are needed:

- open the file containing the GIS vector data;

- double-click on it in the *Available Datasets* window to have it displayed in a viewer;

- open the *GIS Manager* by clicking the appropriate button in the toolbar or by selecting *Tools/GIS/GIS Tools*;

- click the *Feature and attribute table* button to have the feature attributes table displayed (see figure below) and inspect the attributes for all features; if an attribute field is clicked in the lower left panel, statistics for that attribute field are going to be displayed in the lower right panel;

			1		12
l	Clear	Save Selection	Refresh	Delete	?
Attribute values: ED	DIT MODE				
Feature identifer	Theme type	osm_id	name	type	
1	MultiPolygon	4724853		industrial	A
10 N	MultiPolygon	19912075		residential	
100	MultiPolygon	45188519		residential	
101	MultiPolygon	45188521		residential	
102	MultiPolygon	45188522		farm	
103 N	MultiPolygon	45188523		residential	
		45188524		farm	
			tatistics on attrib	ite velvee	
Attribute name	Visible	-			a anna ide
Theme type	V		atistics computed ount : 1	i for the attribut	e osm_iu:
osm_id	V		n : 45188521.0	D	
name	V	M	ax : 45188521.0	00	
type	1	M	ean : 45188521.	00	
		Su	m : 45188521.0	00	

- click the *Feature Info* button in the tool bar or select menu "*Inspect/Feature Info*" to open the *Feature Info* window (see figure below);

Attribute name	Attribute value
Geometry	Point
IDENT	021
LAT	55.15267
LONG	8.558
ALTITUDE	1.0
LINK	C:\Program Files\LEOWorks

- navigate the data viewer and click any feature for which you want to inspect the values of the attribute fields; information is displayed for features in the vector data theme being selected in either *GIS Manager* or *Available Datasets* window.

2.7 Measure tools

It is often useful to have an estimation of how large the objects appearing in a satellite image are. For this, you need some tools allowing you to measure lengths or area of different objects.

In LEOWorks, such tools can be accessed by selecting menu *Tools/Measure* or by clicking the *Measure* button in the toolbar.

Once the *Measure* window is made visible, you can start clicking on the image to draw a line or a polygon defining a distance or an area you want to measure.

While clicking on the image, in the *Measure* window, the Total length/Area is displayed together with the length of each segment drawn on the image).



Both *Measurement details* and *Total length/Area* sections of the *Measure* window are editable, so you can add your own remarks and then copy and paste it in a report.

The measurement of the *Total length and Area* are displayed in number of pixels and squared pixels, respectively. The ground units selected from the measurement unit list can be displayed in meters, feet, kilometers and miles.

For non-geocoded images, it is possible to specify the pixel size in X and Y direction, so the results can be displayed in both pixels and ground units.

3. Basic image processing

3.1 Image display. Gray scale and color images

A color image stores its color information in channels. The information contained in the channels depends on the color model being used to define the image. The most known models are RGB (Red - Green - Blue), HLS (Hue - Lightness - Saturation), HSV (Hue - Saturation - Value) and IHS (Intensity - Hue - Saturation). In all cases, the color image is generated using 3 channels (see image below).



From left to right, RGB, HLS and HIS models

In LEOWorks, color images can be generated by using the RGB model and selecting the data to be used as R, G and B channels (see section 1.3 for indications on how to generate color images).

3.1.1 Pan-sharpening

A typical use of the RGB=>HIS transform when dealing with satellite images is pansharpening. Pan-sharpening is an image transform process using a panchromatic image for sharpening a color image i.e. to increase the image spatial resolution while keeping its spectral properties.

For Pan-sharpening images in LEOWorks, you need to select *Tools/Pan Sharpening* from the main menu. When doing this, the dialog *Select files/bands* will be displayed. Then, you have to select the Red, Green and Blue channels to be sharpened and the Panchromatic image to be used for sharpening.

🛓 Select files	/ bands
Red band:	Venice_Landsat_ETM_multispectral:band_3 👻
Green band:	Venice_Landsat_ETM_multispectral:band_2 👻
Blue band:	Venice_Landsat_ETM_multispectral:band_1 👻
Pan band:	Venice_Landsat_ETM_panchromatic:band_1
	OK Cancel Help

In the image below an example is given. The initial RGB combination of the three bands to be sharpened is displayed on the left, the Panchromatic image on the center and the resulting Pan-sharpened image on the right".



In this example the bands 4, 3 and 2 of a Landsat dataset were used as R, G and B channels respectively, while band 8 of the same dataset was used as a higher spatial resolution band.

Before applying a pan-sharpening, your data need to be prepared so that:

- the panchromatic and the multispectral datasets are accurately co-registered;
- the panchromatic and the multispectral have the same geographical extent.

For co-registering accurately two datasets, please refer to chapter 6.2 (Image to image registration).

If the pan-sharpening datasets are not accurately co-registered, strange effects may appear on the images (see image below).



a-Panchromatic image; b-Image of a Red band of a multispectral dataset; Images a and b are not accurately co-registered; c-Pan sharpening result; Artifacts due to not accurate co-registration are visible in image c

To ensure that two datasets are extending over the same area, the *Spatial Subsetting* tool available in LEOWorks can be used.



The *Spatial Sub-setting* tool (see image above) is activated each time a file is opened. Alternatively, the tool can be activated by selecting *Tools/Subset Image*. An accurate geographic subset of an existing dataset can be defined by specifying the North latitude bound, West longitude bound, South latitude bound and East latitude bound parameters.

The easiest way for performing pan-sharpening would be to use panchromatic and multispectral data measured by the same sensor, as actual remote sensing systems are able to acquire such datasets simultaneously. This way, the data will be perfectly co-registered and covering the same geographical area.

3.2 Radiometric processing

3.2.1 Histograms

A histogram is a specific graph used to display image statistics. In its most common form, the independent variable (the number of gray levels – 256 in many cases) is plotted along the horizontal axis, and the dependent variable (usually the number of pixels) is plotted along the vertical axis. A histogram can help us decide what changes might enhance the quality of the image. By changing the shape of the histogram, the balance of the image will be influenced. In an "image-processing" context, the histogram of an image normally refers to the frequency of the pixel intensity values. In other words, ahistogram is a graph showing the number of pixels in an image at each different intensity value found in that image. For an 8bit grayscale image there are 256 different possible intensities, and so the histogram will graphically display 256 numbers showing the distribution of pixels amongst those grayscale values. Histograms can also be taken from color images, computing individual histograms of red, green and blue channels.



The illustration shows two classification examples based on the histogram shown. One classification has four classes (agriculture, village, town, and other) whereas the other has two (rural and town). Credits ESA

3.2.2 Interactive stretching

Besides inspecting image statistics as shown in 3.3, histograms can be used to interactively stretch the range of the Digital Number (DN) i.e the numbers representing pixels and used to display an image. In LEOWorks, an interactive stretching tool can be accessed by selecting *Tools/Interactive Stretching*.

