User Guide of GuidosToolbox

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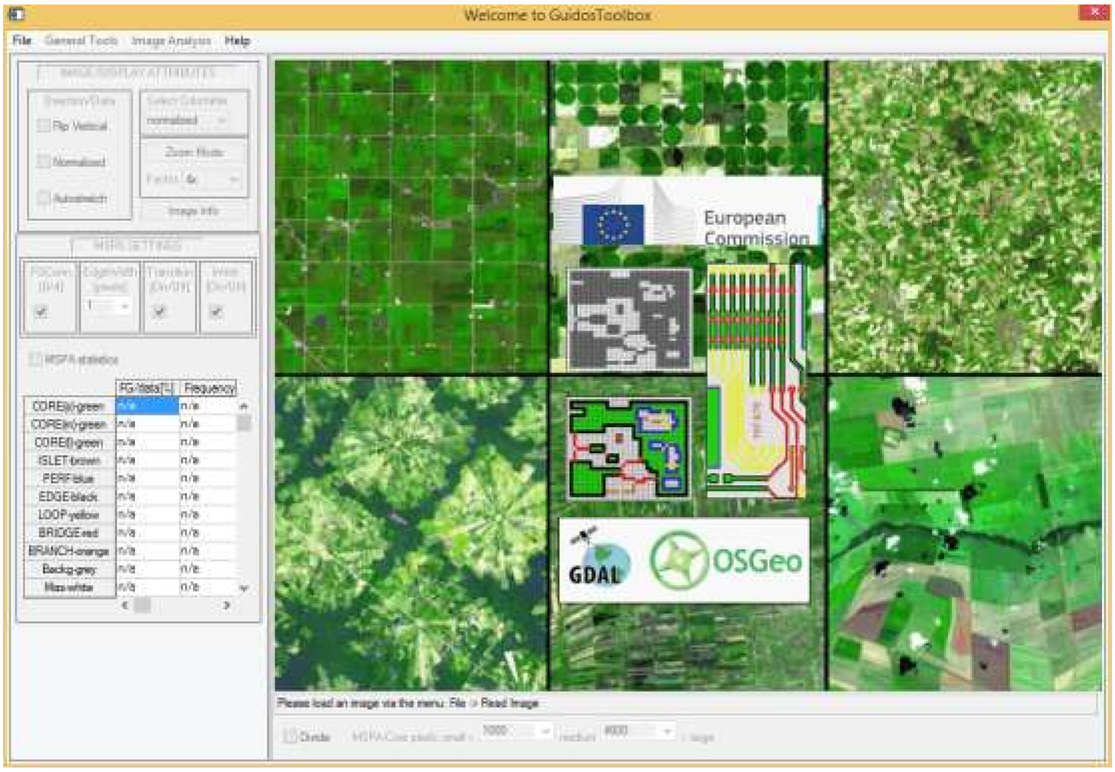
The GuidosToolbox (**G**raphical **U**ser **I**nterface for the **D**escription of image **O**bjects and their **S**hapes) provides generic image processing tools.

All tools are based on geometric concepts only and can thus be applied to any kind of raster data.

This document describes the various menus and features of GuidosToolbox:



Contents

The system requirements are a PC or a Mac with at least 2 GB of system memory, the more the better. This application has been tested on a variety of current Linux distributions, Intel-Mac® OS X 10.11, and Microsoft Windows® XP SP3 – Windows 10 platforms. The latest version of this application, including manual and installation instructions, can be obtained from the GuidosToolbox homepage.

Citation reference for GuidosToolbox:
Vogt P, 2016. GuidosToolbox (Graphical User Interface for the Description of image Objects and their Shapes): Digital image analysis software collection available at: http://forest.jrc.ec.europa.eu/download/software/guidos

If you use MSPA in your work then please add the following reference:
Soille P, Vogt P, 2008. Morphological segmentation of binary patterns. Pattern Recognition Letters 30, 4:456-459, DOI: 10.1016/j.patrec.2008.10.015

Windows and menus

The following graphical elements can be used to interact with GuidosToolbox:

- a horizontal menu bar (top panel)
- a window to set different attributes of the image and its graphical display (top left panel)
- a window to set MSPA parameters and statistics (bottom left panel)
- a viewport (right panel)
- a window for image coordinates & values (bottom right panel)

1. The menu bar of GuidosToolbox

The top menu bar offers 4 pull-down menus:

- File
- General Tools
- Image Analysis
- Help

1.1. The File pull-down menu

The File pull-down menu offers the following options:

- Read Image
- Save Image
- Batch Process
- Exit

1.1.1 Read image

This menu is used to read your input data:

- **GeoTiff:** **The default image type is GeoTiff** (a ".tif"-formatted file having information on projection, etc.). GeoTiff can be read or pre/post-processed by any image processing (IP) or GIS software.

- **Generic:** image of formats like tif, png, bmp, jpeg, etc.

- **IP Software:** IP software (ESRI, ARC, IDRISI, etc.) raster image formats like img, bil, etc. The included Gdal will try to convert these formats into GeoTiff. Alternatively, go back into your IP software and export the image to GeoTiff.

- **ENVI:** an image from an ENVI session (extension ".hdr"). GuidosToolbox will not use the geo-information of the ENVI-data. If you want to maintain the geo-information you should export the data in ENVI to GeoTiff and read this format in GuidosToolbox.

1.1.2 Save Image

This menu is used to save your processed data. The options are similar as in the Read menu. Additional options are:

- **Display Snapshot:** will save a snapshot of the current viewport in GuidosToolbox. This option may be suitable when working with a large image and a quick-look of the processed image is sufficient. In case of saving a MSPA result, the filenames will include the settings of the 4 MSPA parameters. If MSPA statistics were enabled, an additional file containing these statistics will be saved with the same notation and the additional suffix '_stat.txt'.

- **KML:** export to kml-format for visualization in Google Earth, requiring an image in the projection EPSG:4326 (WGS 84). To re-project either use reproject to GoogleEarth or start the GDAL Terminal and use the command gdalwarp and the appropriate EPSG reference codes. The result is stored in a zip-archive. Extract this archive at any location and load the included kml-file into Google Earth. When exporting a MSPA image, a customized header plus MSPA legend is added automatically.

The default data directory is the subdirectory 'data' located in the main GuidosToolbox directory.
Note: Please use the default GeoTiff format for maximum compatibility.

1.1.3 Batch Process

This option allows automatic processing of multiple files in batch mode. Input files must be in the default format (Geo-)Tiff. GuidosToolbox will save the output files in (Geo-)Tiff format to the same location of the input images. The default data directory is the subdirectory 'data' located in the main GuidosToolbox directory but you can use any other directory as well.

- **Conefor Inputs:** this option will generate the node file and the distance (connection) file in the format required by Conefor. The input file can be either a single image or a set of images with a background value of zero in a variety of raster image formats. The distances can be calculated as Euclidean edge-to-edge distance (8/4-connected) or centroid distance between all foreground objects of the raster image.

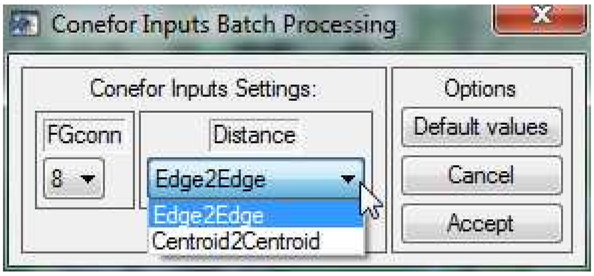


Figure 1: ***Conefor Inputs*: select 8/4-connectivity and distance measures**

The output is saved into the input data directory and contains the log-file 'ConeforInputs.log'; the node and distance file; and in case of centroid distance a dendrogram file for each valid input image.
Note: when using the option **Conefor Inputs** the connectivity is defined via the *pairwise distance* between image objects. This is different to the option **MSPA Conefor Inputs**, where the connectivity is defined via the MSPA-detected *structural connectors* (bridges).

- **Euclidean Distance:** batch-process images for **Euclidean Distance** maps and a summary of the distance histogram properties.

- **MSPA:** this option will open a window to select the MSPA parameters and a switch for statistical output. The resulting filenames will include the settings of the 4 MSPA parameters and, if selected, separate statistics.

- **MSPA Tiling:** this option will perform a MSPA-analysis with an automated buffered tiling of a single image which is larger than the standard maximum file-size (MS-Windows: 10000^2 pixels; Linux/Mac OS X: larger than 10000^2 pixels, depending on the available free RAM). After verifying MSPA-compliance a window will open where the MSPA parameters can be specified. No statistics will be calculated for these large images.

- **Moving Window:** this menu provides options for batch processing of several moving window algorithms. The dimension of the moving window can be specified via a popup window (Figure 3).

- **Fragmentation:** this menu provides several options for batch processing. More information on the individual options is available in the respective sections in this manual.

- **Recode:** first, select a sample image to set up the recoding table. Next, select a series of images to which this recoding table should be applied.

1.1.4 Exit

Quit the program and return to the operating system.

1.2. The General Tools pull-down menu

The General Tools pull-down menu provides generic image processing utilities, which may be useful for a variety of purposes. The following options are available:

- Preprocessing
- Convolution
- Equalization

- Thresholding
- Edge Enhance
- Morphological
- GIS Software
- Original Image
- Undo/Redo

1.2.1 Preprocessing

The Preprocessing menu provides several generic image-processing routines targeted to reassign image pixel values. These routines can also be used for setting up MSPA-compliant input images. The following options are available:

- **Convert → Byte:** convert your data to the data type Byte.

- **RGB → Single Band:** convert RGB-image to single-band image.

- **Reproject for GoogleEarth:** if the geo-header information of the currently loaded GeoTiff file has a EPSG code different to 4326 then this option can be used to reproject the image to EPSG:4326 (WGS 84).

