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Produced by the NASA Center for Aerospace Information (CASI)
DOCUMENTATION OF PROCEDURES FOR
TEXTURAL/SPATIAL PATTERN
RECOGNITION TECHNIQUES

FINAL REPORT

April 15, 1976

RSL Technical Report 278-1

Robert M. Haralick
William F. Bryant

Funded by:
NASA LYNDON B. JOHNSON SPACE CENTER
Contract NAS 9-14453
Houston, Texas 77058
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</tr>
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Introduction

This research was undertaken in an effort to aid the Forestry Application Project on Timber Resources. Mission M230 of the C-130 aircraft was flown over the Sam Houston National Forest on March 21, 1973 at 10,000 feet altitude. The Bendix 24 channel multispectral scanner collected the data. Four forest scenes of this data set were selected for study. They were edits 3, 6, 9, and 14. The categories of timber classes and subclasses are shown in Table I.1.

The application oriented research was to apply and document the capability of existing textural and spatial automatic processing techniques at the University of Kansas to classify the MSS imagery into specified timber categories. The ground truth for the study was supplied by the Forestry Applications Project.

Over a hundred classification experiments were performed on this data using feature selected from the spectral bands and a textural transform band. The textural transform band is an image whose resolution cells have grey tone intensities which indicate one parameter of local neighborhood texture. The textural transform concept is discussed in Section III. The classification was done by equal interval quantizing the images to 32 levels and using a non-parametric table look-up rule discussed in Section II. The various spatial pre- and post-processing options are discussed in Sections IV and V. Sections VI through IX discuss the results using only spectral features. Sections X through XIII discuss the combined spectral textural results.

The results indicate that

1) spatial post-processing a classified image can cut the classification error to 1/2 or 1/3 of its initial value.

2) spatial post-processing the classified image using combined spectral and textural features produces a resulting image with less error than post-processing a classified image using only spectral features.

3) classification without spatial post processing using the combined spectral textural features tends to produce about the same error rate as a classification without spatial post processing using only spectral features.
### TABLE 1.1 THE TYPE (CLASSES) AND CONDITION CLASSES (SUBCLASSES) OF FOREST FEATURES OF INTEREST IN SAM HOUSTON NATIONAL FOREST OF TEXAS

<table>
<thead>
<tr>
<th>Type No.</th>
<th>Type (Class)</th>
<th>Subclass No.</th>
<th>Condition Class (Subclass)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shortleaf pine</td>
<td>1.1</td>
<td>Plantation - 3 years old</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.2</td>
<td>Poletimber - immature</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.3</td>
<td>Sawtimber - immature</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.4</td>
<td>Sawtimber - mature</td>
</tr>
<tr>
<td>2</td>
<td>Loblolly pine</td>
<td>2.1</td>
<td>Plantation - 1 year old</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.2</td>
<td>Plantation - 3 years old</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.3</td>
<td>Seedling and Sapling - adequately stocked</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.4</td>
<td>Poletimber - immature</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.5</td>
<td>Sawtimber - immature</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.6</td>
<td>Sawtimber - mature</td>
</tr>
<tr>
<td>3</td>
<td>Laurel oak - willow oak</td>
<td>3.1</td>
<td>Sawtimber - immature</td>
</tr>
<tr>
<td>4</td>
<td>Sweetgum - nuttal oak - willow oak</td>
<td>4.1</td>
<td>Sawtimber - low quality</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.2</td>
<td>Sawtimber - immature</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.3</td>
<td>Sawtimber - mature</td>
</tr>
<tr>
<td>5</td>
<td>Post oak - black oak</td>
<td>5.1</td>
<td>Sawtimber - immature</td>
</tr>
<tr>
<td>6</td>
<td>Loblolly pine - hardwoods</td>
<td>6.1</td>
<td>Sawtimber - immature</td>
</tr>
<tr>
<td>7</td>
<td>Cut-over land</td>
<td>7.1</td>
<td>Site prepared and windrowed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.2</td>
<td>Not site prepared</td>
</tr>
</tbody>
</table>
These results mean that regardless of how the image is classified, spatial post-processing should be used to reduce the error rate. Furthermore, the best post-processing results can be obtained if textural features are used; but, if no spatial post-processing is going to be utilized, spectral bands only will give about the same results as the combined spectral textural bands.

These conclusions are based on classification into all timber subclasses using large training sets averaging more than 25,000 points per image. Because the training sets were orders of magnitude larger than the number of categories times the number of features, the statistics must be considered as large sample statistics and we used, justifiably, the training data as the test data.

Tables 1.2 and 1.3 summarize the basis of our conclusions. The results of each experiment can be summarized in three ways: by average error, by average misidentification error, and by average false identification error. The average error is defined as the total number of incorrect category assignments divided by the total number of assignments. The average misidentification error is defined as the equally weighted average over all categories of the number of times the category is incorrectly assigned divided by the total number of times the category occurs in the ground truth. The average false identification error is defined as the equally weighted average over all categories of the number of times an incorrect assignment is made to the category divided by the total number of times an assignment is made to the category.

When the ground truth has each category occurring with equal frequency, the average misidentification error will equal the average error. When the number of assignments to each category is the same, the average false identification error will equal the average error. If the prior probability for a category is high and the category has a high misidentification error, then all other things being equal, the average error will be higher than the average misidentification error. If the prior probability for a category is low, and the category has high misidentification error, then all other things being equal, the average error will be lower than the average misidentification error.

From Tables 1.2 and 1.3 it is readily apparent that both the use of textural features and spatial post-processing tends to increase and equalize the average misidentification error and false identification error while cutting the average error to less than half its initial value.
1.1 Contingency Tables of Classification Results

All results are reported with a complete contingency table. The contingency tables are all organized in the same manner. The title for the contingency table tells which images are being compared. The first nine character file name is the name of the ground truth image file. The number following it is the symbolic band number used from that multi-image file. The second nine character file name is the name of the classified image file. The number following it is the number of the symbolic band used from that multi-image file. The row label UNKWN means unknown true category identification. The column label R DEC means reserved decision.

