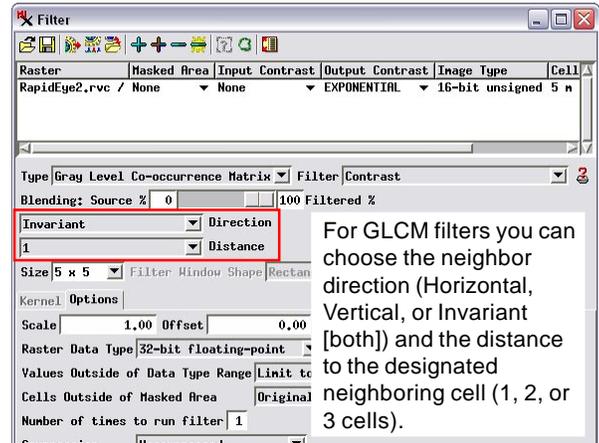


Gray Level Co-occurrence Matrix Filters

The Spatial Filter process in TNTmips (Image / Filter / Spatial Filter) includes a set of Gray Level Co-occurrence Matrix filters designed to extract information about the texture of an image. For a grayscale image (or component of a color image), image texture is defined by the amount, spatial scale, and spatial pattern of variation in brightness values. Some areas of a grayscale image may show little variation in brightness (gray level) over large areas; these areas appear visually smooth. Other image areas may show many large changes in gray level over short distances, and appear visually rough. Texture can be used along with other characteristics in image classification operations.

Gray Level Co-occurrence Matrix (GLCM) filters operate by computing, for each filter window position, how often specific pairs of image cell values occur in neighboring cell positions (such as one cell to the right). The results are tabulated in a co-occurrence matrix, and specific statistical measures are computed from this matrix to produce the filtered value for the target cell.



Sample Filter Window

1	1	2	2	3
1	2	2	3	3
2	2	3	3	4
2	3	3	4	4
3	3	4	4	1

Sample 5 x 5 filter window showing image gray level values ranging from 1 to 4. Red ellipses outline four instances where value 3 occurs one cell to the right of value 2. The filter value will be written to the center cell position (yellow background) in the filtered image.

Gray Level Co-occurrence Matrix for neighbor 1 cell to the right (raw counts)

		neighbor cell value			
		1	2	3	4
reference cell value	1	1	2	0	0
	2	0	3	4	0
	3	0	0	4	3
	4	1	0	0	2

Gray Level Co-occurrence Matrix for the filter window at left showing counts of neighbor relations for different reference cell values (rows) and right-neighbor cell values (columns). Note count of 4 for matrix location [2,3] and different count (0) for location [3,2]; there are no instances where value 2 occurs to the right of value 3. Matrix cells on main diagonal (shaded) register counts where reference and neighbor gray level values are the same.

Gray Level Co-occurrence Matrix for horizontal direction (raw counts)

		neighbor cell value			
		1	2	3	4
reference cell value	1	2	2	0	1
	2	2	6	4	0
	3	0	4	8	3
	4	1	0	3	4

Symmetrical Gray Level Co-occurrence Matrix created by counting each gray-level pair twice, interchanging the reference and neighbor values. The same values now occur in corresponding positions on opposite sides of the main diagonal (for example, identical count of 4 for matrix locations [2,3] and [3,2] as shown by red circles). Note that matrix locations farther from the main diagonal indicate greater difference in gray level values for the reference and neighbor image cell.

A gray level co-occurrence matrix is illustrated above for a 5 by 5 filter window with gray levels ranging from 1 to 4. Each position in the matrix represents a pair of gray levels, one from the reference image cell (matrix row) and one from its neighbor (matrix column), in this example the neighbor one image cell to the right. Pairings where both gray levels are the same appear on the main diagonal of the matrix: [1,1], [2,2], and so on (gray shading above).

In a raw co-occurrence matrix the numbers are simple counts of the number of instances in which that reference-neighbor gray level pairing is found in the filter window. The illustration highlights value 3 occurring four times as the neighbor to value 2 as an example of how the matrix values are calculated. Note that value 2 does not occur to the right of value 3 in the filter window, so the count in matrix position [3,2] is 0.

The texture filters require a co-occurrence matrix that is symmetrical, with the same values occur in corresponding positions on opposite sides of the main diagonal. This is achieved for the example illustrated above by counting each gray-level value pair again

in the opposite direction. The count for matrix position [3,2] then becomes equal to position [2,3]. A final step for the co-occurrence matrix (not illustrated) converts the raw counts to probability values by dividing each count by the sum of all counts to produce a normalized co-occurrence matrix.

A normalized GLCM is computed independently for each cell in the input image using the filter window. Each of the GLCM filters performs a different computation from the matrix in order to compute the output cell value at a particular image cell location.