- **Recode:** a table showing new and current unique pixel values is displayed. The new value entries in the left column can be reassigned to match the desired recoding of image class values. The *Save* button can be used to save a new recode table to a file GTrecode.sav. Any previously saved recoding table can be restored via the *Restore* button. Here, only those entries that match the current class values will be restored. This option is only available for images of data type Byte. Please note that you have to press the Enter key to get a new value accepted in the table.

- **Cost Marker Image:** this menu allows defining a marker image for the Cost analysis (p. 25). Instructions to mark start/target objects as points or polygons as well as missing data are provided via popup windows.

- **Threshold:** FG/BG: apply a threshold to a gray-scale image to obtain a binary image with foreground and background (FG/BG).

- **Group: FG/BG/Missing:** group a sequence of gray-scale image values into FG/BG/Missing.

- **X → FG/BG/Missing:** assign an individual gray-scale pixel value to FG/BG/Missing.

- **Invert:** exchange the current assignment of FG/BG/Missing.

- **Add 1b:** add 1 byte to all current image values.

- **Subtract 1b:** subtract 1 byte of all current image values.

Note: the *Image Info* option may be used at any time to control the output of the Preprocessing functions as well as to examine further required steps to setup a MSPA-compliant input image.

1.2.2 Convolution

The Convolution menu offers the choice for one of the following image convolution filters:

- **Median:** Median filtering is effective in removing salt and pepper noise, (isolated high or low values). The median is the middle value of a given data array, which should not be confused with the average value. A set of predefined median filter box sizes is available in the submenu.

- **Boxcar:** Similar to Median, this filter computes the average value instead.

- **Lee:** The Lee filter technique (Lee, 1986) will smooth additive image noise by generating statistics in a local neighborhood and comparing them to the expected values. A set of predefined box sizes to be used for the Lee filter is offered in the submenu.

- **Sigma:** This filter computes the mean and standard deviation of pixels in a box centered at each pixel of the image, but excluding the center pixel. If the center pixel value exceeds one standard deviation from the mean, it is replaced by the mean in the 5×5 box overlaying the pixel of investigation.

- **Wavelet:** This option will open up a new interface for wavelet processing (Please note that this interface will only be available on systems having the separate IDL wavelet license). The left part of the interface (Figure 2) provides a graphical display of the original image, the filtered image, the wavelet coefficients, and the power spectrum. The right part allows for the selection of first, the wavelet family (Daubechies, Haar, Coiflet, Symlet) and their respective order and second, the cumulative power to use for denoising as well as hard or soft (= stronger smoothing) threshold. The results are displayed in the display *Filtered image* as well as in a text box at the bottom right. Finally the *File → save/close* option is used to apply this filter and to return to the main interface of the program.

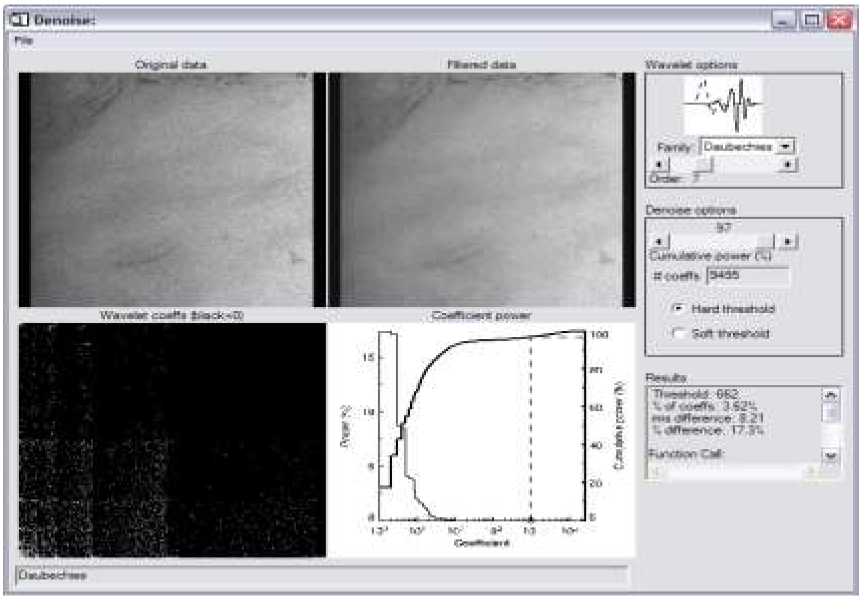


Figure 2: The *Wavelet* interface providing a variety of wavelet and denoise options to be applied to the original image (top left) and resulting in the filtered image (top right).

- **Hilbert:** The Hilbert function outputs a series that has all periodic terms phase-shifted by 90 degrees. This transform has the interesting property that the correlation between a series and its own Hilbert transform is mathematically zero.

- **User-Defined:** A popup window allows the user to select or customize a kernel within dimensions within [3, 501] to be applied to the current image.

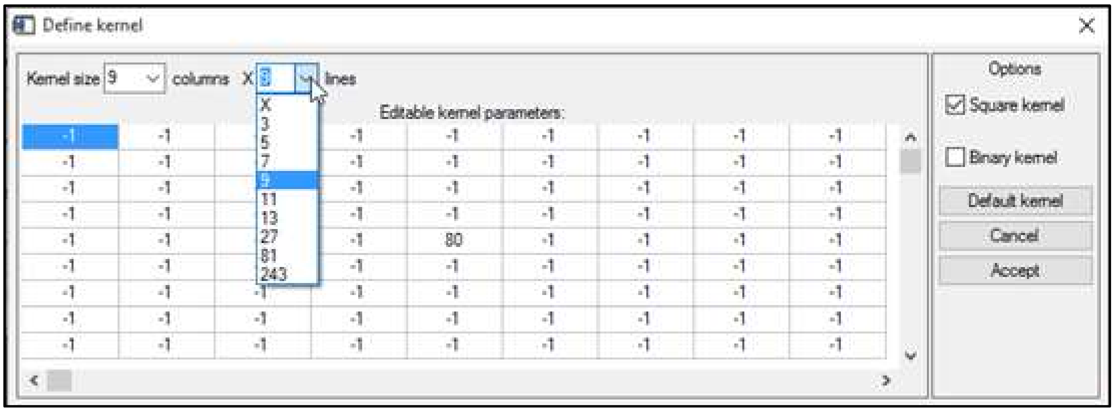


Figure 3: The *Define Kernel* interface showing options to define the kernel dimension within the range [3, 501], select a square and/or a binary kernel and a reset option to go back to the default kernel for the current application.

1.2.3 Equalization

The Equalization menu offers the choice for one of the following image processing algorithms:

- **Contrast:** The image contrast can be adjusted in an interactive mode. This option will close the main window and open up a new, dual window interface (Figure 4). The window on the left displays the histogram of the brightness values of the image and two color bars, which can be dragged with the mouse to set a lower and upper limit for the intensity range into which the image will be rescaled. The result of this procedure is shown in the preview window on the right, which can be saved in a variety of image formats from the *Controls* → *Save image as* menu. Furthermore, the maximum pixel density may be reset from the *Controls* → *Max pixel density* menu to adequately display the histogram. Finally, choosing *Quit/Accept* will close this interface, return to the main interface, and cancel/apply the selected settings to the current image.

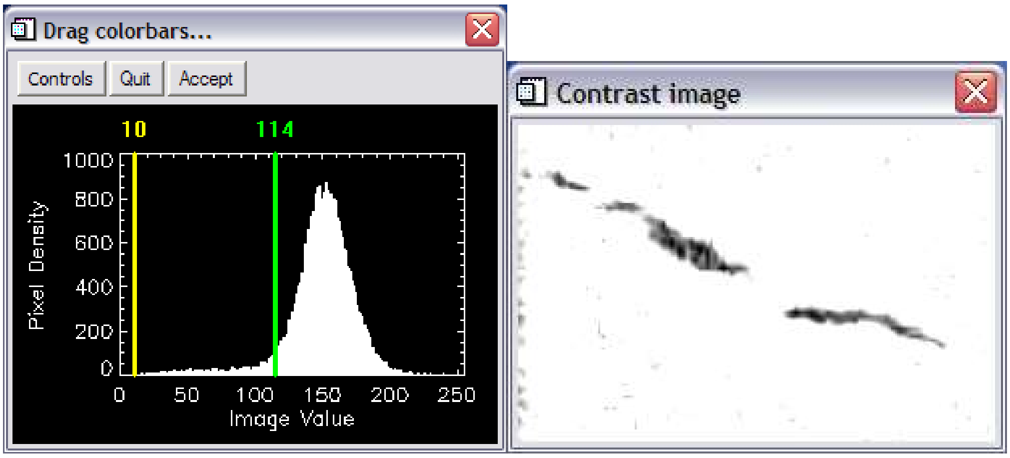


Figure 4: The *Contrast* interface showing on the left the histogram of the brightness values including the two color bars to define the contrast range; and on the right the preview of the selected contrast range applied to the current image.

- **Histogram Equalization:** This function is used to obtain the density distribution of the input array. The histogram is integrated to obtain the cumulative density-probability function and a histogram-equalized image is returned.

- **Adaptive Histogram Equalization:** This function applies contrast enhancement based on the local region surrounding each pixel. Each pixel is mapped to an intensity value, which is proportional to its rank within the surrounding neighborhood.

1.2.4 Thresholding

This option will open a dual window (Figure 5). The left window displays a histogram of the brightness values from the current image. A color bar indicating the current threshold value can be moved with the mouse to set a new threshold value, which is displayed in the right window of this interface. The *Controls* menu provides the option to save the current preview to an image in a variety of image formats and to redefine the maximum pixel density in order to best display the brightness value distribution of the histogram. Finally, the *Quit* or *Accept* buttons are used to cancel/apply the selected threshold. Please note that this process results in a binary image and can therefore only be applied once.