Interactive stretching allows controlling the image histogram over a range of DNs. Drag the vertical lines and the output histogram will be stretched, while the current image will show the results. Note that the process might be quite slow for large images. In this case, unchecking the *Auto apply modification* button will improve the performance.



Interactive stretching is used to enhance the visual quality of a gray scale or color images; pre-defined transformations can be applied to image data, such as histogram equalization, as well as extending the value range domain to 95% of the pixel values

The *Interactive Stretching* tool in LEOWorks displays both the histogram of the original data ("Original" histogram) and the histogram associated to the image being displayed ("Displayed" histogram). When color images are displayed i.e. 3 spectral bands of the original data are used as R, G and B channels, 3 pairs of "Original" and "Displayed" histograms will be displayed.

The DNs range can be modified by moving the histogram slider left-right. See an example bellow showing original and enhanced images.

3.2.3 Filters

Filters are used to improve the quality of the raster image by eliminating spurious data or enhancing features in the data. The no-data values of the source band are not considered by the filter operation. There are several implemented filters grouped in 6 submenus, on a new window: Detect Lines, Detect Gradients, Smooth and Blurr, Sharpen, Enhance Discontinuities and Non Linear Filters. These filters can be accessed from the main menu *Tools/Apply Filter*.

🕌 Create Filtered Band
Filters:
Detect Lines Detect Gradients (Emboss) Smooth and Blurr Sharpen Detect Discontinuities Non-Linear Filters
Band name: filtered_band_1
OK Cancel Help

LeoWorks supports the following filters:

- Detect Lines : Horizontal Edges, Vertical Edges, Left Diagonal Edges, Right Diagonal Edges, Compass Edge Detector, Roberts Cross North-East, Roberts Cross North-West, Roberts Cross North-East;
- Detect Gradients (Emboss): Sobel North, Sobel South, Sobel West, Sobel East, Sobel North East;
- Smooth and Blur: Arithmetic 3x3 Mean, Arithmetic 4x4 Mean, Arithmetic 5x5 Mean, Low-Pass 3x3, Low-Pass 5x5;
- Sharpen: High-Pass 3x3 #1, High-Pass 3x3 #2, High-Pass 5x5;
- Enhance Discontinuities: Laplace 3x3, Laplace 5x5 ;
- Non-Linear Filters: Minimum 3x3, Minimum 5x5, Maximum 3x3, Maximum 5x5, Mean 3x3, Mean 5x5, Median 3x3, Median 5x5, Standard Deviation 3x3, Standard Deviation 5x5, Root-Mean-Square 3x3, Root-Mean-Square 5x5.

Examples of several filters:



Original image

3x3 Min

High-Pass 5x5

3.3 Geometric processing, Transformations

There are many ways of geometrically processing or transforming an image. Some of the most common geometric operators are described below:



Image translation using positive values in both x and y directions;





45 degrees image rotation around (0,0) reference point;



Image scaled by a factor of 1.2 in x and y;



Image flip vertical/horizontal.

To apply one of the geometric operators described in the above paragraph in LEOWorks, you need to select *Tools/Transformations*.

When using the transformation methods, you will be asked to type in some values for the operator's specific parameters and to select the interpolation method, namely the method to be applied for resampling the output image. The interpolation methods are described in the next section.

3.4 Interpolation methods

In order to geometrically correct a distorted image, a procedure called resampling is used. This method determines the digital values to place in the new pixel locations of the corrected output image [CCRS]. The resampling process calculates the new pixel values from the original digital pixel values in the uncorrected image. You will find in LEOWorks three resampling methods: nearest neighbor, bilinear interpolation, and cubic convolution.

Nearest neighbor resampling uses the digital value from the pixel in the original image which is nearest to the new pixel location in the corrected image (see picture below). This is the simplest method and does not alter the original values, but may result in some pixel values being duplicated while others are lost. This method also tends to result in a disjointed or blocky image appearance.



Bilinear interpolation resampling takes a weighted average of four pixels in the original image nearest to the new pixel location (see picture below). The averaging process alters the original pixel values and creates entirely new digital values in the output image. This may be undesirable if further processing and analysis, such as classification based on spectral response, is to be done. If this is the case, resampling may best be done after the classification process.



Cubic convolution resampling goes even further to calculate a distance weighted average of a block of sixteen pixels from the original image, which surround the new output pixel location (see image below). As with bilinear interpolation, this method results in completely new pixel values. However, both these two methods produce images, which have a much sharper appearance and avoid the blocky appearance of the nearest neighbor method.



4. Band arithmetic

4.1 The Band Arithmetic dialog

The *Band Arithmetic* tool ^{**} creates a new image derived from the combination of existing bands. To do so, mathematical operations are used. The users should be careful when defining the math expression, because a correct syntax must be specified.

A name can be specified for the new image. In addition, a description and the units can be optionally provided.

Use the *Edit expression* button to define the mathematical expression. A new window will appear. In our example we chose to create an average image based on the following formula:



(Band1+Band2)/2

After the formula was written correctly, a green text will appear in the right corner: *OK, no errors*. Now you can click the *OK* button.

Because the written formula can vary in complexity, the output bands are always stored as real values and an immediate display of such bands can lead to black images. A better image can be obtained by applying *Tools / Interactive Stretching*. Alternatively, a datatype conversion can be applied by selecting *Tools / Convert* to convert, for example, to 8 bit data.

4.2 Compute a NDVI

The Normalized Difference Vegetation Index (NDVI) is used to measure and monitor plant growth, vegetation cover and biomass production from multispectral remotely sensed data. It is computed as a division between the difference and the sum of the atmospheric corrected NIR and RED bands of remote sensing dataset:

NDVI = (NIR Band – RED Band) / (NIR Band + RED Band)

The RED Band is the red part of the visible spectrum ($0.58-0.68 \mu m$). The NIR Band is the near infrared part of the spectrum ($0.725-1.1 \mu m$). In the case of Landsat TM and ETM images, RED Band correspond to band 3 and NIR Band to band 4.

The NDVI index is computed this way because, healthy vegetation reflects very well in the near infrared part of the spectrum while having low red light reflectance and so producing high values for NDVI.

The values obtained for NDVI range from -1 to +1 but the vegetated land has a NDVI ranging from 0.1 to 0.7-0.8. Values greater than 0.5 indicate dense and vigorous vegetation.

In our case, using Romo.tif example, specify from the next window a Name and the bands corresponding to the Red Channel (3) and NIR Channel (4). After that a formula will appear in the Band maths expression. Click the *OK* button and wait for a moment.

🛓 Compu	ite NDVI
Source: [5] Venice	_Landsat_ETM_multispectral 👻
Name:	ndvi_1
RED Band:	band_3 🔹
NIR Band:	band_4
Band math	s expression:
(band_4-b	and_3)/(band_4+band_3)
	OK Cancel Help

Explore the pixel values of the new created NDVI image using Pixel Info. By default,

a color palette is applied to the resulting image. Use *Color Manipulation* \square to specify different intervals of color for a better interpretation.