The contingency tables have a column labeled ERR. This column designates the number of the resolution cells in each category misidentified. The next column is labeled % ERR and it designates the percent of misidentification error. The contingency tables have a row labeled ERR. This row designates the number of resolution cells in each category falsely identified. The next row is labeled % ERR and it designates the percent of false identification error. The label % SD stands for the percent standard deviation of the error estimates. The entry whose row is labeled TOTAL and whose column is weighted % ERR is the equally weighted average of the misidentification error percentages. The entry whose column is labeled total and whose row is weighted % ERR is the equally weighted average of the false identification error percentages.
Table I.2 summarizes the error rates obtained from the spectral versus the spectral-textural classification using 3 band pairs and no spatial post processing.

<table>
<thead>
<tr>
<th></th>
<th>Average Error</th>
<th>Average Misidentification Error</th>
<th>Average False Identification Error</th>
<th>Average Error</th>
<th>Average Misidentification Error</th>
<th>Average False Identification Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edit 6</td>
<td>22%</td>
<td>30%</td>
<td>5%</td>
<td>22%</td>
<td>23%</td>
<td>6%</td>
</tr>
<tr>
<td>Edit 9</td>
<td>28%</td>
<td>9%</td>
<td>9%</td>
<td>28%</td>
<td>8%</td>
<td>11%</td>
</tr>
<tr>
<td>Edit 14</td>
<td>30%</td>
<td>13%</td>
<td>9%</td>
<td>30%</td>
<td>90%</td>
<td>90%</td>
</tr>
<tr>
<td>Edit 3</td>
<td>42%</td>
<td>14%</td>
<td>25%</td>
<td>40%</td>
<td>25%</td>
<td>29%</td>
</tr>
</tbody>
</table>

texture band not selected by feature selector

Table I.3 summarizes the error rates obtained from the spectral versus the spectral-textural classification using 3 band pairs and spatial post processing.

<table>
<thead>
<tr>
<th></th>
<th>Average Error</th>
<th>Average Misidentification Error</th>
<th>Average False Identification Error</th>
<th>Average Error</th>
<th>Average Misidentification Error</th>
<th>Average False Identification Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edit 6</td>
<td>9.3%</td>
<td>34%</td>
<td>33%</td>
<td>6.8%</td>
<td>38%</td>
<td>37%</td>
</tr>
<tr>
<td>Edit 9</td>
<td>19%</td>
<td>25%</td>
<td>32%</td>
<td>15%</td>
<td>27%</td>
<td>33%</td>
</tr>
<tr>
<td>Edit 14</td>
<td>12%</td>
<td>32%</td>
<td>31%</td>
<td>12%</td>
<td>40%</td>
<td>44%</td>
</tr>
<tr>
<td>Edit 3</td>
<td>24%</td>
<td>35%</td>
<td>40%</td>
<td>12%</td>
<td>40%</td>
<td>44%</td>
</tr>
</tbody>
</table>

texture band not selected by feature selector
Brooner, Haralick and Dinstein (1971) used a table look-up approach on high altitude multiband photography flown over Imperial Valley, California to determine crop types. Their approach to the storage problem was to perform an equal probability quantizing from the original 64 digitized grey levels to ten quantized levels for each of the three bands: green, red, and near infrared. Then after the conditional probabilities were empirically estimated, they used a Bayes rule to assign a category to each of the 10^3 possible quantized vectors in the 3-dimensional measurement space. Those vectors which occurred too few times in the training set for any category were deferred assignment.

The rather direct approach employed by Brooner et al. has the disadvantage of requiring a rather small number of quantized levels. Furthermore, it cannot be used with measurement vectors of dimension greater than four; for if the number of quantized levels is about 10, then the curse of dimensionality forces the number of possible quantized vectors to an unreasonably large size. Recognizing the grey level precision restriction forced by the quantizing coarsening effect, Eppler, Helmke, and Evans (1971) suggest a way to maintain greater quantizing precision by defining a quantization rule for each category - measurement dimension as follows:

1. fix a category and a measurement dimension component;
2. determine the set of all measurement patterns which would be assigned by the decision rule to the fixed category;
3. examine all the measurement patterns in this set and determine the minimum and maximum grey levels for the fixed measurement component;
4. construct the quantizing rule for the fixed category and measurement dimension pair by dividing the range between the minimum and maximum grey levels for the category into equal spaced quantizing intervals.

This multiple quantizing rule in effect determines for each category a rectangular parallelepiped in measurement space which contains all the measurement patterns assigned to it. Then as shown in Figure II.1, the equal interval quantizing lays a grid over the rectangular parallelepiped. Notice how for a fixed number of quantizing levels, the use of multiple quantizing rules in each band allows greater...
grey level quantizing precision compared to the single quantization rule for each band.

A binary table for each category can be constructed by associating each entry of the table with one corresponding cell in the gridded rectangular parallelepiped. An entry is a binary 1 if the decision rule assigns a majority of the measurement patterns in the corresponding cell to the specified category; otherwise, the entry is assigned to be a binary 0.

The binary tables are used in the implementation of the multiple quantization rule table look-up in the following way. Order the categories in some meaningful manner such as by prior probability. Quantize the multispectral measurement pattern using the quantization rule for category $c_1$. Use the quantized pattern as an address to look up the entry in the binary table for category $c_1$ to determine whether or not the pre-stored decision rule would assign the pattern to category $c_1$. If the decision rule makes the assignment to category $c_1$, the entry would be a binary 1 and, all is finished. If the decision rule does not make the assignment to category $c_1$, the entry would be a binary 0 and the process would repeat in a similar manner with the quantization rule and table for the next category.

One advantage to this form of the table look-up decision rule is the flexibility to use different subsets of bands for each category look-up table and thereby take full advantage of the feature selecting capability to define an optimal subset of bands to discriminate one category from all the others. A disadvantage to this form of the table look-up decision rule is the large amount of computational work required to determine the rectangular parallelepipeds for each category and the still large amount of memory storage required (about 5,000 8 bit bytes per category).

Eppler (1974) discusses a modification of the table look-up rule which enables memory storage to be reduced by five times and decision rule assignment time to be decreased by 2 times. Instead of pre-storing in tables a quantized measurement space image of the decision rule, he suggests a systematic way of storing in tables the boundaries or end-points for each region in measurement space satisfying a regularity condition and having all its measurement patterns assigned to the same category.