Direction and Distance

You can specify different spatial neighbor relationships using the Direction and Distance menus (see illustration at top of this page). For Direction you can choose Horizontal (right and left neighbors), Vertical (up and down neighbors), or Invariant (right, upper right, upper, and upper left neighbors). The Invariant setting is best for the general case in which there are no preferred directions of textural elements in the image. The Distance setting determines the (over)

offset between reference and neighbor cells; the choices are 1 (the default), 2, or 3 cells. Increasing the Distance setting increases the scale of the texture being sampled.

GLCM Filters

Selecting Gray Level Co-occurrence Matrix from the Type menu on the Spatial Filter window provides a choice of eight filters on the Filter menu. Results of each of the filter types for a 3 by 3 filter window with invariant direction and distance = 1 are shown below for the grayscale image illustrated to the right, which has both smooth and rough areas.



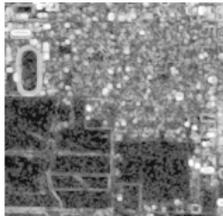
Sample Image

The GLCM filters fall into three conceptual subsets: Contrast, Order-Disorder, and Statistics.

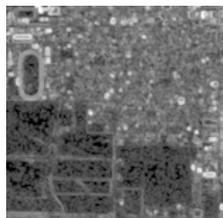
GLCM Contrast Subset

The filters in the Contrast subset use the gray-level pairings in the GLCM matrix to measure the magnitude of the differences in gray levels (or lack thereof) in the image area. These filters use a weighted average of the normalized GLCM values for each filter window to compute the filter result. Remember that positions on the main diagonal of the GLCM represent equal reference-neighbor gray levels. Positions off of the main diagonal represent unequal gray-level pairings, with the brightness difference between neighbors increasing toward the corners opposite the main diagonal. The averaging weight values for these filters vary with the distance from the GLCM main diagonal.

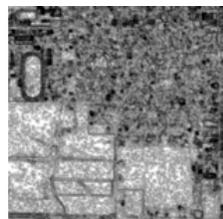
Contrast (also called Sum of Squares Variance) measures gray-level contrast by using GLCM weighting factors equal to the square of the gray level difference. Thus the averaging weights are 0 for matrix positions on the main diagonal and increase exponentially away from the diagonal. The filter result is 0 for areas with identical image values and is high where there are large differences in tone.



Dissimilarity uses weighting factors equal to the absolute value of the gray level difference, so the weights vary linearly with distance from the matrix main diagonal (rather than by the square of the difference as for Contrast). The output is similar to the Contrast result, and in displays the two can be made to appear nearly identical by judicious selection of display contrast.



Homogeneity (also called Inverse Distance Moment) is effectively the inverse of Contrast. It measures the smoothness of the image area. The weights are equal to the inverse of the square of the gray-level difference (the inverse of the Contrast weights). This filter produces higher result values for areas with little difference in gray level, which produces a GLCM with non-zero values concentrated along or near the main diagonal.



GLCM Order-Disorder Subset

The filters in this subset measure whether the image values in the

filter window are regularly or randomly arranged. In a more ordered image area, particular image cell value pairs occur more frequently than others, whereas in a random image area all gray-level pairings would have similar low frequency values.

These filters also use a weighted average of the normalized GLCM values for the filter result. Their names come from the fields of physics and thermodynamics, and so are a bit more difficult to place in a visual context.

Angular Second Moment (also called Uniformity or Energy) measures the textural uniformity of the image area. Its value is highest when the area has either a constant image value or a repeating pattern of values. The averaging weight for this filter is just the GLCM matrix value, so the result is the sum of the squared matrix cell values.



Because of this square relationship, one or a few matrix positions with large frequencies (corresponding to smooth areas or repeating patterns, respectively) produce a large filter value, whereas the consistent low frequencies of a random pattern result in a low value.

Entropy measures the randomness or disorder of the image area. The averaging weight for each GLCM position is a negative logarithmic function of the frequency. This weighting minimizes the influence of higher-frequency gray-level pairs and yields higher values when there is a random distribution of brightness values.



GLCM Statistics Filters

Each filter in this subset computes a standard statistical measure of the values in the GLCM matrix.

Mean is the sum of each image gray level multiplied by its normalized frequencies of combination with the other gray levels.

Variance measures the spread of the GLCM frequency values by computing the statistical variance (square of the standard deviation) of the matrix relative to the GLCM mean. A filter window with a constant gray level yields a 0 value for the GLCM variance.

Correlation measures the linear dependency of a gray level on those of neighboring image cells. A filter value of 1 indicating perfect correlation would result from an area with constant image value, whereas a value of 0 indicates no correlation.



GLCM Mean



GLCM Variance



GLCM Correlation

Usage

Most of the GLCM filters typically produce results with small non-integer cell values. Therefore MicroImages recommends that for best results you apply the GLCM filters with Blending set to 100% Filtered and the Raster Data Type set to 32-bit floating point (the default settings).