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Latitude	45.549072 (45°32'5)	7" N)	DD(DMS)	16.2		
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NDVI derived from band 3 and 4 of Venice Landsat data

5. Attaching coordinates to pixels

Geocoding

When analyzing satellite images, you may want to know the position of the visible objects and phenomena on the Earth surface. In digital image processing this is possible using a geocoding i.e. a math transform allowing to compute coordinates for each pixel in an image. These coordinates are computed in a coordinate system related to the Earth surface.

GCPs

The registration procedures implemented in LEOWorks allow you to compute and attach geographic coordinates to every pixel in a satellite image i.e. to perform a Geocoding. The geocoding is in fact a math transform whose parameters are computed based on Ground Control Points (GCPs).

A GCP is a marker for a certain position within an image. The properties of a GCP are:

- its position inside the image (the image coordinates);
- its position on the Earth surface (the geographical or map coordinates);
- a graphical symbol showing its location on the image;
- the name (sometimes is helpful to have a name);
- and a textual description (if considered necessary).

5.1 Image to Map Registration

In Image to Map registration, the GCPs are selected exclusively by inspecting the image and choosing features that are also visible on a map in such a way their geographic or map coordinates can be accurately indicated. Geocoding a scanned map or a satellite image using GCPs, are typical cases of applying the Image to Map registration procedure. In general, the GCPs' coordinates are also determined using a GPS receiver.

As it can be seen in the image below, the GCPs' coordinates are indicated in the map coordinate system. They can also be indicated as latitude, longitude (geographical) coordinates. It is very important to provide the coordinate system of the GCPs used to compute the geocoding. It is also important to not concentrate the GCPs on one location of the image but to choose them on the overall image. Note that at any time you can import or export a set of GCPs previously defined. Note also that the GCPs become visible by clicking the image and the *Show GCPs* button in the toolbar or the *View/GCPs* menu.

Once you have enough GCPs (minimum required is 4, but it is recommended to have at least 6 or more to obtain the best results) for computing the geocoding using the chosen math transform, the *Attach* button becomes active and you can click it to compute the geocoding.

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For simplicity and easiness, the geocoding attached will show latitude and longitude coordinates in WGS84.

After performing the registration process and clicking the *Attach* button, if you choose *Inspect/Information...* from the main menu, you will have on the *Geocoding* tab a description of the geocoding applied to your image i.e. the image is georeferenced.

()	Y	East	North	Delta E	Delta N	Label	GCP
42.500 4	481.500	25.136883	44.580193	0.000002	0.000023	GCP 7	<u>+</u> -
055.5 2	280.500	25.941870	44.626492	0.000002	0.000023	GCP 2	
095.5 2	2798.5	25.952188	44.050632	0.000002	0.000019	GCP 3	
65.500 2	2847.5	25.054138	44.038857	0.000002	0.000023	GCP 4	
							•
Current C	GCP Geo-	Coding	Attach /	/ Detach Geo	-Coding) 4 >	
	GCP Geo-	Coding WGS84			– Coding WGS84(D) ∢ [►]	
Current C CRS: RMSE Lat		3	GCP CRS	5:	5) 4 F 9D)	

5.2 Image to Image Registration

In Image to Image registration, the GCPs required for the geocoding are defined based on a geocoded image i.e. the image to geocode is considered as a slave image while another geocoded image is considered as a master image. See the image bellow for an example on identifying the same feature on two satellite images and on a map.

In LEOWorks, this procedure can be accessed by selecting *Tools/Registration/Image to Image*. The tool is enabled only when at least two data viewers are available.



The GCP placing tool becomes available after selecting the Master and Slave views in the *Collect GCPs – image to image* window. If GCPs are not visible in any of the viewers, you can make them visible by selecting the image and then *View/GCPS* from the main menu (the same result is obtained by clicking the *Show GCPs* button in the toolbar).

When clicking in the slave image, the image coordinates of the GCPs are recorded, while clicking in the master image, the geographical coordinates are recorded. That is why, when doing Image to Image registration, you need to indicate the slave view containing the image to be geocoded and the master view containing the geocoded image. See the image bellow.

000 x	Y	Collect GCF East	North	Delta E	Dalas N	Label	GCP
	•				Delta N	Label	
	177.500	8.549438	55.152462	0.000004	0.000000	GCP 1	
30.500	125.500	8.549168	55.166527	0.000003	0.000000	GCP 2	_* •
21.500	35.500	8.573785	55.190872	0.000002	0.000000	GCP 3	
00.500	150.500	8.568104	55.159763	0.000002	0.000000	GCP 4	- 1
Current	Geo-Cod	ing	Attach / D	etach GCP C	eo-Coding-		
Current	Geo-Cod	ing	Attach / D Master Vie				
Current RMSE La		ing 0.0		w [2] ba	nd_3		
	t:	-	Master Vie	w [2] ba	nd_3		

As in the Image to Map registration, coordinates are attached to pixels after clicking the *Attach* button. The button is enabled only if a sufficient number of GCPs is selected which in turn depends on the selected method (Linear, Quadratic or Cubic Polynomial).
5.3 Reprojection

Reprojection is the procedure that converts a cartographic projection to another. It can be applied to both, raster and vector data. We try now to reproject the Romo.tif image, which is in the UTM Zone 32N projection, to a Geographic Lat/Lon system.

The *Reprojection* window contains two tabs which needs some specifications from the user. First of all, a name for the new image, in that case "Venice_Landsat_ETM_multispectral_reprojected", and a destination folder. Then, in the *Parameters* tab you must specify the new projection (Geographic lat/Lon WGS84). Press *Run* and look to the new product using *Information* dialog button. The Geographic Projection is shown in the *Geo-Coding* tab.

Reprojection	Reprojection
I/O Parameters Reprojection Parameters	I/O Parameters Reprojection Parameters
Source dataset Name: [5] Venice_Landsat_ETM_multispectral	Coordinate Reference System (CRS) © Custom CRS
	Transformation: Geographic Lat/Lon (WGS 84)
Target dataset	Geodetic datum: World Geodetic System 1984
Name:	Transformation Parameters
Venice_Landsat_ETM_multispectral_reprojected	Predefined CRS Select
V Save as: BEAM-DIMAP Directory:	O Use CRS of [2] Venice_Landsat_ETM_panchromatic
C: \Users\adrian.stoica \eoworks.data	Output Settings
V Open in LEOWorks	Preserve resolution Output Parameters
	No-data value: NaN
	Resampling method: Nearest 👻
	Output Information
	Scene Width: 1109 pixel Center Longitude: 12°19' E
	Scene Height: 656 pixel Center Latitude: 45°29'35" N
	CRS: WGS84(DD) Show WKT
Run Close Help	Run Close Help

The same steps are necessary for vector data, if you need to convert its projection.

6. Radiometric calibration

6.1 Why radiometric calibration

Collecting information about the energy reflected or reemitted by objects through remote sensing is possible by using instruments placed on satellites or airplanes.