Let $D = D_1 \times D_2 \times \ldots \times D_N$ be measurement space. A subset $R \subseteq D_1 \times D_2 \times \ldots \times D_N$ is a regular region if and only if there exists constants
L_1 and H_1 and functions L_2, L_3, ..., L_N, H_2, H_3, ..., H_N

\[(L_n: D_1 \times D_2 \times \ldots \times D_{n-1} \to (\mathbb{R}, \mathbb{R}); H_n: D_1 \times D_2 \times \ldots \times D_{n-1} \to (\mathbb{R}, \mathbb{R})]\]

such that

\[R = \{(x_1, \ldots, x_N) \in D | L_1 \leq x_1 \leq H_1, L_2(x_1) \leq x_2 \leq H_2(x_1), \ldots, L_N(x_1, x_2, \ldots, x_{N-1}) \leq x_N \leq H_N(x_1, x_2, \ldots, x_{N-1})\} \]

From the definition of a regular region, it is easy to see how the table look-up by boundaries decision rule can be implemented. Let \(d = (d_1, \ldots, d_N)\) be the measurement pattern to be assigned a category. To determine if \(d\) lies within a regular region \(R\) associated with category \(c\) we look up the numbers \(L_1\) and \(H_1\) and test to see if \(d_l\) lies between \(L_1\) and \(H_1\). If so, we look up the numbers \(L_2(d_1)\) and \(H_2(d_1)\) and so on. If all the tests are satisfied, the decision rule can assign measurement pattern \(d\) to category \(c\). If one of the tests fails, tests for the regular region corresponding to the next category can be made.

The memory reduction in this kind of table look-up rule is achieved by only storing boundary or end-points of decision regions and the speed-up is achieved by having one-dimensional tables whose addresses are easier to compute than the three or four-dimensional tables required by the initial table look-up decision rule. However, the price paid for by these advantages is the regularity condition imposed on the decision regions for each category. This regularity condition is stronger than set connectedness but weaker than set convexity.

Another approach to the table look-up rule can be based on Ashby's (1964) technique of constraint analysis. Ashby suggests representing in an approximate way subsets of Cartesian product sets by their projections on various smaller dimensional spaces. Using this idea for two-dimensional spaces we can formulate the following kind of table look-up rule.

Let \(D = D_1 \times D_2 \times \ldots \times D_N\) be measurement space, \(C\) be the set of categories, and \(J \subseteq \{1, 2, \ldots, N\} \times \{1, 2, \ldots, N\}\) be an index set for the selected two-dimensional
spaces. Let the probability threshold $\alpha$ be given. Let $(i, j) \in J$; for each $(x_1, x_2) \in D_i \times D_j$ define the set $S_{ij}(x_1, x_2)$ of categories having the highest conditional probabilities given $(x_1, x_2)$ by

$$S_{ij}(x_1, x_2) = \{ c \in C | \sum_{x_1, x_2} P_{x_1, x_2}^{c} (c) \geq \alpha_{ij} \}$$

where $\alpha_{ij}$ is the largest number which satisfies

$$\sum_{c \in S_{ij}(x_1, x_2)} P_{x_1, x_2}^{c}(c) \geq \alpha$$

$S_{ij}(x_1, x_2)$ is the set of likely categories given that components $i$ and $j$ of the measurement pattern take the values $(x_1, x_2)$.

The sets $S_{ij}$, $(i, j) \in J$, can be represented in the computer by tables. In the $(i, j)^{th}$ table $S_{ij}$ the $(x_1, x_2)^{th}$ entry contains the set of all categories of sufficiently high conditional probabilities given the marginal measurements $(x_1, x_2)$ from measurement components $i$ and $j$, respectively. This set of categories is easily represented by a one word table entry; a set containing categories $c_1$, $c_7$, $c_9$, and $c_{12}$, for example, would be represented by a word having bits 1, 7, 9, and 12 on and all other bits off.

The decision region $R(c)$ containing the set of all measurement patterns to be assigned to category $c$ can be defined from the $S_{ij}$ sets by

$$R(c) = \bigcap_{(i, j) \in J} \{ (d_1, d_2, \ldots, d_N) \in \prod_{i=1}^{N} D_i | (c) = \bigcap_{(i, j) \in J} S_{ij}(d_i, d_j) \}$$

This kind of a table look-up rule can be implemented by using successive pairs of components (defined by the index set $J$) of the (quantized) measurement patterns as addresses in the just mentioned two-dimensional tables. The set intersection required by the definition of the decision region $R(c)$ is implemented by taking the Boolean AND of the words obtained from the table look-ups for the measurement to be assigned a category. Note that this Boolean operation makes full use of the natural parallel compute capability the computer has on bits of a word. If the $k^{th}$ bit is the only bit which remains on in the resulting word, then the measurement pattern is assigned to category $c_k$. If there is more than one bit on or no bits are on, then the measurement pattern is deferred its assignment (reserved decision).
Thus we see that this form of a table look-up rule utilizes a set of "loose" Bayes rules in the lower dimensional projection spaces and intersects the resulting multiple category assignment sets to obtain a category assignment for the measurement pattern in the full measurement space.

Because of the natural effect which the category prior probabilities have on the category assignments produced by a Bayes rule it is possible for a measurement pattern to be the most probable pattern for one category yet be assigned by the Bayes rule to another category having much higher prior probability. This effect will be pronounced in the table look-up rule just described because the elimination of such a category assignment from the set of possible categories by one table look-up will completely eliminate it from consideration because of the Boolean AND or set intersection operation. However, by using an appropriate combination of maximum likelihood and Bayes rules, something can be done about this.