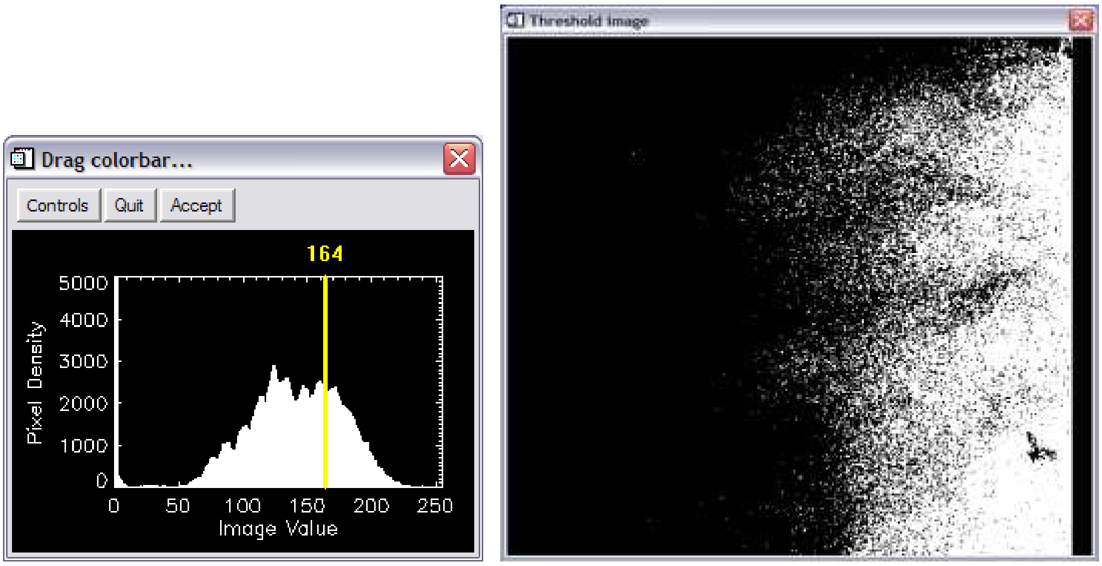


Figure 5: The *Thresholding* interface provides a color bar to set and preview a brightness threshold value on the current image.

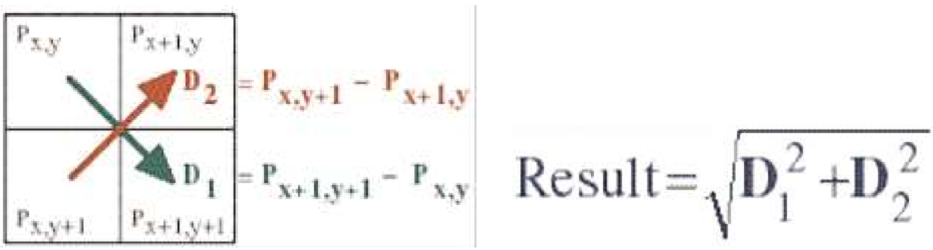
1.2.5 Edge enhance

This Edge enhance menu provides a series of edge enhance filters which are described in the following:

- **Canny:** This filter produces results similar to the Sobel operator, but is separable (Canny, 1986). This means that it can be performed in two passes, computing the derivative in the horizontal and the vertical direction. They are then combined to calculate the gradient or the difference of the two components.

- **Laplace:** The image is convolved with the kernel $\begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}$

- **Roberts:** The diagram below shows the principle of the Roberts operator (1965) where two differences in orthogonal directions are combined to determine the gradient.



- **Sobel:** Similar to the Roberts filter, the Sobel filter computes the derivatives in two orthogonal directions, which are combined as the square root of the sums of their squares to obtain a result independent of orientation.

- **Sharpen:** This filter adds the Laplace filter of the image to the image itself. The *Define Kernel* window (Figure 3) offers the option to use a different user-defined filter.

- **Unsharp masking:** This filter subtracts the original image from a smoothed version of the original image. Different smoothing box sizes are selectable from the submenu.

- **Skeleton:** This filter combines thresholding with the Sobel filter.

1.2.6 Morphological

Mathematical morphology is a methodology of analyzing digital image objects on the basis of shape. A discussion of this topic is beyond the scope of this manual. A suggested reference is Soille, 2003; In short, a user-selectable object of predefined size and shape (structuring element) is defined and the image is scanned for the presence or absence of this shape of interest (some examples in Table 1). This option will open a new window (Figure 6) providing a series of morphological filters (Dilate, Erode, Open, Close, Tophat, Gradient), structuring element types (horizontal, vertical, diagonal up, diagonal down, circular) and sizes (1-10). Any combination of filter and structure type and size can be selected and tested by pressing the *Test* button in the upper panel. The *Define kernel* window (Figure 3) allows for selection of the default or user-defined kernel to be applied to the previously selected settings. The result of this process is displayed in the graphical display of this window. Other combinations may be tested at any time after restoring the original state in the display via the *Reset* button. When using the *Tophat*-filter, the contrast of the resulting image can be adjusted with the sliders in the horizontal panel above the display. Finally, the *Quit/Accept* button will close this window and cancel/apply the selected filter settings to the current image in the main window.

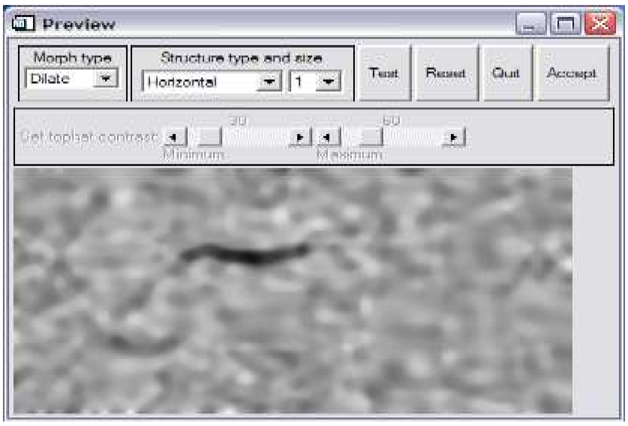


Figure 6: The *Morphological filter* interface providing a preview for a variety of combinations of filters with structuring element type and sizes.

Filter	Description
Dilate	fills holes of size equal to or smaller the structuring element.
Erode	removes islands smaller than the structuring element
Open	an erosion followed by a dilation, pixels are removed
Close	a dilation followed by an erosion, pixels are added
Tophat	= image – open(image) on an inverted image to show low brightness peaks
Gradient	= dilate(image) – erode(image) to highlight the boundary of the structure

Table 1: **Description of some basic morphological filters.**

1.2.7 GIS Software

The GIS Software menu provides access to the following GIS related software packages on the host PC running GuidosToolbox:

a) **Conefor:** this menu provides access to the Conefor GUI and command-line version, related documentation, and the Conefor homepage. The entry *Check for Updates* permits to test for and if available install a newer version of the Conefor GUI.

b) **JRC SW:** this menu provides links to other software projects developed at the Joint Research Centre of the European Commission. Those projects may suite into the scope of GuidosToolbox, such as:
IMPACT: this software toolbox offers a combination of elements of remote sensing, photo interpretation, and processing technologies in a portable and stand-alone GIS environment allowing users to easily accomplish all necessary pre-processing steps to produce a reliable land cover map from Earth observation data.
Nestedness: is a measure of order in an ecological system, referring to the order in which the number of species is related to area or other factors. The more a system is "nested" the more it is organized.

c) **GDAL Terminal:** this option will open a separate terminal to access all GDAL-commands. Use this terminal to work on your data, for example to reproject (gdalwarp), format conversion (gdal_translate), get information (gdalinfo), and much more. The GDAL-commands of the Linux and Windows versions are provided by the included FWTools package, and in the Mac version via the kyngchaos GDAL-framework.

d) **OpenEV Viewer:** this option will open a separate window with the image viewer OpenEV as provided by the FWTools package. Note that OpenEV is not available in the Mac version of GuidosToolbox.

e) **QGIS:** this option will open QGIS if it is found in the operating system.

1.2.8 Original image

Selecting the *Original Image* button can restore the initially loaded image.

1.2.9 Undo/Redo

GuidosToolbox stores the settings of one processing step. The *Undo* button may be used to undo the last processing step. If selected, this button will change to *Redo* allowing reverting to the previous step.

1.3. The Image Analysis pull-down menu

The Image Analysis pull-down menu offers the following options:

- Pattern
- Network
- Fragmentation
- Distance
- Cost
- Contortion
- Change

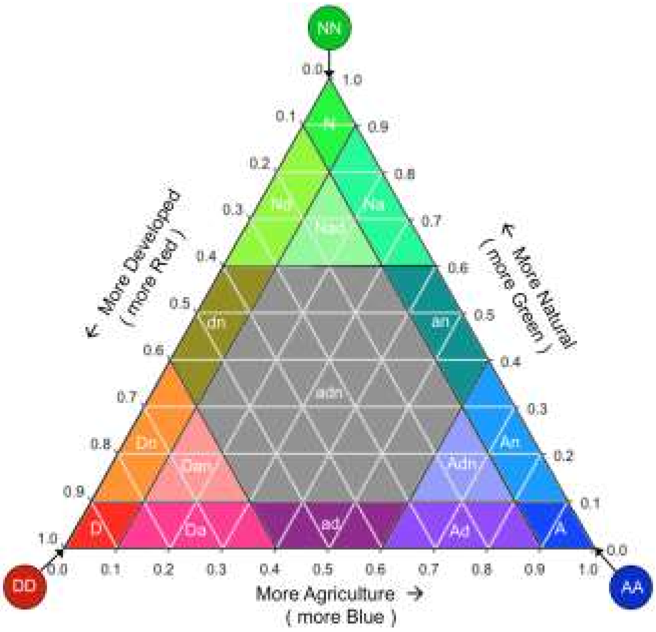
1.3.1 Pattern

This menu provides access to the following pattern analysis tools:

- **MSPA:** this option will process a binary input image using the mathematical morphology algorithm described in Soille & Vogt, 2009 with application details outlined in the MSPA Guide.