The energy reaching the remote sensing instrument is quantitatively and qualitatively influenced by the atmosphere as the electromagnetic radiation, either coming from the Sun or from an active instrument, it has to travel through it.

Using radiometric calibration, it is possible to reduce the atmospheric effects and improve the interpretations of the remote sensing data.

6.2 The Calibrate tool

Use the *Calibrate* tool in order to calibrate the values from an image with measurements made on the field.

The calibration procedure involves a validation using reference data. The new result is based on a polynomial function. You can use in a further step the *Interactive Stretching* in order to obtain a better visualization, like in the next example:



Landsat band 6 showing temperature values after radiometric calibration. There are many applications using thermal bands (in the case of Landsat TM sensor the resolution of band 6 is 120m and 60m for Landsat ETM), ocean turbidity, Chlorophyll concentration etc.

To perform a radiometric calibration in LEOWorks, you have to open and display the bands you want to calibrate and select *Tools/Calibrate*.

No	X	Y	Raw	New	Delta E	Label	GCP
L	410.500	81.504	36.642	35.000	1.642	GCP 1	
	528.500	153.504	32.670	34.000	-1.33	GCP 2	1
	615.500	232.504	26.218	25.000	1.218	GCP 3	- A 1
	755.500	417.504	31.419	33.000	-1.581	GCP 4	
5	763.500	566.504	20.051	20.000	0.051	GCP 5	
							2

A typical calibration process would involve the following steps:

- select the method to be used for the transformation to be applied to each pixel in the band. The method can be chosen between linear, quadratic and cubic polynomial functions. The choice of the method will determine the number of points selected on the image and measured on the field;

- select on the image the points for which the field values are known (e.g. temperature);

- type the known field values in the table displayed in the *Calibration* window, in the *New* column

- click the calibrate button and check the delta values for each point; alternatively you can inspect the graph of the calibration function (see below)



7. Image classification

Digital image classification

Digital image classification uses the spectral information represented by the digital numbers in one or more spectral bands, and attempts to classify each individual pixel based on this spectral information. The objective is to assign all pixels in the image to particular classes or themes (e.g. water, coniferous forest, deciduous forest, corn, wheat, etc.). As a result, the classified image consists of a mosaic of pixels, each of which belong to a particular theme, and is essentially a thematic map of the original image.

Common classification procedures can be broken down into two broad subdivisions based on the method used: *supervised classification and unsupervised classification*.

7.1 Unsupervised Classification

In unsupervised classification, spectral classes are grouped first, based solely on the numerical information in the data, and are then matched (if possible) by the analyst to information classes.

Unsupervised classification can be used to cluster pixels in a data set based on statistics only, without any user-defined training classes.

Cluster analysis (or clustering) is the classification of objects into different groups, or more precisely, the partitioning of a data set into subsets (clusters or classes), so that the data in each subset (ideally) share some common trait - often proximity according to some defined distance measure. Data clustering is a common technique for statistical data analysis, which is used in many fields, including machine learning, data mining, pattern recognition, image analysis and bioinformatics. The computational task of classifying the data set into k clusters is often referred to as k-means clustering.

In LEOWorks, the k-means clustering algorithm is used. Given the number of clusters k, the basic algorithm is:

- randomly choose k pixels whose samples define the initial cluster centers.
- assign each pixel to the nearest cluster center as defined by the Euclidean distance.

- recalculate the cluster centers as the arithmetic means of all samples from all pixels in a cluster.

- repeat previous steps until the convergence criterion a priori defined by the user is met.

To perform an unsupervised classification in LEOWorks:

- 1. Open the image you want to classify;
- 2. Open the *Classification* Manager by selecting *Tools/Classification/ Unsupervised*;
- 3. In the *Unsupervised Classification* dialog, on the *I/O parameters* tab, choose the name for the target dataset;

4. In the *Unsupervised Classification* dialog, on the *Processing Parameters* tab, set the values for the parameters;

(솔) Unsupervised Classification 🛛	Supervised Classification
I/O Parameters Processing Parameters	1/O Parameters Processing Parameters
Source dataset source:	Number of classes: 14
[1] Venice_Landsat_ETM_multispectral	Number of iterations: 30
	Random seed: 31415
Target dataset Name: Venice_Landsat_ETM_multispectral_Unsupervised ✓ Save as: BEAM-DIMAP ▼ Directory: D:\Leoworks ✓ Open in LEOWorks	Source band names: band_1 band_2 band_3 band_4 band_5 band_6 band_7 band_1_calib
Run Close Help	Run Close Help

- 5. Press *RUN*; After processing is finished, a new dataset will be added in the *Available Datasets* window;
- 6. Double click the band named "X classes" to display it; a color image will be displayed showing the result of the unsupervised classification;



7. By selecting *Tools/Classification/Report*, you can display a classification report, showing the frequency and number of pixels and the estimated area for each class; the report can be exported in a .csv (comma separated values) format by pressing the *Export* button on the right side of the window; the file can be further open and analyzed e.g. using Microsoft Excel;

Class	Pixel Value	Frequenc	No. of Pi	Area(sq m)	1
Unclassified	0	0	0	0	
class_1	1	21.206	109,870	98,883,000	
class_2	2	11.639	60,303	54,272,700	
class_3	3	9.236	47,850	43,065,000	
class_4	4	9.16	47,456	42,710,400	
class_5	5	7.7	39,892	35,902,800	
class_6	6	7.49	38,805	34,924,500	
class_7	7	7.143	37,007	33,306,300	
class_8	8	5.648	29,263	26,336,700	
class_9	9	5.584	28,933	26,039,700	
class_10	10	4.497	23,300	20,970,000	
class_11	11	4.176	21,638	19,474,200	
class_12	12	2.903	15,043	13,538,700	
class_13	13	2.757	14,282	12,853,800	
class_14	14	0.861	4,463	4,016,700	
Total		100	518,105	466,294,500	

8. By selecting *Tools/Classification/Legend*, you can display the legend showing the colors used to display the classes (see image below); you can edit the color for each class by clicking the color, choosing another one and clicking the *Apply* button. Once edited, a legend can be saved (by clicking the export color palette button) and further re-used (by clicking the import color palette button) to display classification results (of course, the result should contain the same number of classes); the legend can also be exported as image by clicking the *Save legend as image* button (this can be useful e.g. in writing a report or composing a map).

Class	Colour	Apply
Unclassified	232, 237, 174	ົລ
class_1	98, 46, 179	
class_2	186, 166, 187	🛛 💾 🛗
class_3	8, 56, 151	-
class_4	10, 235, 165	
class_5	42, 147, 63	
class_6	124, 7, 240	
class_7	108, 26, 160	
class_8	220, 254, 108	
class_9	I 172, 2, 111	
class_10	I89, 144, 247	
class_11	— 116, 211, 155	
class_12	58, 245, 54	
class_13	27, 163, 103	
class_14	112, 74, 246	

The resulting classes are somewhat artificial and based purely on statistics but can at the same time be real. Often they can be attributed to real land cover features such as crops, roads, settlements, tidal flats etc.