For any pair \((i, j)\) of measurement components, fixed category \(c\); and probability threshold \(\beta\), we can construct the set of \(T_{ij}(c)\) having the most probable pairs of measurement values from component \(i\) and \(j\) arising from category \(c\). The set \(T_{ij}(c)\) is defined by

\[
T_{ij}(c) = \{(x_1, x_2) \in D_i \times D_j \mid P_c(x_1, x_2) \geq \beta_{ij}(c)\},
\]

where \(\beta_{ij}(c)\) is the largest number satisfying

\[
\sum_{(x_1, x_2) \in T_{ij}(c)} P_c(x_1, x_2) \geq \beta
\]

Tables which can be addressed by (quantized) measurement components can be constructed by combining the \(S_{ij}\) and \(T_{ij}\) sets. Define \(Q_{ij}(x_1, x_2)\) by

\[
Q_{ij}(x_1, x_2) = \{(c \in C \mid (x_1, x_2) \in T_{ij}(c)) \cup S_{ij}(x_1, x_2)\}
\]

The set \(Q_{ij}(x_1, x_2)\) contains all the categories whose respective conditional probabilities given measurement values \((x_1, x_2)\) of components \(i\) and \(j\) are sufficiently high (a Bayes rule criteria) as well as all those categories whose most probable measurement values for components \(i\) and \(j\) respectively are \((x_1, x_2)\) (a maximum likelihood criteria). A decision region \(R(c)\) containing all the (quantized) measurement patterns can then be defined as before using the \(Q_{ij}\) sets:
\[ R(c) = \left\{ (d_1, d_2, \ldots, d_N) \in D_1 \times D_2 \times \cdots \times D_N \mid \{c\} = \bigcap_{(i,j) \in J} Q_{ij}(d_i, d_j) \right\} \]

A majority vote version of this kind of table look-up rule can be defined by assigning a measurement to the category most frequently selected in the lower dimensional spaces.

\[ R(c) = \left\{ (d_1, d_2, \ldots, d_N) \in D_1 \times D_2 \times \cdots \times D_N \right\} \]

\[ \# \{ (i,j) \in J \mid c \in Q_{ij}(d_i, d_j) \} \geq \# \{ (i,j) \in J \mid c \in Q_{ij}(d_i, d_j) \} \]

for every \( c \in C - \{c\} \)

Classification results were run with \( \beta = 0.07\alpha \) and \( \alpha \) chosen to minimize the number of reserved decisions. Figure II.2 illustrates a graph of the number of reserved decisions versus probability threshold \( \alpha \).
Figure II.1 illustrates how quantizing can be done differently for each category thereby enabling more accurate classification by the following table look-up rule: (1) quantize the measurement by the quantizing rule for category one (2) use the quantized measurement as an address in a table and test if the entry is a binary one or binary zero, (3) if it is a binary one assign the measurement to category one; if it is a binary zero, repeat the procedure for category two.
Figure 11.2 illustrates a graph of the number of reserved decisions versus probability threshold $\alpha$. 
Texture

Spatial environments can be understood as being spatial distributions of various area-extensive objects having characteristic size and reflectance or emissive qualities. The spatial organization and relationships of the area-extensive objects appear as spatial distributions of grey tone on imagery taken of the environment. We call the pattern of spatial distributions of grey tone, texture.

Figure III.1, taken from Lewis (1971), illustrates how texture relates to geomorphology. There are some plains, low hills, high hills, and mountains in the Panama and Columbia area taken by the Westinghouse AN/APQ 97 K-band radar imager system. The plains have apparent relief of 0-50 meters, the hills have apparent relief of 50-350 meters, and the mountains have apparent relief of more than 350 meters. The low hills have little dissection and are generally smooth convex surfaces whereas the high hills are highly dissected and have prominent ridge crests.

The mountain texture is distinguishable from the hill texture on the basis of the extent of radar shadowing (black tonal areas). The mountains have shadowing over more than half the area and the hills have shadowing over less than half the area. The hills can be subdivided from low to high on the basis of the abruptness of tonal change from terrain front slope to terrain back slope.

There have been six basic approaches to the measurement and quantification of image texture: autocorrelation functions (Kaizer, 1955), optical transforms, (Lendaris and Stanley, 1970), digital transforms, (Gramenopoulos, 1973; Hornung and Smith, 1973; Kirvida and Johnson, 1973), edgeness (Rosenfeld and Thurston, 1971), structural elements, (Matheron, 1967; Serra, 1973), and spatial grey tone co-occurrence probabilities, (Haralick et al., 1973). The first three of these approaches are related in that they all measure spatial frequency directly or indirectly. Spatial frequency is related to texture because fine textures are rich in high spatial frequencies while coarse textures are rich in low spatial frequencies.

An alternative to viewing texture as spatial frequency distribution is to view texture as amount of edge per unit area. Coarse textures have a small number of edges per unit area. Fine textures have a high number of edges per unit area.

The structural element approach uses a matching procedure to detect the spatial regularity of shapes called structural elements in a binary image. When
the structural elements themselves are single resolution cells, the information provided by this approach is the autocorrelation function of the binary image. By using larger and more complex shapes, a more generalized autocorrelation can be computed.

The grey tone co-occurrence approach characterizes texture by the spatial distribution of its grey tones. Coarse textures are those for which the distribution changes only slightly with distance and fine textures are those for which the distribution changes rapidly with distance.

III.1 Optical Processing Methods and Texture

Edward O'Neill's (1956) article on spatial filtering introduced the engineering community to the fact that optical systems can perform filtering of the kind used in communication systems. In the case of the optical systems, however, the filtering is two-dimensional. The basis for the filtering capability of optical systems lies in the fact that the light amplitude distributions at the front and back focal planes of lens are Fourier Transforms of one another. The light distribution produced by the lens is more commonly known as the Fraunhofer diffraction pattern. Thus, optical methods facilitate two-dimensional frequency analysis of images.

The paper by Cutrona et al. (1960) provides a good review of optical processing methods for the interested reader. More recent books by Goodman (1968), Preston (1972), Shulman (1970) comprehensively survey the area.

In this section, we describe the experiments done by Lendaris and Stanley, Egbert et al., and Swanlund using optical processing methods in aerial or satellite imagery. Lendaris and Stanley (1970) illuminated small circular sections of low altitude aerial photography and used the Fraunhofer diffraction pattern as features for identifying the sections. The circular sections represented a circular area on the ground of 750 feet. The major category distinction they were interested in making was man-made versus non man-made. They further subdivided the man-made category into roads, road intersections, buildings, and orchards.