- **Moving Window:** this menu provides access to several moving window algorithms. Via an initial pop-up window, the user can specify the size of a square (kernel) window, which is then applied to the current image. Here, this user-defined window is overlaid over each pixel of the input image, the selected metric is calculated for the area of the window, and the result is re-assigned to the center pixel of the overlaid window in the output image. All texture indices in this menu are derived from analyzing the attribute adjacency table (e.g., Musick and Grover 1991), in which Fij (i,j = 1 to t) is the frequency of adjacent pixel pairs with land-cover types {i,j}. When forming the attribute adjacency table, adjacency is evaluated in the four cardinal directions, each edge is counted once, the order of pixels in pairs is not preserved, and pairs involving a missing pixel are not included (Riitters et al. 1996b). The metrics P2 and LM are calculated from the proportions of cell values in the window. For those metrics, missing cell values are not included in the calculation, and the calculation result is missing if all cells in the window are missing. The metrics P22 and P23 are calculated from the cell|cell adjacency values (edge) proportions in the window. We define *N* as the total number of edges between all pixels in cardinal directions, and the subset *n* as the number of edges that have foreground on one side or the other. All edges (N-n) that do not have foreground on either side are excluded in the metric calculation. If there are missing cells in the (kernel) window, the edges involving missing cells are not included. As a result, the total number of edges is less than *N* and the total number of edges involving foreground may be less than *n*, if missing cells are adjacent to foreground cells. Finally, the overall contagion measures Shannon and SumD account for all classes in the image (while P22 is based only on the foreground class). In this sense P22 can be seen as class-level contagion (one row of the attribute adjacency table), while Shannon/SumD is landscape-level contagion (the entire attribute adjacency table). The following moving-window processing options are available:

- LM (Landscape Mosaic): a tri-polar classification of a location according to the relative proportions of three classes in the window surrounding that location. The classification model uses the critical values of 10%, 60%, and 100% along each axis to partition the tri-polar space into 19 mosaic classes. More details on the concept of Landscape Mosaic and application examples can be found in Wickham et al. (1994) and Riitters et al. (2009).



Value [byte] - Class Name	Color	RGB
0 - Missing		255/255/255
1 - A		000/000/255
2 - D		255/000/000
3 - N		000/255/000
4 - Ad		128/000/255
5 - An		000/128/255
6 - Dn		255/128/000
7 - Da		255/000/128
8 - Na		000/255/128
9 - Nd		128/255/000
10 - Adn		128/128/255
11 - Dan		255/128/128
12 - Nad		128/255/128
13 - ad		128/000/128
14 - an		000/128/128
15 - dn		128/128/000
16 - adn		128/128/128
17 - NN		000/191/000
18 - AA		000/000/191
19 - DD		191/000/000

Figure 7: **The Landscape Mosaic (LM) tri-polar classification scheme showing 19 mosaic classes and their proportions of the 3 land cover categories *Natural*, *Agriculture*, and *Developed*. A capital letter denotes more than 60% and a small letter a contribution in the range of [10-60]% of a given land cover category.**

The input image for LM must be a Byte array with no more than 3 target classes with the assignment **AND** (1-**A**griculture, 2-**N**atural, 3-**D**eveloped) plus an optional class for missing values (0 Byte).

- P2: the proportion of foreground pixels (2b) in the moving window. More details on the concept of P2 and P22 (below) and application examples can be found in Riitters et al. (1997, 2002).

The input image for P2 must be *MSPA-compliant*: a Byte array having 0b – missing (optional), 1b – background, 2b – foreground.

- P22: the proportion of adjacent pixel pairs in cardinal directions that include at least one foreground pixel, for which both pixels are foreground (2b|2b). Note: If n = 0, then P22 is missing. P22 estimates the conditional probability that, given a foreground pixel, its neighbor is also foreground.

The input image for P22 must be *MSPA-compliant*: a Byte array having 0b – missing (optional), 1b – background, 2b – foreground.

- **P23:** the proportion of adjacent pixel pairs in cardinal directions that include at least one foreground pixel (2b), for which the neighboring pixel is *interesting background* (2b|3b). Here, the original data background (1b) is subdivided into non-interesting background (1b) and interesting background (3b). A P23 map shows foreground (2b) fragmented by *interesting background (3b)*. More details on the concept of P23 and application examples can be found in Wade et al. (2003) and Riitters et al. (2012). In a similar fashion one can divide the background not into two but into *x* subclasses. Then setup a loop, recode the input map accordingly with the interesting background subclass *x* set to 3b, and run P23 in a loop for each of these recoded maps in order to retrieve the impact of each background subclass *x* on the foreground class. For example, a land-cover map may contain the four classes Forest, Developed, Agriculture, and Water. If we choose Forest as foreground then we have: $1=P_{FF}+P_{FD}+P_{FA}+P_{FW}$. Here, P_{FF} is the proportion of pixel pairs having Forest-Forest (P22 in GuidosToolbox), and the other 3 components describe the proportions of Forest to Developed, Agriculture, and Water, resp. These 3 components (P23 in GuidosToolbox) then describe how the foreground (Forest) is fragmented by each of the remaining background land-cover types.
Note: if all background is interesting, then P23 = (1 – P22). By taking different subsets of background as *interesting*, it is possible to partition the total fragmentation (1 – P22) into components attributable to different background classes.
The input image for P23 must be a Byte array having the classes:
- Missing, 0b (optional),
- non-interesting background, 1b (optional),
- foreground, 2b (mandatory),
- interesting background, 3b (mandatory).

- Shannon: Shannon edge-type evenness, the classical overall contagion measure used in Landscape Ecology literature, see Li and Reynolds, (1993).
The input image must be a Byte array with optional missing pixels set to 0 byte.

- SumD: an alternative contagion measure is the sum of the main diagonal ("same-class") elements of the attribute adjacency matrix, see Wickham and

Riitters (1995) and Riitters et al. (1996). In contrast to the Shannon index this index is not affected by adjacencies among different classes, and the same value is obtained for all of the ways pixel pairs could be tallied.
The input image must be a Byte array with optional missing pixels set to 0 byte.

1.3.2 Network

The MSPA-analysis can be converted into a *Network* for further analysis in a graph-theory application, here *Conefor* (Saura, 2009a). A *Network* is composed of *Nodes* (↔ MSPA class: Core) and *Links* (MSPA class: Bridge = connectors between different Cores) and the remaining MSPA classes are neglected. A connected set of nodes and links is called a *Component*. The following Network options are available after a MSPA-analysis:

- **NW Components:** individual components of the network are displayed in alternating colors. The color black is used for node-only components having no links. The information window below the main display shows the unique component identifier, the total area of the component, and the contribution of links. Saving the result will produce the following three files:
  a) <name>_nw.tif: same graphics as displayed in GuidosToolbox
  b) <name>_nw_nwdata.tif: image with component IDs
  c) <name>_nw_stat.txt (only when saving the entire image): statistics for each component, total area, and contributed area of links.

- **Node/Link Importance:** this option will show the connectivity importance for each node and each link of the network. The connectivity importance is calculated according to equation 4 in Saura (2009b) and having the following three contributions: $dPC = dPCintra + dPCflux + dPCconnector$, where the importance corresponds to the term dPCconnector only. The information window below the main display shows the node/link ID, and its absolute and relative connectivity importance. The top 1, 5, 10 % relative importance of nodes/links are displayed in decreasing intensity of green and red color.
  Saving the result will produce the following four files:
  a) <name>_cs22.tif: same graphics as displayed in GuidosToolbox
  b) <name>_cs22_conn.tif: the connectivity importance for each node and link.
  c) <name>_cs22_ids.tif: the unique identifier of each node and link where nodes have a negative sign to distinguish them from links.
  d) <name>_cs22_stat.txt (only when saving the entire image): statistics for each component, its nodes and links, area, and connectivity importance.

- **NW Component Connectors:** this option will locate and calculate the connectivity importance of the 10 shortest pathways (links) between the 5 largest components. The connectivity importance will account for intermediate components if they are part of this pathway. The information window below the main display shows the area and ID of the components and the connectivity importance of each component connector. Please note that the new links will show properly in zoom mode but they may not show properly in the overview display because this image is only a resampled version of the entire full-resolution image. Saving the result will produce the following two files:

a) <name>_nwconnect.tif: same graphics as in GuidosToolbox.

b) <name>_nwconnect_stat.txt (only when saving the entire image): statistics for the 10 links connecting the 5 largest components, starting from the largest to the second largest (12), to the third (13), fourth (14), and fifth largest (15), the second largest to the third largest (23), etc. Each line shows the IDs of the individual components connected (A and B); the connectivity importance of this new link accounting for intermediate components along the pathway; the entire length of the link and the effective length of it through the background; the component IDs of intermediate components if they were encountered along the pathway of this link. Here, the effective length can be seen as a proxy for the costs to establish such a pathway.

Note: A note of caution on images having a very large single component or with a Foreground cover > 50 %. Here, the connecting pathway between smaller component pairs may traverse a very large component. When deriving the importance, this pathway is removed, which will result in segregating the network and thus may lead to counterintuitive results.

- **MSPA Conefor Inputs:** this option will setup and save the two input files *nodes_mspa_<input>.txt* and *links_mspa_<input>.txt* for further analysis in Conefor (Saura, 2009a). Use this option for detailed graph-theory analysis, which is beyond the network connectivity importance provided within GuidosToolbox. **Note:** when using the option **MSPA Conefor Inputs** the connectivity is defined via the *MSPA-detected structural connectors* (bridges). This is different to the option **Conefor Inputs**, where the connectivity is defined via the *pairwise distance* of image objects.

1.3.3 Fragmentation

Fragmentation can be seen as the spatial heterogeneity, or the spatial composition and arrangement of foreground objects in an image. It accounts for the number of objects and the distance between them, hence addressing foreground and background characteristics at the same time. Due to its holistic nature the description of fragmentation is rather complex and, in the case of landscapes, usually defined for a given species of interest and as such very specific. Moreover, current fragmentation definitions are only descriptive and for this reason do not allow *quantifying* the degree or changes of fragmentation for a given image. For quantifying fragmentation, we apply different concepts. All provide normalized values in the range [0% – 100%]. The Entropy requires a minimum image dimension of 500 pixels in any direction. In the Divide Range panel below the viewport the fragmentation values can be grouped into small/medium/large. The title bar in GuidosToolbox shows fragmentation values for the entire image, the foreground only, and the range of minimum-maximum values.