7.2 Supervised Classification

The supervised classification allows the user to define the classes to be identified in the image by the use of training fields. Then, based on a decision rule, the pixels are classified according to their spectral signatures (values in each band) and the signature of each class (statistical parameters derived from the training fields). The decision rule is varying from one method to another. In LEOWorks, three supervised classification methods are made available:

- Minimum distance;
- Parallelepiped;
- Maximum likelihood.

For more details about these methods, you can check different remote sensing image analysis books.

Training Fields

In LEOWorks you can define training fields using the tools made available for this purpose in the classification manager:

- 1. After displaying an image (can be either a gray scale image of a band or a color combination of three bands), make the *Classification Manager* window visible, if not visible, by selecting *Tools/Classification/Supervised*.
- 2. To create a class, you need to click the *Create class* button . It is always needed to give it a name and it is also useful to type in a description. The new class will be added in the *Existing classes/training fields* list in the *Classification Manager* window.

Name			Descriptio	Description			
Agriculture	9		arable fiel	arable fields			
Urban			bildings ar	nd industiral f	acilities		
Sea Deep							
Sea Shallo	W						
Bands	Min	Max	Mean	St. dev	No. pixels		
band_1	72	87	79.889	1.899	7115		
band_2	63	79	71.062	2.723	7115		
band_3	43	58	51.123	2.240	7115		
band_4	13	18	15.080	0.727	7115		
band_5	8	16	11.597	0.928	7115		
band_6	130	134	132.501	0.658	7115		
band_7	5	15	10.309	1.259	7115		
band 1 c.	0	41	28.214	5.133	7115		

3. Select the class, click the *Draw Polygon TF* tool and start drawing training fields on the image; to define more classes, repeat the steps 2 and 3; in the figure bellow an example is given in which 3 classes were defined; you can always edit the colors used to display a class or delete a class by pressing the appropriate buttons in the *Classification* window; for any defined class you can load TFs from an existing .shp file by selecting a class and clicking the *Import TF from shape file for selected class* button; alternatively you can import TFs from a shape file for all classes (if classes are not defined, they will be created according to information existing in the selected shape file);

TFs with defined classes can be exported in a shape file; to do so, you need to select the desired classes and click the *Export TF to shapefile* button



- 4. For each of the defined classes, you can inspect the statistics by simply selecting the class in the *Existing classes/training fields* list and watching the panel below that list.
- 5. You can also inspect the statistics of any individual TF by clicking the *View statistics for a single TF* button and then clicking a training field; see the example below.



6. To perform the classification considering the defined classes and display the results, you need to select one of the supervised methods in the *Classification method* list and then go through steps 4 to 8 defined in the Unsupervised classification section; when processing finishes, the result is automatically added in the *Available Datasets* window and can be displayed (see image below).



7. As in the case of unsupervised classification, the classification report can be generated and the classification legend can be edited and saved (see steps 7 and 8 in the previous section).

8. Radar Images

SAR sensors operate in the microwave region of the electromagnetic spectrum with typical wavelengths between 1cm and several meters. As an active system, a SAR emits by itself microwave radiation to the ground and measures the electric field backscattered by the illuminated ground patch. These measurements are transformed into a high resolution image. Because SAR systems are operated with an illumination of its own, they can perform equally well during day and night.

LEOWorks includes a reduced set of tools for processing SAR (Synthetic Aperture Radar) data. A simplified view of the workflows one can follow to process radar data is shown in the diagram below.

Due to the high complexity of the processing, all radar data processing workflows need to start with data stored in native formats, such as ENVISAT ASAR (.N1), ERS (.E1) or Sentinel 1 (.tiff).

Such sample data can be downloaded from the LEOWorks website: http://leoworks.terrasigna.com/

A normal processing chain for radar images may include the following steps:

Raw (detected data) -> Radiometric Calibration -> Terrain Correction -> Speckle Filtering -> Ocean tools

8.1 Radiometric calibration of radar data

The objective of SAR calibration is to provide imagery in which the pixel values can be directly related to the radar backscatter of the scene. This is a mandatory step in most of the workflows involving radar data.

In LEOWorks, a simplified procedure is made available in which the type of data (i.e. coming from an SENTINEL, ENVISAT, ERS, RADARSAT etc. mission) is automatically identified and the radiometrically calibrated image is produced. The Calibration is available in *Tools/Radar/Radiometric Correction/Calibrate*, where the user has to select the Source and the Target dataset, as well as the source Band and a possible External Auxiliary File, to be used.

Calibration	Calibration 33
I/O Parameters Processing Parameters Source dataset source: [1] ASA_WSM_IPNIPA20021117_104436_000000672011_00180_03741_004 ♥ Target dataset Name: ASA_WSM_IPNIPA20021117_104436_000000672011_00180_03741_0043.N1_Callb	I/O Parameters Amplitude Amplitude Intensity Source Band: External Aux File: Scale in dB Create gamma0 virtual band Create beta0 virtual band
Run Close Help	Run Close Help

An example of a radar image sample, before and after applying a radiometric correction procedure is given in the figure below.



Details on setting the input and the output for this procedure are given in the LEOWorks help pages, accessible from the Help menu.

8.2 Terrain correction

Due to topographical variations of a scene and the tilt of the satellite sensor, distances can get distorted in the SAR images. Image data not directly at the sensors' Nadir location will have some distortion. Terrain corrections are intended to compensate for these distortions so that the geometric representation of the image will be as close as possible to the real world.

In LEOWorks, such a procedure is available in which the type of data (i.e. coming from an SENTINEL, ENVISAT, ERS, RADARSAT etc mission) is automatically identified and the terrain corrected data is produced. The procedure is available in *Tools/Radar/Geometric/Terrain Correction/Range-Doppler Terrain Correction,* where the user has to select the Source and the Target dataset, as well as the source Band and different processing parameters to be used.

Range Doppler Terrain Correction	Range Doppler Terrain Correction
File Help	File Help
File Help I/O Parameters Processing Parameters Source Product source: [1] ASA_WSM_IPXPDE20021117_104431_000000672011_00180_03741_0009.N1	File Help I/O Parameters Processing Parameters Source Bands: Amplitude Intensity Digital Elevation Model: SRTM 3Sec (Auto Download) DBM Resampling Method: BILINEAR_INTERPOLATION DBM Resampling Method: BILINEAR_INTERPOLATION Source GR Pixel Spacings (az x rg): 75.0(m) x 75.0(m) Pixel Spacing (deg): 6.73736463009641E-4 Map Projection: WGS84(DD) I/Mask out areas without elevation Output complex data Output bands for: Output complex data
	Selected source band DEM Latitude & Longitude
	Incidence angle from ellipsoid Local incidence angle Projected local incidence angle
	Apply radiometric normalization
	Save Sigma0 band Use projected local incidence angle from DEM V
	Save Gamma0 band Use projected local incidence angle from DEM
	Save Beta0 band Auxiliary File (ASAR only): Latest Auxiliary File
Run Close	Run Close

In the figure below is given an example of a radar image sample, before (left image) and after applying a terrain correction procedure (right image).