The pattern vectors they used from the diffraction pattern consisted of 40 components. Twenty components were averages of the energy in 90° wedges of the diffraction pattern. They obtained over 90 percent identification accuracy.
Ulaby and McNaughton used an optical processing system to examine the texture of ERTS imagery over Kansas. They used circular areas corresponding to a ground diameter of about 37 km and looked at the diffraction patterns for four different physiographic regions in Kansas. They used a diffraction pattern sampling unit having 32 sector wedges and 32 annular rings to sample and measure the diffraction patterns. (See Jensen (1973) for a description of the sampling unit and its use in coarse diffraction pattern analysis.) They were able to interpret the resulting angular orientation graphs in terms of dominant drainage patterns, roads and fields but interpreted the spatial frequency graphs in terms of stress patterns, rough terrain and field patterns. Their results indicated that the spatial frequency information was highly correlated with physiography.

Swanlund (1969) has done work using optical processing on aerial images to identify species of trees. Using imagery obtained from Itasca State Park in northern Minnesota, photo interpreters identified five (mixture) species of trees on the basis of the texture: Upland Hardwoods, Jack pine overstory/Aspen understory/Upland Hardwoods understory, Red pine overstory/Aspen understory, and Aspen. They achieved classification accuracy of over 90 percent.

III.2 Texture and Edges

The autocorrelation function, the optical transforms, and the fast digital transforms (FFT and FHT) basically all reference texture to spatial frequency. Rosenfeld and Thurston (1971) conceive of texture not in terms of spatial frequency but in terms of edgeness per unit area. An edge passing through a resolution cell is detected by comparing the values for local properties obtained in pairs of nonoverlapping neighborhoods boarding the resolution cell. To detect microedges, small neighborhoods must be used. To detect macroedges, large neighborhoods must be used.

The local property which Rosenfeld and Thurston suggested was the quick Roberts gradient (the sum of the absolute value of the differences between diagonally opposite neighboring pixels). Thus, a measure of texture for any subimage is obtained by computing the Roberts gradient image for the subimage and from it determining the average value of the gradient in the subimage. Triendl (1972) uses the Laplacian instead of the Roberts gradient.
Sutton and Hall (1972) extended Rosenfeld and Thurston's idea by making the gradient a function of the distance between the pixels. Thus, for every distance $d$ and subimage $I$ defined over a neighborhood $N$ of resolution cells, they compute

$$g(d) = \sum_{(i, j) \in N} \{|I(i, j) - I(i+d, j)| + |I(i, j) - I(i-d, j)| + |I(i, j) - I(i, j+d)| + |I(i, j) - I(i, j-d)|\}.$$ 

The graph of $g(d)$ is like the graph of the minus autocorrelation function translated vertically.

Sutton and Hall applied this textural measure in a pulmonary disease identification experiment using radiographic imagery and obtained identification accuracy in the 80 percentile range for discriminating between normal and abnormal lungs when using a 128 x 128 subimage.

### III.3 Digital Transform Methods and Texture

In the digital transform method of texture analysis, the digital image is typically divided into a set of non-overlapping small square subimages. Suppose the size of the subimage is $n \times n$ resolution cells, then the $n^2$ grey tones in the subimage can be thought of as the $n^2$ components of an $n^2$-dimensional vector. In the transform technique, each of these vectors is re-expressed in a new coordinate system. The Fourier Transform uses the sine-cosine basis set. The Hadamard Transform uses the Walsh function basis set, etc. The point to the transformation is that the basis vectors of the new coordinate system have an interpretation that relates to spatial frequency (sequency) and since frequency (sequency) is a close relative of texture, we see that such transformation can be useful.

Gramenopoulos (1973) used a transform technique using the sine-cosine basis vectors (and implemented it with the FFT algorithm) on ERTS imagery to investigate the power of texture and spatial pattern to do terrain type recognition. He used subimages of 32 by 32 resolution cells and found that on Phoenix, Arizona ERTS image 1940-17324-5 spatial frequencies larger than 3.5 cycles/km and smaller than 5.9 cycles/km contain most of the information needed to discriminate between terrain types. The terrain classes were: clouds, water, desert, farms, mountains, urban, riverbed, and cloud shadows. He achieved an overall identification accuracy of 87 percent.

Hornung and Smith (1973) have done work similar to Gramenopoulos but with aerial multispectral scanner imagery instead of ERTS imagery. Maurer (1974)
used Fourier series analysis on some color aerial film to obtain textural features to help determine crop types.

Kirvida and Johnson (1973) compared the fast Fourier, Hadamard, and Slant Transforms for textural features on ERTS imagery over Minnesota. They used 8 x 8 subimages and five categories: Hardwoods, Conifers, Open, Water, City. Using only spectral information, they obtained 74 percent correct identification accuracy. When they added textural information, they increased the identification accuracy to 99 percent. They found little difference between the different transform methods.

III.4 Spatial Grey Tone Dependence: Co-occurrence

One aspect of texture is concerned with the spatial distribution and spatial dependence among the grey tones in a local area. Darling (1968) used statistics obtained from the nearest neighbor grey tone transition matrix to measure this dependence for satellite images of clouds and was able to identify cloud types on the basis of their texture. Read and Jayaramamurthy (1972) divided an image into all possible (overlapping) subimages of reasonably small and fixed size and counted the frequency for all the distinct grey tone patterns. This is one step more general than Darling but one that requires too much memory if the grey tones can take on very many values. Haralick (1971) and Haralick et al. (1972, 1973) suggested an approach which is a compromise between the two. He measures the spatial dependence of grey tones in a co-occurrence matrix for each fixed distance and/or angular spatial relationship and uses statistics of the matrix as measures of image texture.

The co-occurrence matrix P = (p_{ij}) has its (i, j)^{th} entry \( P_{ij} \) defined as the number of times grey tone \( i \) and grey tone \( j \) occur in resolution cells of a subimage having a specified spatial relation, such as distance 1 neighbors. The textural features for the subimage are obtainable from the co-occurrence matrix by measures such as

\[
\sum_i \sum_j P_{ij}^2, \sum_i \sum_j P_{ij} \log P_{ij}
\]

and

\[
\sum_i \sum_j \frac{P_{ij}}{1 + |i-j|}
\]
Haralick et al. (1973) list 14 different kinds of measures.