The aim is to *describe* fragmentation using different concepts. Based on the nature of the selected approach each concept will provide slightly different results, which may be more or less suitable for a given task. Besides *quantifying* the fragmentation state on a given map these measures permit the comparison of the degree of fragmentation of different sites, the *quantification of changes* in fragmentation over time, and *monitoring* as well as *measuring progress* in planning programs and political directives.

The Fragmentation submenu ***Index*** provides methodologies resulting in a normalized fragmentation value (index) for the entire image.

- **Entropy:** this option will calculate the Entropy of the entire image.

- **Hypsometry:** starting from the Euclidean distance map a first pop-up window shows the *Hypsometric Curve* (Figure 8).

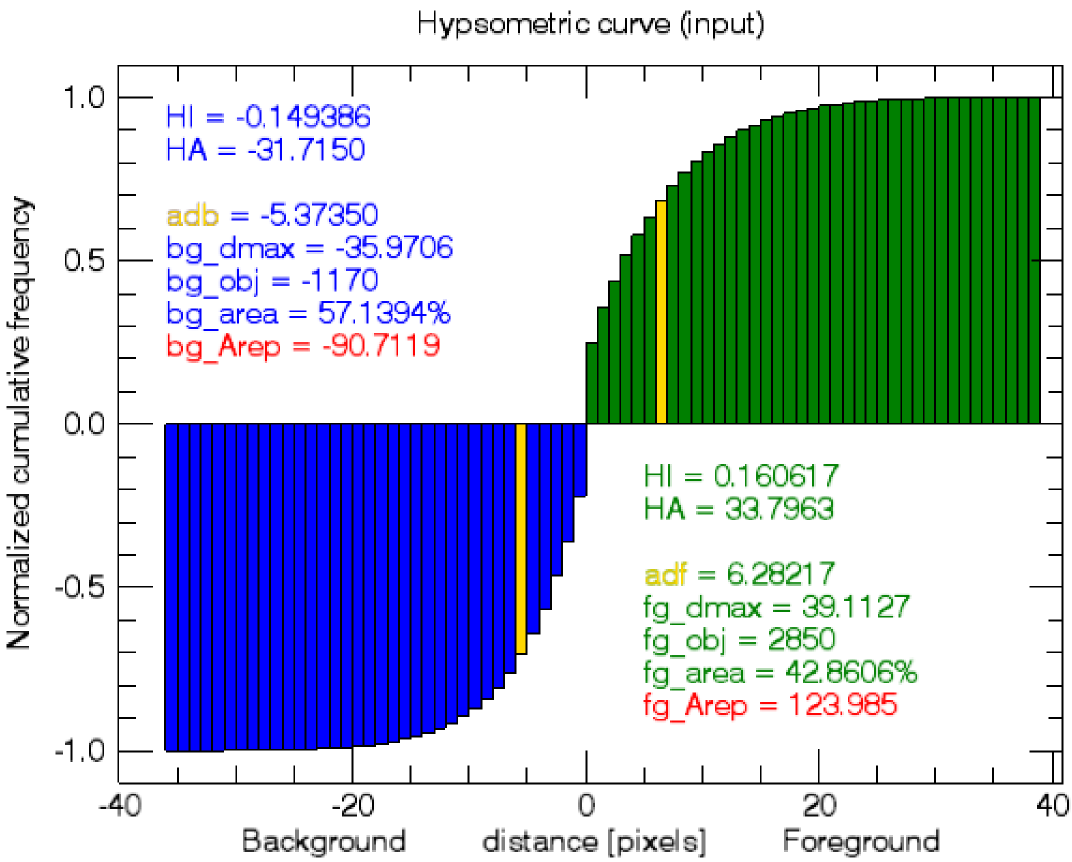


Figure 8: Hypsometric Curve for the Euclidean distance distribution in the foreground and in the background and related distance measures.

The *Hypsometric Curve* is a summary description of the Euclidean distance histogram. When viewing the image distance distribution as a pseud-elevation map the Hypsometric Curve summarizes the relief or contour lines in the foreground the same process is known as bathymetry in the background. Figure 8 shows the normalized cumulative frequencies of Euclidean distances as well as the following related statistics for the background and the foreground:

- *Hypsometric Index (HI)*: adb/bg_max   or   adf/fg_max
- *Hypsometric Area (HA)*: integral area under the curve
- *Average distance (adb/adf)*
- *Maximum distance (bg_max/fg_max)*
- *Number of objects (bg_obj/fg_obj)*
- *Total area of objects (bg_area/fg_area)*
- *Representative area (bg_Arep/fg_Arep)*

The *Representative Area* is calculated for a vicarious object of circular shape with a radius of adf/adb. In a similar way, a representative square object could be defined having the edge length sqrt(Arep). As with the *Average Distance* (adf/adb), changes in the *Representative Area* are indicative for fragmentation processes.

A second pop-up window shows the *Normalized Hypsometric Curve*.

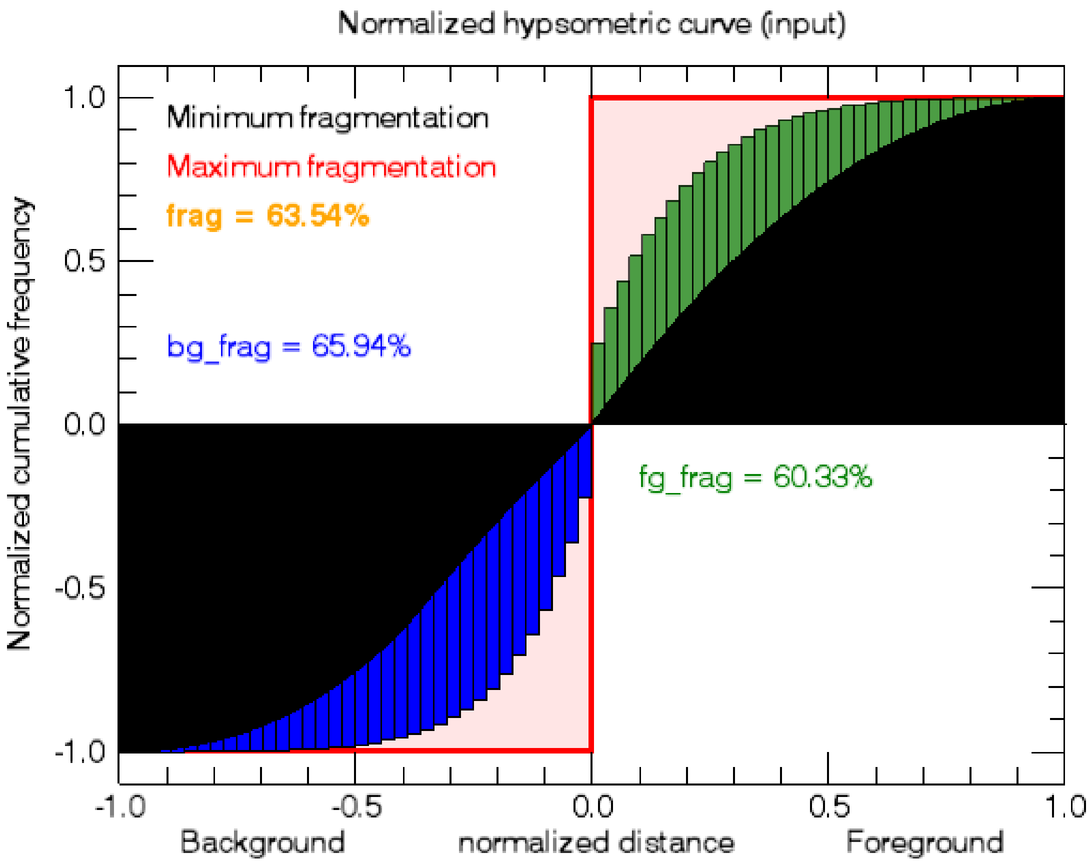


Figure 9: Normalized Hypsometric Curve for minimum (black), maximum (red), and actual fragmentation state in the foreground (green) and in the background (blue).

The *Normalized Hypsometric Curve* (NHMC) is the Hypsometric Curve scaled by the maximum distance in the foreground and in the background.

Figure 9 shows the NHMC for three images having the same dimension as the actual image and the following three conditions:
- minimum fragmentation (black): NHMC of an image with maximum foreground aggregation: all foreground pixels accumulated to a circle in the center of the image. If the foreground coverage is too large to fit a circle in the image a rectangle is used instead.
- actual image (blue/green): NHMC of the actual image
- maximum fragmentation (red): NHMC of a checkerboard image with 50% coverage. This theoretical maximum condition for fragmentation is characterized by all foreground as well as all background pixels having a distance of 1 and thus resulting in the step-function outlined in red in Figure 9.

For a given image, the degree of fragmentation corresponds to the area covered between minimum fragmentation (black) and maximum fragmentation (red). In Figure 9 this area is highlighted in blue for the background and in green for the foreground. Accounting for the dual nature of fragmentation (foreground is fragmented by background and vice versa) the degree of fragmentation for a given image is defined by the weighted sum of fragmentation in the foreground and the background:

Frag(hypso) = (bg_area/100.0 * bg_frag) + (fg_area/100.0 * fg_frag)

The so-defined fragmentation provides values in the range of [0, 100] %, accounting for and summarizing key fragmentation aspects: duality, perforations, amount, division, and dispersion of image objects.