8.3 Speckle filtering

Radar images are generated from data obtained after coherent analysis of interaction between the transmitted microwave and the Earth surface. The speckle noise arises from coherent summation of the signals scattered from ground scatterers distributed randomly within each pixel. The speckle noise is sometimes suppressed by applying a speckle removal filter on the digital image before display and further analysis.

In LEOWorks, two procedures are available for reducing the speckle in the radar data, in *Tools/Radar/Speckle filtering/*

- Multi-temporal Products
- Single Products

In the command window, the user has to select the Source and the Target dataset, as well as the source Band and type of filter to be used.

Reprojection	Reprojection
I/O Parameters Reprojection Parameters	I/O Parameters Reprojection Parameters
Source dataset Name:	Coordinate Reference System (CRS)
[5] Venice_Landsat_ETM_multispectral	Custom CRS
	Transformation: Geographic Lat/Lon (WGS 84)
Target dataset	Geodetic datum: World Geodetic System 1984 -
Name: Venice_Landsat_ETM_multispectral_reprojected	Transformation Parameters
Vence_candade_nn_indidspect al_eprojected	Predefined CRS Select
Directory:	Use CRS of [2] Venice_Landsat_ETM_panchromatic
C:\Users\adrian.stoica\leoworks.data	Output Settings
V Open in LEOWorks	Preserve resolution Output Parameters
	No-data value: NaN
	Resampling method: Nearest 👻
	Output Information
	Scene Width: 1109 pixel Center Longitude: 12°19' E
	Scene Height: 656 pixel Center Latitude: 45°29'35" N
	CRS: WGS84(DD) Show WKT
Run Close Hep	Run Close Help

An example of a radar image sample, before and after applying a speckle reduction procedure is given in the figure below.



Details on setting the input and the output for this procedure are given in the LEOWorks help pages, accessible from the Help menu.

8.4 Ocean tools

One of the main application domains of radar data is the observation of the marine environment and the analysis of objects and phenomena on the ocean and sea surface.

In LEOWorks, radar data can be used to:

- identify ships
- estimate the wind field
- detect oil spills
- create land / sea masks

8.4.1 Object Detection

The operator is used to detect objects such as ships on sea surface from SAR imagery, and is available in *Tools/Radar/Ocean tools/Object Detection*.

The object detection operation consists of the following four major operations:

- 1. **Pre-processing:** Calibration is applied to source image to make further pre-screening easier and more accurate.
- 2. **Land-sea masking:** A land-sea mask is generated to ensure that detection is focused only on the area of interest.
- 3. **Pre-screening:** Objects are detected with a Constant False Alarm Rate(CFAR) detector.
- 4. **Discrimination:** False alarms are rejected based on object dimension.

To run the processor some parameters have to be set:

- For Adaptive Thresholding operator, the following parameters are used (see Figure 2):
 - 1. Target Window Size (m): The target window size in meters. It should be set to the size of the smallest target to detect.
 - 2. Guard Window Size (m): The guard window size in meters. It should be set to the size of the largest target to detect.
 - 3. Background Window Size (m): The background window size in meters. It should be far larger than the guard window size to ensure accurate calculation of the background statistics.
 - 4. PFA (10^(-x)): Here user enters a positive number for parameter x, and the PFA value is computed by 10^(-x). For example, if user enters x = 6, then PFA = 10⁽⁻⁶⁾ which is 0.000001.

1-Read 3-AdaptiveTh	resholding	4-Object-Discrimination	5-Write	
Target Window Size (m):				80
Guard Window Size (m):				400.0
Background Window Siz	e (m):			600.0
PFA (10^(-x)):				6.5

- For Object Discrimination operator, the following parameters are used (see Figure 3):
 - 1. Minimum Target Size (m): Target with dimension smaller than this threshold is eliminated.

2. Maximum Target Size (m): Target with dimension larger than this threshold is eliminated.

80.
400.

Results of applying object detection to identify ships are given in the pictures below. To display the results of Object detection, one should access Layer manager (*View/Managers/Layer manager*), click the "+" button to add a layer and then select the appropriate layer containing the result.



8.4.2 Oil Spill Detection

The operator is used to detect dark spots such oil spills on sea surface from SAR imagery, and is available in *Tools/Radar/Ocean tools/Oil Spill Detection*.

The oil spill detection operation consists of the following four operations:

1. **Pre-processing:** Calibration and speckle filtering are applied to source image in this step.

- 2. **Land-sea masking:** Land-sea mask is created in this step to ensure that detection is focused only on area of interest.
- 3. **Dark spot detection:** Dark spots are detected in this step with an adaptive thresholding method.
- 4. **Clustering and discrimination:** Pixels detected as part of the dark spot are clustered and then eliminated based on the dimension of the cluster and user selected minimum cluster size.

To run the processor some parameters have to be set:

- 1. Source Bands: All bands (real or virtual) of the source product. User can select one or more bands for producing multi-looked images. If no bands are selected, then by default all bands are selected.
- 2. Background Window Size: The window size in pixels for computing local mean backscatter level.
- 3. Threshold Shift (dB): The detecting threshold is lower than the local mean backscatter level by this amount.
- 4. Minimum Cluster Size: The minimum cluster size in square kilometer. Cluster with size smaller than this size is eliminated.

Dil-Spill-Detection		Soll-Spill-Detection	X
1-Read 3-Oil-Spil-Detection 4-Oil-Spil-Clustering 5-Write		1-Read 3-Oil-Spill-Detection 4-Oil-Spill-Clustering 5-Write	
Source Bands:		Minimum Cluster Size (sq.lm):	0.1]
Background Window Size:	61		
(file) is null		[fie] is null	

Results of applying oil spill detection are given in the pictures below.



8.4.3 Wind Field Estimation

As the wind blows across the ocean surface, it generates surface roughness generally aligned with the wind direction. Consequently the radar backscatter from this roughened surface is related to the wind speed and direction. This operator retrieves wind speed and direction from C-band SAR imagery.

The operator is used to detect dark spots such oil spills on sea surface from SAR imagery, and is available in *Tools/Radar/Ocean tools/Oil Spill Detection*.

The general approach for the wind field retrieval is as the follows:

- 1. First a land-sea mask is generated to ensure that the estimation is focused only on the sea surface area.
- 2. Then the SAR image is divided into grid using user specified window size.
- 3. For each grid, a wind direction (with 180° ambiguity) is estimated from features in the SAR image using a frequency domain method.
- 4. With the wind direction estimated for the grid, finally the wind speed is estimated by using CMOD5 model for the Normalized Radar Cross Section (NRCS).

To run the processor some parameters have to be set:

- 1. Source Bands: All bands (real or virtual) of the source product. User can select one or more bands for producing multi-looked images. If no bands are selected, then by default all bands are selected.
- 2. Window Size: The dimension of a window for which wind direction and speed are estimated.

	ate-LandMask 3-Wind-Field-Estimation 4-Write	
1-Redu 2-Crea		
	Amplitude	
	Intensity	
Source Bands:		
Window Size (kn	0:	20.0

Results of applying wind field estimation are given in the pictures below.