Using statistics of the co-occurrence matrix, Haralick performed a number of identification experiments. On a set of aerial imagery and eight terrain classes (old residential, new residential, lake, swamp, marsh, urban, railroad yard, scrub or wooded), he obtained 82 percent correct identification with 64 x 64 subimages. On an ERTS Monterey Bay, California, image, he obtained 84 percent correct identification using 64 x 64 subimages and both spectral and textural features on seven terrain classes: coastal forest, woodlands, annual grasslands, urban areas, large irrigated fields, small irrigated fields, and water. On a set of sandstone photomicrographs, he obtained 89 percent correct identification on five sandstone classes: Dexter-L, Dexter-H, St. Peter, Upper Muddy, Gasket.

The wide class of images on which they found that grey tone co-occurrence carries much of the texture information is probably indicative of the power and generality of this approach.

III.5 A Textural Transform

Each of the approaches described for the quantification of textural features had the common property that the textural features were computed for subimages of typical sizes such as 8 x 8, 16 x 16, 32 x 32, or 64 x 64 resolution cells. To determine the textural features for one pixel we would naturally center a subimage on the specified resolution cell and compute the textural features for the subimage. If we had to determine the textural features for each pixel in an image we would be in for a lot of computation work and would significantly increase the size of our data set. Thus, the usual approach has been to divide the image into mutually exclusive subimages and compute the textural features on the selected subimages. Unfortunately, this procedure produces textural features at a coarser resolution than the original image.

In this section we generalize the grey tone co-occurrence textural feature extractor to the textural transform mode and show how by only doubling or tripling the computation time required to determine the grey tone co-occurrence matrix it is possible to produce a resolution preserving textural transform in which each pixel in the transformed image has textural information about its own neighborhood derived from both local and global grey tone co-occurrence in the image. This kind of textural transform is in the class of image dependent non-linear spatial filters.
Let $Z_r \times Z_c$ be the set of resolution cells of an image $I$ (by row-column coordinates). Let $G$ be the set of grey tones possible to appear on image $I$. Then $I: Z_r \times Z_c \rightarrow G$. Let $R$ be a binary relation on $Z_r \times Z_c$ pairing together all those resolution cells in the desired spatial relation. The co-occurrence matrix $P: G \times G \rightarrow [0,1]$, for image $I$ and binary relation $R$ is defined by

$$P(i,j) = \frac{\#\{(a,b),(c,d)\} \in R | I(a,b) = i \text{ and } I(c,d) = j\}}{\#R}$$

The textural transform $J,J: Z_r \times Z_c \rightarrow (-\infty,\infty)$, of image $I$ relative to function $f$, is defined by

$$J(y,x) = \frac{1}{\#R(y,x)} \sum_{(a,b) \in R(y,x)} f[P(I(y,x),I(a,b))]$$

Assuming $f$ to be the identity function, the meaning of $J(y,x)$ is as follows. The set $R(y,x)$ is the set of all those resolution cells in $Z_r \times Z_c$ in the desired spatial relation to resolution cell $(y,x)$. For any resolution cell $(a,b) \in R(y,x)$, $P(I(y,x),I(a,b))$ is the relative frequency by which the grey tone $I(y,x)$, appearing at resolution cell $(y,x)$, and the grey tone $I(a,b)$, appearing at resolution cell $(a,b)$, co-occur together in the desired spatial relation on the entire image. The sum

$$\sum_{(a,b) \in R(y,x)} P(I(y,x),I(a,b))$$

is just the sum of the relative frequencies of grey tone co-occurrence over all resolution cells in the specified relation to resolution cell $(y,x)$. The factor $\frac{1}{\#R(y,x)}$, the reciprocal of the number of resolution cells in the desired spatial relation to $(y,x)$ is just a normalizing factor.
Spatial Pre-Processing

Spatial enhancement processes can be implemented before or after the classification of the original images. One spatial averaging process which can be used before classification of the original image is rectangular convolution. A $2 \times 2$ rectangular convolution, for example, is the process that replaces the left upper resolution cell of each $2 \times 2$ window by the average of the grey tones in the $2 \times 2$ window. A $3 \times 3$ rectangular convolution replaces each grey tone with the average of the grey tones in a $3 \times 3$ window centered around it. The process of rectangular convolution can be implemented before or after texture transform. The window size for the rectangular convolution process can be as big as required.

Figure IV illustrates how the rectangular convolution can enhance the textural transform processed images. Notice that the rectangular region on the left lower corner is not easy to distinguish on the image with no rectangular convolution before or after texture transform, Figure IV a, but it is distinguishable on Figure IV d, the image with $2 \times 2$ rectangular convolution before texture transform and no rectangular convolution after texture transform, as it is on Figures IV e to IV i. The two strips on the middle of the image are not easily distinguished on Figures IV a to IV f, but they are easily distinguished on Figure IV g, the image with $3 \times 3$ rectangular convolution before texture transform and no rectangular convolution after texture transform. They are also distinguishable on images IV h and IV i which have been processed with a $3 \times 3$ convolution after the textural transform. For distinguishing rectangular region and the two strips on the image, Figure IV i, the image with $3 \times 3$ rectangular convolution before and after texture transform seems best.
V. Spatial Post-Processing

Spatial post processing the classified image can be used to reduce image complexity and achieve some degree of spatial simplification and generalization. Two post processing techniques are region filling and shrinking. A region filling operation assigns an unassigned resolution cell to the category assignment of one of its neighboring resolution cells.

A resolution cell can be defined to have the four resolution cells above, below, to the left, and to the right of it as neighbors or to have those plus the resolution cells diagonally neighboring it as its neighbors. The first set of resolution cells is called its 4-neighbors and the second set of resolution cells is called its 8-neighbors. The concepts of 4-neighboring and 8-neighboring is illustrated in Figure V.1.

A region filling operation which assigns an unlabeled resolution cell to the category assignment of one of its four nearest neighbors is called a 4-fill operation. A region filling operation which assigns an unlabeled resolution cell to the category assignment of one of its eight nearest neighbors is called an 8-fill operation. A region filling operation which iterates first filling using 4 neighbors and then 8 neighbors then 4 then 8 etc., until all resolution cells are labeled, we shall for simplicity call region filling.