- **MeshSize**: introduced by Jaeger (2000) the *effective mesh size* (m_{eff}) is based on the probability of two points chosen randomly in a region will be connected. The probability is converted into the size of a patch (m_{eff}) by multiplying it by the data area of the image:

$$m_{\text{eff}} = \frac{1}{A_{\text{total}}}\left(A_1^2 + A_2^2 + \ldots + A_i^2 + \ldots + A_n^2\right)$$

with n = number of patches, A_{total} = data area, A_i = area of patch i (i=1,..,n). Mathematically, the MeshSize is very similar to the *Area-weighted Mean Patch Size*, the only difference is the division by the data area instead of the foreground area. Hence, the *Area-weighted Mean Patch Size* provides an absolute measure of patch structure, whereas the MeshSize provides a relative measure of patch structure. The unit of MeshSize is area, i.e. hectare, and it corresponds to the size of meshes of a regular grid having the same degree of fragmentation as the actual image. MeshSize is mainly an indication of foreground segmentation but by definition cannot account for other fragmentation aspects like perforation and dispersion. The range of MeshSize is from a theoretical minimum value of zero (totally fragmented to have virtually no more foreground area; relative fragmentation = 100%) to a maximum value of A_{total}, when the entire data area is covered by foreground (relative fragmentation = 0%). The smaller

the MeshSize the more fragmented is the landscape. Within GuidosToolbox the relative fragmentation described by MeshSize is obtained by scaling the MeshSize of the actual image into the range of minimum/maximum MeshSize.
Note: the calculated MeshSize in hectare is calculated assuming a pixel resolution of 1 meter. MeshSize for data with different pixel resolution can be derived by multiplying the MeshSize from GuidosToolbox with the square of the actual pixel resolution. For example: if the MeshSize (within GuidosToolbox and assuming 1 meter pixel resolution) was calculated as 10 ha; and the actual pixel resolution of the data is 30 meter, then the actual MeshSize of the data is 10 ha * 30^2 = 9000 ha.

The Fragmentation submenu ***Map*** provides methodologies resulting in spatial distribution of normalized fragmentation values.

- **Entropy**: In thermodynamics, entropy describes the degree of disorder in a system. Transferring this concept into spatial geometry (raster images) we can use entropy as a descriptor for spatial fragmentation. Starting from the classical definition of entropy in information theory H = -∑ Pi * log(Pi) (Shannon, 1948) we define the discrete set of probabilities *Pi* as the probability that the difference between 2 adjacent pixels is equal to *i* and log is the base 2 logarithm. The original entropy definition has been implemented in many ways and it is important to distinguish the above definition of Pi from other commonly used indicators such as Shannon's diversity index or the Eveness index (where Pi is the proportion of *species*) and variations of contagion indices (where Pi is the proportion of different type of pixel edges). In short, in Shannon's original concept Pi refers to percentages of species classes in categorical maps, as defined in the species diversity literature. In contrast, here we investigate differences between cell values in all 8 directions (that is, the values of i), which is meaningful because raster images are continuous variables where their magnitude has meaning. While the entropy in the edge-type evenness is derived from the attribute adjacency table, the spatial entropy here is calculated on spatial tiles and assuming 8-connectivity for the foreground pixels.
  For a given amount of foreground area, an image with a single compact foreground object has minimum entropy while the entropy reaches its maximum value when the given area is split into the maximum number and dispersed over the entire image. Maximum entropy is thus found for a checkerboard distribution. These two boundary conditions define the possible range of fragmentation in the image. The spatial entropy is calculated by averaging calculations using box size tiles of 50 and 33 starting from the center of the image. This approach replaces the precise but slower performing moving window computation. Finally, a smoothing filter is applied in order to return a spatial contiguous per pixel distribution. The result shows the normalized fragmentation as a function of spatial entropy.

- **Entropy_mw:** same as Entropy but using a moving window approach with a box size of 50x50 pixels.

- **Contagion**: Contagion describes the degree of clumpiness of image objects. With this definition, fragmentation can be defined as the complement of contagion (1 – contagion), an image region with high contagion is equivalent to having low fragmentation. The contagion of foreground objects is calculated via the moving window metric P22 in the user-selected box size window. The result shows the normalized fragmentation as a function of spatial contagion.

Note: Entropy and Contagion can both be seen as local aggregation measures but with an important difference: while Contagion will consider the Foreground objects only, the Entropy based fragmentation assessment is based on the *simultaneous* evaluation of Foreground and Background together (duality). For example, an image with predominant Background cover (i.e. 95 %) and a few isolated Foreground objects (5 %) will result in high fragmentation values for Contagion. For Entropy, this image will have low fragmentation values because the dominant area coverage (Background) is only slightly fragmented by the Foreground. In fact, we will get the same low fragmentation value for Entropy when using the inverted image with 95 % Foreground cover and 5 % background; in this case the dominant area coverage is now *Foreground*, which is only slightly fragmented by the *Background*. In short, Entropy derives Fragmentation for the interplay of Fore- and Background while Contagion will focus on the Foreground only.

1.3.4 Distance

This menu provides several options for distance analysis.
Note: when using geotiff data the distance value in pixels is only meaningful for images having **equal-area projection**!

- **Label Objects:** this option will label all foreground objects having a size larger or equal the value specified via the MSPA parameter 2 *EdgeWidth.* In addition, the MSPA parameter 1 *FGconn* can be set to define 4 or 8-connectivity for the foreground objects. Labeled objects are displayed in alternating colors, objects smaller than the minimum object size in pale blue, and potential missing data is displayed in white. Moving the mouse cursor over a labeled object will show the object ID and the number of pixels of the selected object. Saving a label object image will produce the following four files with the prefix <name>_labelobjects_<X>conn_<Y>, where X stands for 4- or 8-connectivity and Y stands for the selected minimum object size in pixels:
  a) prefix.tif: same graphics as displayed in GuidosToolbox
  b) prefix_ids.tif: the unique identifiers of the objects
  c) prefix_pixels.tif: the number of pixels for each object
  d) prefix_stat.txt (only when saving the entire image): table listing the number of pixels for each object.

- **Euclidean Distance:** this option calculates the approximate Euclidean distance map for both, the background and the foreground. A pop-up window shows the distance histogram including foreground and background specific information on the average distance value (adf/adb), the total number of objects (fgo/bgo), and the maximum distance found in the image. Background data have a negative sign to distinguish them from foreground data. The GuidosToolbox title bar shows adf/adb and the spatial distance distribution is displayed in the viewport. For each pixel, this map shows the shortest distance to the nearest foreground/ background boundary. The distance is provided in pixel units since the actual spatial pixel resolution is unknown. The color code is designed to mimic a pseudo elevation map: blue colors represent ocean (background), yellow/red/green colors represent land or mountains (foreground), and a value of zero is assigned to the coastline (intersection of foreground/background). Saving a Euclidean distance image will save the actual distance image as well as the statistics shown in the histogram display. As in any other image, the zoom function can be used to retrieve more detailed pixel information via the mouse cursor.

- **Influence Zones:** an influence zone is defined as the outside region separating selected foreground objects. The boundary of an influence zone is derived by applying a morphological watershed operator to the Euclidean distance map of the background area in the image. Considering the gray scale (Euclidean distance) image as a surface, each local minimum can then be thought of as the point to which water falling on the surrounding region drains. The boundaries of the watersheds lie on the tops of the ridges. Small objects in the original image can produce spurious minima in the gradients, which leads to over-segmentation. For this reason the default minimum object size is set to 500 pixels. Omitted Objects smaller than the minimum object size are displayed in pale blue color. Objects for which influence zones are calculated are displayed in alternating colors. Potential missing data is displayed in white and the influence zones boundaries (watershed lines) in black color. Influence zones are calculated for foreground objects larger or equal to the specified minimum area in pixels, which can be set via the MSPA parameter 2 *EdgeWidth*.
  In addition, the panel below the viewport allows setting buffer zones for both, foreground and background. Here, a non-zero value for the foreground buffer zone corresponds to the perimeter width of the foreground objects to be excluded from the calculation. Consequently, this parameter can be used to define core-foreground objects. In this case the title-bar will show, and the calculation will be conducted for foreground *core* objects having the minimum area specified via the MSPA parameter 2 *EdgeWidth.* A non-zero value for the background buffer zone will add a dark grey colored buffer zone of the specified width around, and if sufficiently large holes are present, inside the selected core or foreground objects. The boundary of the background buffer zone is depicted in pink color. Background buffer zones will terminate at the boundary of the influence zones. Clicking the *Divide* switch will reset both, the foreground and background settings to their default value of zero, omitting buffer

zones and showing influence zones only. In summary, the influence zones provide a segmentation of the user-specified objects and buffer zones can be added to define *core areas* as well as *outreach zones* of any size.

Note: the threshold of small objects to be excluded from the calculation can be set to any value via the MSPA parameter 2 *EdgeWidth* drop-down menu. You can either select a pre-defined value or specify a custom value in the first entry of the drop-down menu. A new custom value will only be assigned after the Enter key has been pressed. Having entered a new small object threshold value the influence zones will be recalculated automatically. A value of one (1) will calculate influence zones for all foreground objects. Since influence zones are defined to describe the **outer** region of objects they are calculated for **filled foreground objects**. For this reason, objects insides holes of surrounding objects will have the same object ID and hence, the total number of objects when calculating influence zones may be smaller compared to the total number for object labeling. Finally, as with Euclidean distance, the distance value in pixels in geotiff data is only meaningful for images having equal area projection!
Saving an influence zone image will produce the following two files with the prefix <name>_influence_<X>conn_<Y>_<b1>_<b2>, where X stands for 4- or 8-connectivity, Y stands for the selected minimum object size in pixels, and b1 and b2 stand for the selected foreground and background buffer zone width, respectively:
a) prefix.tif: same graphics as displayed in GuidosToolbox
b) prefix_ids.tif: image showing the unique identifiers of the objects, buffer zones and watersheds, etc. using negative values for special data and positive values for the individual objects, i.e. the following notation:

- 6: buffer zone
- 5: buffer zone boundary
- 4: missing data
- 3: watershed
- 2: omitted Foreground pixel
- 1: hole in Foreground
0: Background
1-x: unique object identifier

1.3.5 Cost

The modules in this section are designed to conduct a Cost analysis, requiring the following two input images:

a) **Resistance map**: a single-band image of datatype Byte providing a relative resistance value within [1, 100] byte for each pixel. Resistance values of 0 are not allowed. If the resistance map contains values larger than 100 byte then the user should setup an appropriate re-scaled resistance map within [1, 100] byte, for example using the Recode option. A resistance map could be a land-cover map, where for a given species a specific resistance value is assigned to each land-cover class. The land-cover class specific resistance value can then be seen as a measure of the difficulty for that species to traverse a pixel within that land-cover class.

b) **Marker map**: a single-band image of datatype Byte with the same dimensions as the resistance map and having the following values:
0b: background
1b: start object A (either a single pixel or the area of an object)
2b: target object B (optional, only needed for Cost Map AB)
3b: no or missing data, or areas that should be neglected (optional)
The start/target objects A and B must be unique and must not overlap.