To display the results of Wind Field Estimation, one should access Layer manager (*View/Managers/Layer manager*), click the "+" button to add a layer and then select the appropriate layer containing the result.

8.4.4 Create Land/Sea Mask

The Create Land Mask operation will turn any pixels on land into no data value. If the "preserve land" check box is set to true then all land pixels will be preserved and all ocean pixels will be set to no data value.

The operator will automatically download a course SRTM 5 minute DEM the first time it is used. This DEM is used to very quickly determine if a pixel is on land or

in the ocean. Alternatively, a geometry from the product could also be used. This could be a user create ROI or an imported Shape file.

The operator is available in *Tools/Radar/Ocean tools/Create Land Mask*.

The following parameters are used by the operator:

- 1. Source Band: All bands (real or virtual) of the source product. User can select one or more bands.
- 2. Mask the Land: Checkbox indicating that land pixels will become nodata value.
- 3. Mask the Sea: Checkbox indicating that sea pixels will become nodata value.
- 4. Use Geometry as Mask: Select a geometry or ROI from the product to use as the mask. Anything outside the area will be nodata value.
- 5. Invert Geometry: Anything inside the ROI or geometry will be nodata value.
- 6. Bypass: Skip any land masking.

I/O Parameters Proc	essing Parameters	
Source Bands:	Amplitude Intensity	
 Mask the Land Mask the Sea Use Geometry as 	F	
Bypass	pins	

Results of applying Mask Creation operator are given in the pictures below.



Details on each of the procedures and algorithms implemented in the Radar operators are given in the LEOWorks help pages, accessible from the Help menu.

9. Showing results

9.1 Feature extraction - GIS tools

9.1.1 Edit a vector layer

To create a new object in the selected and displayed vector layer, the user must start the editing on the selected layer. Steps:

1. Select the vector layer in the *GIS manager* and press the *Start Editing* button, as in the following image;



2. After the editing started, only one drawing tool will be active, according to the layer data type: polygon, polyline or point.

Press the button of the *active drawing* tool, then move the mouse cursor in the view area and insert points. Polygons and polylines can be closed with a double click.

9.1.2 Add/remove attribute fields

To add a new attribute field, press the *Add or remove attribute* button, as in the following image.



The *Add/remove attributes* dialog is shown, as in the next figure. To add a new attribute, insert the name for the new attribute field and select the field type as in the image below.

\checkmark	String
	Calendar date
	Integer
	Double

In LEOWOrks, fields of type: String (storing text), calendar date (storing e.g. data acquisition time), integers (for storing different types of numerical values e.g. population) or doubles (for storing e.g. percentage or area).

The *Add attribute* button is activated now (see image below). To add the new attribute press the *Add attribute* button. To remove an existing attribute, select the attribute to be deleted in the attribute list and press the *Delete attribute* button which should become activated. When all attributes are added or removed, press the *Apply changes* button. Pressing the *Ok* button, it closes the dialog.

ayer attributes	
New attribute name	
Attribute type	
String	
Attribute list	
Attribute Name	Attribute Type
osm_id	Long
name	String
type	String
Add attribute	Delete attribute
Add attribute	Delete attribute Add coordinates
Add attribute	
	Add coordinates
	Add coordinates
Add attribute SqMeters Meters	Add coordinates Add area attribute

9.1.3 Edit attribute field values

To set values for an attribute for the current edited layer, first make sure that the layer is selected in the *GIS manager* and that the editing session is opened on this layer. Then press the *Feature Table* button, as in figure.



The object and attribute table is shown, with the information that it is in the *Edit Mode*. To modify value for an attribute, execute double click in the cell that contains the attribute value. The cell can be edited and the attribute value can be modified.

						3
	Clear	Save Selec	tion	Refresh	Delete	?
Attribute values: B	EDIT MODE					
Feature identifer	Theme type	osm_id		name	type	
1	MultiPolygon	4724853			industrial	
10	MultiPolygon	19912075			residential	
100	MultiPolygon	45188519			residential	
101	MultiPolygon	45188521			residential	
102	MultiPolygon	45188522			farm	
103	MultiPolygon	45188523			residential	
104	MultiPolygon	45188524			farm]
		·				
Attribute name	Visible			istics on attrib		
Theme type	V	1	Statistics computed for the attribute Count : 1		e osm_ia:	
osm_id	V	-		: 45188521.0	0	
name	1	ł	Max	: 45188521.0	00	
type	v	t.		1 : 45188521.		
			Sum	: 45188521.0	00	

To stop the editing process, press the "Stop edit" button, as shown in the next figure.



9.1.4 Create a new vector layer

To create a new vector layer, there must be a vector layer or a raster layer already opened and displayed. The creation of a new vector layer starts by pressing the *New vector layer* button, as is shown in figure below.



The *New vector layer* dialog is shown, like in the following figure. The user must provide the layer name, in the *Layer name* edit field. The layer type can be selected from the *Layer type* panel, by ticking the button for point, polyline or polygon. The default value is point type. To add a new attribute, the user must set the attribute's field name in the *Attributes* panel, the *Name* edit field. The types can be selected from the *Type* list. After setting the attribute field name and type, the *Add attribute*

button is activated. To add the new attribute, press the *Add attribute* button, and it is added to the layer's attributes list, as in the figure below.

🔬 New layer			
Layer name MyNewTheme	Attribute definition Attribute Name Date	Attribute Type Calendar date	▼ Add attribute
Layer type Point Polyline Polygon	Layer attributes Attribute Name SHAPE StringAttribute DoubleAtrribute	Attribute Type Point String Double	Delete attribute
Create lay	er	Cancel	?

To remove an attribute, the latter has to be selected in the attributes list, from the *Attributes* panel. After the attribute is selected, the *Delete attribute* button is activated, as in the next figure. Pressing this button removes the attribute.

🛓 New layer			
	Attribute definition		
Layer name	Attribute Name	Attribute Type	Add attribute
MyNewTheme		Calendar date	- Add attribute
	Layer attributes		Delete attribute
Layer type	Attribute Name	Attribute Type	
	SHAPE	Point	
Point	StringAttribute	String	
Polyline	DoubleAtrribute	Double	
<u> </u>	Date	Calendar date	
Polygon			
Create laye	er	Cancel	?

After the setting of the layer name, the *Create layer* button is activated. To create the new vector layer, press this button. After pressing it, a window is shown, where the user is asked to select the folder where the new vector layer will be created.



9.1.5 Query by attribute field values

Access the *Query by attribute* dialog window either from the *Subset* dialog (when opening files) from the *subset by attributes* tab, or from the *GIS Manager*. The *Query by attribute* allows you to select objects in a vector GIS dataset based on their attribute values.