Figure V.2 illustrates the advantage of region filling alternating between 4-neighbors or 8-neighbors. A labeled resolution cell in an area of unlabeled resolution cells would grow as a diamond region under repetitive 4-fill operations. It would grow as a square region under repetitive 8-fill operations. And it would grow almost as a circle under repetitive 8-fill and 4-fill operations.

Region shrinking is the opposite kind of operation from region filling. A region shrinking operation assigns a labeled resolution to "unassigned" if its neighbors have different labels from it.

A region shrinking operation which assigns a labeled resolution cell to "unassigned" if k of its four nearest neighbors have labels which are different than its own label is called a 4-k shrink operation. A region shrinking operation which assigns a labeled resolution cell to "unassigned" if k of its eight nearest neighbors have labels which are different from its own label is called and 8-k shrink operation.
Figure V.1a illustrates the 4-neighborhood of a resolution cell and
Figure V.1b illustrates the 8-neighborhood of a resolution cell.
Figure V.2 illustrates the effect of 4 and 8-filling or a single resolution cell.
In Figure V.3 we illustrate the effect of the filling and shrinking operations on a classified image. Figure V.3a is a classified image. The black areas represent unassigned resolution cells. (The decision rule leaves unassigned those resolution cells having multispectral signatures which do not provide enough information to make a reliable assignment.) Figure V.3b shows the classified image of Figure V.3a after a complete region filling. Notice that after a complete region filling, all resolution cells have a label. Figure V.3c shows the classified image of Figure V.3a after a 4-0 shrink. Notice that it has more black area than the image in Figure V.3a due to the effect of its relabeling labeled resolution cells to "unassigned".
Example showing that convex sets are regular

Example of a non-convex set which is regular

Example of a non-convex set which is not regular

Figure 3 illustrates the relationship between set convexity and regularity
VI  Spectral Analysis: Edit 6

Of the 6 best spectral bands on edit #6, .40 - .44, .588 - .643, .65 - 
.69, .72 - .76, .981 - 1.045, and 2.10 - 2.36 micrometers, the feature selection
procedure selected band pairs .40 - .44 and .65 - .60 with .40 - .44 and 2.10 - 
2.36 micrometers as the best 2 band pairs for the table look-up rule. Figure VI.1
shows the .72 - .76 micrometer band and Figure VI.2 shows the ground truth
training data overlay on this band. The alpha-beta thresholds were set at .3 and 
.021. This threshold selection was too low for of the 159,500 points to be
classified, 67,323 were reserved assignments because of incompatible assignments
between the first and second band pairs and 6,928 were reserved assignment because
there was more than one possible assignment common to the two band pairs. Figure
VI.3 shows the resulting classification. The contingency table, Table VI.1 shows
an equally weighted misidentification error rate of 36% and equally weighted false
identification error rate of 34%. The largest cause of the misidentification error
was category 2.4, immature poletimber loblolly pine, being assigned to category
1.3, immature sawtimber shortleaf pine, and category 2.6, mature sawtimber
loblolly pine being assigned to category 2.5, immature sawtimber loblolly pine
and being assigned to category 2.3, seedling and sapling loblolly pine.

If the classified image is filled so that all resolution cells whose category
assignment was reserved is assigned to the category of its spatially nearest resolution
cell neighbor which is assigned, the error rate remains substantially the same, about
a 36% misidentification and false identification error rate (Figure VI.4 and Table
VI.2). This implies that for those resolution cells whose assignment was reserved
because of the low probability of correct assignment, category assignments,
almost as good as those originally assigned, can be made using the spatial in-
formation carried by the initially classified image with the reserved decisions.

Perhaps what is even more surprising about the amount of spatial information
the classified image has is that by performing spatial operations on it, the classifica-
tion accuracy can increase. For example, if the completely filled image is shrunk
for one iteration with a simple 4-shrink operator and then filled up again, Table VI.3
shows an accuracy increase: 33% misidentification error rate and 35% false
identification error rate. Comparable results are also obtained by using the initially
classified image with reserved decisions and performing a 4-fill iteration followed
by an 8-fill iteration followed by a 4-shrink iteration and then completely filled (Figure VI.5 and Table VI.4).

The best (percentage wise) 2 band pair results came from starting with the initially classified image with reserved decisions and doing a 4-fill, an 8-fill, a 4-shrink, an 8-shrink, and then a complete filling up. This yields a 31% misidentification error rate and 7% false identification error rate (Table VI.5 and Figure VI.6). Notice, however, that all the points in category 2.4, poletimber immature loblolly, have been misidentified as category 1.3, sawtimber immature shortleaf pine, and all the points in category 2.6, mature sawtimber loblolly pine, have been misidentified as categories 1.3, 2.3 and 2.5. Furthermore, no points were assigned to categories 2.4 and 2.6. This suggests that the tree stands in those areas of immature loblolly and mature sawtimber loblolly pine had a substantial number of trees spectrally similar to those in categories 1.3, 2.3, and 2.5. Areas predominantly in categories 2.4 and 2.6 would have some resolution cells initially assigned to categories 2.4 and 2.6 plus wrong assignments to categories 1.3, 2.3, or 2.5. Hence, a context sensitive shrinking operation on the 4-fill and 8-fill image which would leave alone any resolution cell assigned to category 2.4 if it neighbors a resolution cell of category 1.3 and which would leave alone any resolution cell assigned to category 2.6 if it neighbors a resolution cell of category 1.3, 2.3 or 2.5 has the possibility of permitting a higher probability of correct identification.

If instead of doing only one 4-shrink then 8-shrink iterations, two such iterations are made before a complete filling, then the results are not quite as good: 34% misidentification error rate and 6% false identification error rate (Table VI.6).

The use of additional spectral bands can sometimes increase identification accuracy. In the case of the edit #6 data, this did not seem to be the case. The three best band pairs were:

1. 0.40 - 0.44 and 0.65 - 0.69 micrometers
2. 0.40 - 0.44 and 2.10 - 2.36 micrometers
3. 0.72 - 0.76 and 0.981 - 1.045 micrometers

The alpha-beta thresholds were set at 0.6 and 0.042, respectively. The resulting number of reserved decisions due to no common category assignment was 51,794
and the number of reserved decisions due to more than one possible category assignment was 19,706 (Figure VI.7 and Table VI.7). Higher thresholds would have been better.