These two input maps are combined and the cost map is calculated with a generalized geodesic distance function (Soille 1994). The Cost Marker map can be setup via the dedicated user interface: Cost Marker Image.

The Cost submenu provides the following two options:

- **Cost Map A:** this option will calculate and display the cost map starting from object A.

- **Cost Map AB:** this option will calculate a cost map starting from object A and a second one starting from object B, which are then combined into the final cost map AB. Pixels having the minimum value of this map are defined as *Least Cost Range* pixels and the skeleton of this range is called the *Least Cost Path*. The latter is a subset of the Least Cost Range and shows one trajectory of minimum cost between the start and target objects A and B.

The title bar will inform about the minimum and maximum cost values encountered in the image. The cost inside a start/target object is set to zero. The division panel below the viewport can be used to group the cost surface into the ranges small/medium/large using either pre-defined or custom values in the respective threshold drop-down menu. This option may be of interest to highlight cost corridors between A and B with a slightly increased minimum cost (i.e. 1.1 x least cost) in order to visualize and/or investigate potential alternative connecting pathways. While positive values show the actual cost the following values are reserved for special assignments:

- 3: pixels that cannot be reached from or are between the start/target object
- 2: missing data
- 1: start/target object A/B
  0: Least Cost Path

Depending on the selected file format saving a cost map will provide:
- **GeoTiff**: <input filename>_costmap<A or AB>-data/range_geo.tif, a twin set of Geotiff-images of data type:
  a) long integer with the actual cost map
  b) byte matching the visual display of the GuidosToolbox viewport. When linked against the corresponding data image in a GIS this image may be useful to visualize the (user-selected) cost ranges.

- **Generic-Tiff**: <input filename>_costmap<A or AB>.tif, two images:
  a) long integer Tiff-image with the actual cost map
  b) byte PNG-image matching the visual display of the viewport.
- **Generic-PNG**: <input filename>_costmap<A or AB>.png:
  long integer with the actual cost values.

The image files are accompanied by <input filename>_costmap<A or AB>.txt, providing a summary of the cost map options, minimum/maximum cost and, if selected, the cost range grouping thresholds.

1.3.6 Contortion

Contortion describes the degree of regularity of a foreground object perimeter. Its value corresponds to the number of times a given object perimeter direction changes its sign. Contortion can be used for shape description, in particular to distinguish random shapes from regular shapes. For example, when following the perimeter of a rectangle the direction changes one time in the horizontal and one time in the vertical direction → the contortion of a rectangle is 2. In satellite images, regularly shaped objects such as buildings, and agricultural fields will have low contortion values while natural objects are more likely to be non-regular and hence have higher contortion values. An important feature of contortion is the rotational invariance: imagine two rectangular football fields, one in horizontal orientation and the other rotated by 45°. When represented in a raster grid the perimeter of the first field will have 4 corners, while the perimeter of the second field will have many more than 4 corners due to its staircase representation along the diagonal lines in the image grid. While the number of corners of these two football fields in the raster image representation is different, the contortion of them is the same, namely 2. The Contortion submenu provides the following three options:

- **Contortion:** by default, the contortion is calculated for foreground objects having an area of larger or equal to 200 pixels. This setting avoids the time-consuming calculation for all small objects that may not be of interest. In the resulting image, small objects are denoted as *omitted* and displayed in black color. The title bar shows the fraction of calculated versus total number of foreground objects in the image. The Divide Range panel below the GuidosToolbox viewport can be used to group the contortion value range into small/medium/large using either pre-defined or custom values in the respective threshold drop-down menu.
  Note: the threshold of small objects to be excluded from the contortion calculation can be set to any value via the MSPA parameter 2 *EdgeWidth* drop-down menu. You can either select a pre-defined value or specify a custom value in the first entry of the drop-down menu. A new custom value will only be assigned after the Enter key has been pressed. Next, the contortion will be recalculated automatically.

- **Contortion/Pixels:** this option will display the ratio of contortion by area for each calculated foreground object. While the small object threshold can be changed the Divide Range panel is not active for this option.

- **Contortion/Perimeter:** this option will display the ratio of contortion by perimeter for each calculated foreground object. While the small object threshold can be changed the Divide Range panel is not active for this option.

1.3.7 Change

This menu provides the following two options for change analysis. A popup window is used to specify two input images, which can then be processed for:

- **Simple Change:** this option will calculate a simple by-pixel difference of image *A* minus image *B*, starting at the top left corner of the image. The dimension of the resulting image is equivalent to the smaller image of the two input images.

- **Morphological Change:** this option will conduct a Morphological Change Detection (MCD), described in Seebach et al. (2013). MCD will remove unwanted spurious changes caused by mis-registration between classified maps and their thematic accuracies. MCD requires that both input images are binary MSPA-compliant maps (2b – FG, 1b – BG, 0b – Missing (optional)) in GeoTiff format, having the same projection, pixel-resolution, location, and an area in common. The resulting GeoTiff image will show the essential changes in the common area of input image *A* and *B*. The output values have the following assignment: 11b – BG/BG, 12b – BG/FG (gain), 21b – FG/BG (loss), 22b – FG/FG, 176b – neglected, spurious changes, 255b – undetermined (missing data in either input image). The title bar lists net percent change values for FG (Foreground) and FGi (Foreground interior area: 1-pixel eroded FG), with negative values indicating a net loss. Finally, *Elasticity* (Riitters et al., 2015) is the ratio of FGi to FG. For example, in case of forest loss higher elasticity values indicate higher fragmenting effects on the remaining forests.

- **Compare PNGs:** this option will open two images into a new window. A slider at the bottom of the window can be used to change the transparency in order to directly compare pixels of the two images.

1.4. The Help pull-down menu

The Help pull-down menu offers the following options:

- GuidosToolbox Manual
- MSPA Guide
- News
- Homepage
- Disclaimer
- Changelog
- GuidosToolbox Workshop

- Check for Updates
- About GuidosToolbox

1.4.1 GuidosToolbox Manual

This option opens the GuidosToolbox Manual in a separate window. The manual provides general information on the organization of the graphical elements within GuidosToolbox and the nature and functionality of the various menus and options.

1.4.2 MSPA Guide

This option opens the MSPA Guide in a separate window. The guide contains important, detailed information on the input data requirements for the processing of MSPA, the MSPA parameters, the resulting MSPA image output, and on the use of the MSPA-standalone version. Please read this document carefully. It contains all MSPA related information, GuidosToolbox is only a graphical interface, designed to facilitate the MSPA processing.

1.4.3 News

This option displays current ongoing activities and upcoming changes to be included in a future version of GuidosToolbox.

1.4.4 Homepage

This option opens the GuidosToolbox homepage in a web browser providing current information on the GuidosToolbox software collection.

1.4.5 Disclaimer

This option opens the GuidosToolbox disclaimer in a popup window.

1.4.6 Changelog

This option displays recent changes and feature additions for the current version of GuidosToolbox.

1.4.7 GuidosToolbox Workshop

Use this option to install or upgrade the GuidosToolbox Workshop material. This material contains presentations with many details on the motivation, design, functioning, and application fields of the different methodologies available in GuidosToolbox. It is complemented by key reference publications, as well as sample data sets and instructions to illustrate using these tools. This package is used during the 1-2 day GuidosToolbox training courses but it should also be easy to follow by the interested user of GuidosToolbox.

1.4.8 Check for Updates

Use this option to check for and install a *Program* and/or a new *Revision release* of GuidosToolbox. A *Program release* includes major changes within the libraries of the programing framework and thus requires a fresh installation of GuidosToolbox. A *Revision release* is a small patch, which will either fix issues found after the release of the current program version and/or add some new features. It can be installed automatically into an existing installation.

1.4.9 About GuidosToolbox

This option provides information on the currently installed version of GuidosToolbox, homepage and contact information, the operating system dependent accessible additional software, and the maximum image dimensions supported in GuidosToolbox. On Linux and Mac OS X the maximum supported image dimension for MSPA is recalculated dynamically accounting for the currently available amount of RAM in the system.

2. The Image/Display Attributes window (top left panel)

This panel allows changing the image and display attributes of the image shown in the viewport in the right panel.

The left side provides:
- Flip Vertical: select this option to vertically flip the image.
Note: this option is not applicable for geotiff images.

- Normalized: display the image values using either their apparent values (default) or normalizing them into the range [0, 100].

- Autostretch: this switch will scale the present image values into [min, max]. This feature can be used to visualize images with small contrast range when using color tables spanning the entire range of [0, 255] byte.

The right side provides:
- Select Colortable: a series of predefined color tables as well as a user-defined one, which may be adjusted in a new window.

- Zoom Mode/Factor: these settings are used to specify a rectangular Region Of Interest (ROI), a sub region of the image:
Prior to the definition of the ROI, a zoom factor in the range of [1, 10] should be selected from the *Factor* drop-down menu. Next, a rectangular ROI is defined by holding down the left mouse button and dragging the mouse inside the graphic display. The selected region is outlined in green color and constantly updated until the mouse button is released. The selected zoom factor is then applied to the selected area and displayed in the viewport. The

Zoom Mode button changes to *Quit Zoom*, providing the option to return to the display showing the entire image extent.

- Image Info: a separate window will display details of the currently loaded image, such as data type, number of bands, unique pixel values, and geoheader information including projection name and EPSG-code if a GeoTiff image was loaded.