Query by attrib Queries on attribu		UTM_Venice.sh	p		
include					
Query	Query builder	Clear	Save Quer	y Result Refre	sh ?
Attribute values: \					
Feature identifer	Theme type	osm_id	name	type	
1	MultiPolygon	4724853		industrial	
10	MultiPolygon	19912075		residential	
100	MultiPolygon	45188519		residential	
101	MultiPolygon	45188521		residential	
102	MultiPolygon	45188522		farm	
103	MultiPolygon	45188523		residential	
104	MultiPolygon	45188524		farm	
105	MultiPolygon	45188525		residential	
106	MultiPolygon	45188527		residential	
107	MultiPolygon	45188528		farm	
108	MultiPolygon	45188529		residential	
109	MultiPolygon	45315262		farm	-

For generating a query, the *Query builder* is used (see figure above). The query values can be introduced by hand or be selected from a list, as in the following figure. The editable query field is marked with the red triangle.

the_geom	AND	OR	allotments
osm_id name	=		basin vineyard
type	<	<=	wood
	>	>=	grass residential
	LIKE	NOT LIKE	cemetery
	residential	Set query value	greenhouse_horti farmland
			village_green brownfield
(type LIKE '%residen	tiai%;)		

In order to perform a query on a selected layer, an attribute field must be selected in the *Theme attribute fields* list box, by clicking it. Then select the operator, by pressing one of the buttons situated in the *Query operation* area. After selecting the *Theme attribute field* and the *Query operation*, a query value must be set. Finally, press the *Set query value* button. The query is shown in the query area. Press the *Verify* button. If the query is correct, the message *Query is correct* is shown. By pressing the *Done* button, the query string is transferred to the *Object and attribute table* window. Press the *Close* button, to close the query builder. In order to execute the query, press the *Query* button in the *Object and attribute table* window. Press the *Query* button and the query is done directly. The query results are shown in the *Object and attribute window* and in the view, as in the following figure.

Landsat_ETM_20	01-08-26_mul	tispectral-ba	nd_1			
Query by attrit	outes: landuse	UTM Venice.s	hp			
Queries on attribu						
(type LIKE '%res	idential%')				1. 12	
	Duery builder	Clear	Save Query R	Refresh	? .	- A
	Zuci y Dallaci		Save Query i	Renear		ALSON !!
Attribute values:	VIEW ONLY				Bernith	
Feature identifer	Theme type	osm_id	name	type	10	
3	MultiPolygon	16307813	Murano	residential		KIS-
4	MultiPolygon	19908199		residential		
9	MultiPolygon	19911898		residential	12 8	71)5~
10	MultiPolygon	19912075		residential	1000	
11	MultiPolygon	19912364		residential	$\mathcal{K}^{\mathcal{F}}$	
12	MultiPolygon	19916665		residential		
25	MultiPolygon	30950038		residential	Party and	
27	MultiPolygon	30950133		residential	Sel	
29	MultiPolygon	30953673		residential	Ser	
37	MultiPolygon	36112741	Ca' Savio	residential		
40	MultiPolygon	44620863		residential		
41	MultiPolygon	44620906		residential	-	
P	T	A Color				

9.2 Composing and printing maps

The Map menu provides access to functions allowing one to create map compositions that can be printed or exported as PDF or JPEG files.

The Map menu contains the following functions:

- create a new map composition;
- add different types of elements to the map;
- print or export the map as PDF or JPEG;
- show or hide the map grid or the map composer ruler;

To create a new map composition, you have to choose the *Create* option and generate a predefined map composition using the image in the current viewer.

By default, the new composition contains a snapshot of the viewer to which the geographical coordinates of the upper left and lower right corners were added, together with a grid showing coordinates in map units, a scale bar and a North arrow (see the image below).

If the Viewer you start from contains a color-indexed image (e.g. resulting from a supervised or unsupervised classification), the legend of the image is automatically added in the map composition.

For getting a correct map grid and a good-looking map image, no-data (gray area) should be avoided in the viewer. To this goal, one may need to zoom and pan or even resize the viewer window.

The size of the page can be increased vertically and horizontally using the arrow keys. If the size is not modifying when using the arrow keys, this is because you previously edited a text map element and this still has the focus (it is the only map element that can hold the focus). To remove the focus and use the arrow keys again, you have to press the CTRL and TAB keys simultaneously.



To add different types of elements to the map, you have to click the *Insert* item in the map menu and then one of the elements being displayed when the menu is expanded.



9.2.1 Creating a Legend

For creating a legend to be included in your map, you need to generate a number of image samples and then to add text explaining the meaning of those samples as shown in the image below:

Legend



dense forest close to the urban area

havily urbanized - built-up area

For generating an image sample, you need to select *Map/Insert/Legend Imagette*. A dialog will ask you to select the size of the image that will be generated. Then you have to left-click on the map image at the desired location. A small image is acquired and inserted in the current map composition. This can be moved to the desired location or even resized.

To type the explanation for a certain legend element, you have to select *Map/Insert/Text*. A dialog asking to select the font type, size and color will be displayed and then a text box containing a predefined text will be added to the map composition. The text box can be edited and then moved to the right position.

9.2.2 Annotating with shapes

Adding lines, polygons, rectangles or ovals to the map composition is quite straightforward. After selecting the command from the *Map/Insert* menu and defining the line width and the line color, rectangles and ovals are automatically added to the map composition. Rectangles and ovals can be resized or moved.

For adding polylines or polygons, after selecting the appropriate command from the *Map/Insert* menu, you need to left-click on the image to define the polyline or polygon as desired. The line or polygon is ended with a double-click and the shape will be drawn. Polylines and polygons can only be moved.

9.3 Animations

By selecting *Animation* from the main Leoworks *Tools* menu, one can get access to a tool, which allows generating movies from individual satellite images stored in JPEG files. Once selected, the *Animation* tool allows you to select a number of images to be used for generating the movie.

Generating a list of files

You can add images by clicking the *Add* button. At any time you can remove or add new images, by pressing the *Remove* or *Add* buttons respectively. The list of available images is displayed in the *Input* panel of the *Animation* tool window.

You can also change the position of an image by pressing the *Up* and *Down* buttons.



Once added in the list, an image can be previewed by pressing the *Preview* button. Another possibility to preview the images is to click an image in the list and then use the *UP* and *DOWN* keys to move in the list and preview the images.

If the images are larger than the available frame they can be viewed using the sliders, BUT the animation will only run with the top-left part of the image. Such images have to be resized in order to view the animation of the complete image.

Setting the number of frames per second

In the frames per second panel, a cursor allows you to set the number of frames per second. Each image in your list is a frame in your future animation. Depending on the frames per second chosen value, your animation will be shorter or longer in time.

Preview and save animations

You can preview your animation by pressing the *Start animation* button. This will launch a continuous play of the newly created animation. This can be saved by pressing the *Save* button. A ".mov" file will be generated.

Any previously created animation can be played by pressing the Open button. Since all created animations are saved in .mov files, they can be played in mostly any media player installed on your computer.

----- Document END -----