3. The MSPA window (bottom left panel)

This window is divided into the following two segments:

3.1. MSPA Parameters

This window allows changing the settings of the four MSPA parameters (more details can be found in **Help → MSPA Guide**):

1. **FGconn:** The default setting for the connectivity of the foreground pixels is 8-connectivity (cardinal and diagonal directions) but may also be constrained to 4-connectivity (cardinal directions only).

2. **EdgeWidth:** The MSPA analysis scale driving the distance of the non-Core boundary classes (default: 1); the selected value is equivalent to the resulting boundary width in pixels. The x-entry in the drop-down menu can be used to insert a custom value within [0, 100]. A new custom value will only be assigned after the Enter key has been pressed.

3. **Transition:** Transition pixels are those pixels of an Edge or a Perforation where the Core area intersects with a Loop or a Bridge. The default value (1: tick mark set) is to show transition pixels as Loop or Bridge pixels connecting to the Core area. However, doing so will interrupt the visual integrity of a closed Edge or Perforation perimeter. The closed perimeter display can be maintained by switching transition to off (0: tick mark unset). Please note that when transition is off, short Bridges of 2 pixels will not be visible since they are hidden under the Edge/Perforation pixels.
   Note: Changing the Transition setting will only change the visual appearance but not the actual pixel values of the processed image.

4. **Intext:** This parameter allows distinguishing internal from external background, where internal background is defined as completely surrounded by Perforation. The default is to enable this distinction, which will add a second layer of classes to the seven basic classes. All classes, with the exception of Perforation, which by default is always internal (105 byte), can then appear in internal or external background.

3.2. MSPA Statistics

This option allows calculating simple statistics of the MSPA classes. The visualized colors of the seven basic MSPA classes are the basis for these statistics showing for each class the percentage (number of class pixels per foreground and per data area) and its frequency (number of unique objects of the given class). Please note that the purpose of these basic statistics is to provide a quick summary only and more elaborate analysis is left to the user. For example, the statistics do not account for the distinction of internal/external classes. Yet, since they are based on the visualized MSPA color classes, they will change when changing the parameter Transition, although this change has no effect on the image data itself. The statistics will be reset in case of changing a MSPA parameter impacting the statistics. More details on the MSPA classes is available in **Help → MSPA Guide**.

4. The Viewport window (top right panel)

This window displays the original, processed or the zoomed area of the image. The image is either displayed in its original size or automatically down-sized to fit the viewport of GuidosToolbox. Any processing is performed on the original non-zoomed image.

5. The Pixel Locator/Value panel

This panel below the viewport shows the pixel coordinates, value and type for the current location of the mouse pointer in the viewport. This feature works in full display as well as in Zoom Mode and in addition will list the related specific class names when investigating certain image types in the viewport.

6. The Divide Range panel

This panel below the Pixel Locator/Value panel allows dividing the data range of the following image types into the 3 groups: small/medium/large. The two thresholds defining these groups are defined via two drop-down menus. The user can either select predefined settings or enter custom thresholds to define threshold values for the 3 groups. A new custom value will only be assigned after the Enter key has been pressed.

- MSPA: divide the MSPA core area [pixels],
- Fragmentation: divide the Fragmentation range [%],
- Contortion: divide the Contortion range,
- Cost: divide the Cost range,
- Distance: divide the distance range [pixels] for foreground and background.
- Influence Zones: define the width of buffer zones for Foreground (to define Core-objects) and Background (buffer zones ranging outside of Foreground or Core objects).

7. Limitations and known issues

The following list summarizes certain limitations and suggestions for potential issues arising when using GuidosToolbox:

- **Maximum image dimensions:** The supported maximum dimensions in x and y are listed under Help → About GuidosToolbox. On Linux and Mac OS X the maximum size for MSPA image processing is recalculated dynamically accounting for the currently available amount of RAM in the system. To increase the dimensions the user should exit from any other running applications occupying the system memory load.
- **Cost Analysis:** at present this type of analysis is implemented using the data type long integer. For very large images, and depending on the average resistance values, the maximum of this data type may be superseded. In this case it will not be feasible to conduct a cost analysis.
- **GuidosToolbox window size:** The size of the program window is driven by the currently loaded image dimensions and, at present, cannot be maximized to fit the entire screen.
- **Save Image → kml does not work:** On certain 64-bit versions of MS-Windows the option to save an image in kml-format may not work due to a conflict with other GIS-software installed in the system. A patch to address this issue is available in the folder *C:\GuidosToolbox\guidos_progs*. If needed, the user should double-click the file *fix_saveaskml.bat* and provide the administrator password to apply the patch.
- **GDAL:** The provision of OpenEV requires providing the rather old version 1.6 of the GDAL (and related Proj) geospatial libraries. Current versions can be obtained from the GdalBinaries website.
- **Data folder on network drive:** Some users have reported issues when processing images stored on network drives. Image data should preferably be stored in the default *GuidosToolbox\data* folder or on a local hard drive.
- **Concurrent use of external software:** Opening/processing a raster file in GuidosToolbox and simultaneously with an external software (i.e., Erdas, ENVI, ArcMap, QGIS) should be avoided.
- **Batch processing under MS-Windows:** A MS-Windows system-inherent problem will limit the number of files for batch processing (only 32000 bytes of string can be read). This problem can be alleviated by shortening the length for the full path to the image files or bypassed completely by using the Linux or the Mac OS X version of GuidosToolbox instead.
- **Undo/Redo:** since only one step is saved in the action history the user is advised to save intermediate results to the hard drive.

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9. References

Canny, J. (1986). A computational approach to edge detection. *IEEE Transactions Pattern Analysis Machine Intelligence (PAMI)* 8(6):679-698.

Jaeger, J.A.G. (2000). Landscape division, splitting index, and effective mesh size: New measures of landscape fragmentation. *Landscape Ecology* 15(2), 115-130

Lee (1986). *Optical Engineering* 25(5), 636-646

Li, H., and Reynolds, J.F. (1993). A new contagion index to quantify patterns of landscapes. *Landscape Ecology* 8:155-162.

Musick, H. B., and H. D. Grover. 1991. Image textural measures as indices of landscape pattern. Pages 77-103 in M. G. Turner and R. H. Gardner, editors. 1991. *Quantitative Methods in Landscape Ecology*. Springer-Verlag.

Riitters, K. H., O'Neill, R.V., Wickham, J.D., and K. B. Jones. (1996). A note on contagion indices for landscape analysis. *Landscape Ecology* 11 no. 4, pp. 197-202.

Riitters, K. H., R. V. O'Neill, and K. B. Jones. (1997). Assessing habitat suitability at multiple scales: a landscape-level approach. *Biological Conservation* 81:191-202.

Riitters, K.H.; Wickham, J.D.; O'Neill, R.V. [and others]. (2002). Fragmentation of continental United States forests. *Ecosystems* 5:815–822.

Riitters, K.H.; Wickham, J.D.; Wade, T.G. (2009). An indicator of forest dynamics using a shifting landscape mosaic. *Ecological Indicators* 9:107-117.

Riitters, K.H.; Coulston, J.W.; Wickham, J.D. (2012). Fragmentation of forest communities in the eastern United States. *Forest Ecology and Management* 263:85-93.

Riitters, K.; Wickham, J.; Costanza, J.K.; Vogt, P. (2015). A global evaluation of forest interior area dynamics using tree cover data from 2000 to 2012 Landscape Ecology, http://dx.doi.org/10.1007/s10980-015-0270-9.

Roberts, L. G. (1965). Machine perception of three-dimensional solids, in *Optical and Electro-Optical Information Processing*

Saura, S. and Torné, J. (2009a). Conefor Sensinode 2.2: a software package for quantifying the importance of habitat patches for landscape connectivity. *Environmental Modelling & Software* 24: 135-139. DOI:10.1016/j.envsoft.2008.05.005

Saura, S. and Rubio, L. (2009b). A common currency for the different ways in which patches and links can contribute to habitat availability and connectivity in the landscape. *Ecography*. DOI 10.1111/j.1600-0587.2009.05760.x

Seebach, L., Strobl, P., Vogt, P., Mehl, W., San-Miguel-Ayanz, J. (2013) Enhancing post-classification change detection through morphological post-processing – a sensitivity analysis. *International Journal of Remote Sensing*, 34 (20), 7145–7162. DOI: 10.1080/01431161.2013.815382

Shannon, C. E. (1948) A mathematical theory of communication. *The Bell System Technical Journal*, 27, 379–423 and 623–656

Sobel, I. (1970). Camera Models and Machine Perception, AIM-21. Stanford Artificial Intelligence Lab, Palo Alto.

Soille, P. (1994). Generalized geodesy via geodesic time. *Pattern Recognition Letters* 15(12), pp. 1235-1240. DOI: 10.1016/0167-8655(94)90113-9

Soille, P. (2000). Morphological Image Analysis: Principles and Applications. Second Edition, Springer-Verlag, Berlin.

Soille, P. and Vogt, P. (2009). Morphological segmentation of binary patterns. *Pattern Recognition Letters*. DOI: 10.1016/j.patrec.2008.10.015

Vogt, P. (2015). Quantifying landscape fragmentation. In GHERARDI, D. F. M.; ARAGÃO, L. E. O. C. (Ed.). Simpósio Brasileiro de Sensoriamento Remoto, 17. (SBSR). São José dos Campos: INPE, 2015. ISBN 978-85-17-0076-8. Available from: <http://urlib.net/8JMKD3MGP6W34M/3JJLLP2>, pp. 1239-1246.

Wade, T.G.; Riitters, K.H.; Wickham, J.D.; Jones, K.B. (2003). Distribution and causes of global forest fragmentation. *Ecology and Society* 7(2):7, [online] URL: http://www.ecologyandsociety.org/vol7/iss2/art7

Wickham, J.D., and Riitters, K.H. (1995). Sensitivity of landscape metrics to pixel size. *International Journal of Remote Sensing* 16:3585-3594.

Wickham, J. D. and D. J. Norton. (1994). Mapping and analyzing landscape patterns. *Landscape Ecology* 9:7-23.