After a complete filling, there was a 34% misidentification and 33% false identification error rate (Figure VI.8 and Table VI.8). If the completely filled image had a 4-shrink operation and then another complete filling, the misidentification error rate improved to 31% and false identification error rate improved to 16% (Figure VI.9 and Table VI.9). If before the complete filling is done an iteration of a 4-fill followed by an 8-fill and a 4-shrink followed by an 8-shrink is done, the misidentification error rate improves to 30% and the false identification error rate improves to 5%, the best 3-band pair result (Figure VI.10 and Table VI.10). As in the two band pair case, doing two iterations of the 4-shrink followed by the 8-shrink instead of one iteration, does not provide as much improvement: a 36% misidentification error rate and a 6% false identification error rate (Table VI.11). The best 3 band pair result confused the same categories as the best 2 band pair result. Category 2.4, poletimber immature loblolly was assigned as category 1.3, immature shortleaf pine. Category 2.6, mature sawtimber loblolly pine was assigned to categories 2.3 and 2.5, seedling and sapling loblolly and sawtimber immature loblolly pine.
Figure VI.1  The .72 - .76 micrometer band

Figure VI.2  The ground truth training data overlayed on the .72 - .76 micrometer band.
Figure VI.3 The classification of the best two band pairs for alpha-beta thresholds of .3 and .021.

Figure VI.4 The classified image of Figure VI.3 after a complete filling.
### Table VI.1
The contingency table of the best 2 band pairs for alpha-beta thresholds of .3 and .021.

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### Table VI.2
The contingency table of the best 2 band pairs after a complete filling.

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<th>2.5</th>
<th>2.6</th>
<th>7.2</th>
<th>TOTAL</th>
<th>ERR</th>
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Table VI.2 The contingency table of the best 2 band pairs after a complete filling.

**ORIGINAL PAGE IS OF POOR QUALITY**
### Table VI.3

The contingency table of the best 2 band pairs after complete filling, 4-shrink, and complete filling operations.

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<tr>
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<td>0 2670 171</td>
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</tr>
<tr>
<td>2.3</td>
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<td>2</td>
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### Table VI.4

The contingency table of the best 2 band pairs after 4-fill, 8-fill, 4-shrink, and complete filling operations.

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<td>0 2670 171</td>
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<td>0 7727 156</td>
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**ORIGINAL PAGE IS OF POOR QUALITY**
Figure VI.5  The classified image of Figure VI.3 after 4-fill, 8-fill, 4-shrink, and then complete filling operations.

Figure VI.6  The classified image of Figure VI.3 after 4-fill, 8-fill, 4-shrink, 8-shrink, and then complete filling operations.
### Table VI.5
The contingency table of the best 2 band pairs after 4-fill, 8-fill, 4-shrink, 8-shrink, and complete filling operations.

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### Table VI.6
The contingency table of the best 2 band pairs after 4-fill, 8-fill, 4-shrink, 8-shrink, 4-shrink, 8-shrink and complete filling operations.
Figure VI.7  The classification of the three best band pairs for alpha-beta thresholds of .6 and .042.

Figure VI.8  The classified image of Figure VI.7 after a complete filling.
### Table VI.7

The contingency table of the best 3 band pairs for alpha-beta thresholds of .6 and .042.

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### Table VI.8

The contingency table of the best 3 band pairs after a complete filling.

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<td>119</td>
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<td>5</td>
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<td>5625</td>
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<td>7</td>
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<td>213</td>
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<td>668</td>
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</table>

ORIGINAl PAGE IS OF POOR QUALITY
Figure VI.9  The classified image of Figure VI.8 after a 4-shrink operation and then a complete filling.

Figure VI.10  The classified image of Figure VI.7 after 4-fill, 8-fill, 4-shrink, 8-shrink and complete filling operations.
CONTINGENCY TABLE FOR SAMH2 GDT - 1 SAMH2FB02 - 1 SCALE FACTOR 10** 0

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<tr>
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<td>ERR</td>
<td>0</td>
</tr>
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</tr>
<tr>
<td>ERR</td>
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</tr>
</tbody>
</table>

Table VI.9  The contingency table of the best 3 band pairs after complete filling, 4-shrink, and complete filling operations.

CONTINGENCY TABLE FOR SAMH2 GDT - 1 SAMH2FB02 - 1 SCALE FACTOR 10** 0

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<th>ROW = TRUE CAT</th>
</tr>
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<td>0</td>
</tr>
<tr>
<td>ERR</td>
<td>0</td>
</tr>
</tbody>
</table>

Table VI.10  The contingency table of the best 3 band pairs after 4-fill, 8-fill, 4-shrink, 8-shrink, and complete filling operations.
### Table VI. 11

The contingency table of the best 3 band pairs after 4-fill, 8-fill, 4-shrink, 8-shrink, 4-shrink, 8-shrink and complete filling operations.

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<th>2.3</th>
<th>2.4</th>
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<th>2.6</th>
<th>7.2</th>
<th>TOTAL</th>
<th>ERR</th>
<th>ERR</th>
</tr>
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<td>0 2098</td>
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<td></td>
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</tr>
<tr>
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<td>0 26</td>
<td>0 0 1434 1434</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>0 14</td>
<td>0</td>
<td>0</td>
<td>0 5611 5625 14</td>
<td>0</td>
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<td></td>
</tr>
<tr>
<td>TOTAL</td>
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<td>0 13553</td>
<td>26910 159900 4192</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ERR</td>
<td>0 660 22 3484</td>
<td>0 26</td>
<td>0 0 4192 ***** *****</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table VI. 11

The contingency table of the best 3 band pairs after 4-fill, 8-fill, 4-shrink, 8-shrink, 4-shrink, 8-shrink and complete filling operations.
VII Spectral Analysis: Edit 9

Using the same initial six spectral bands to select features from, the feature selector chose band pairs .40 - .44 and .65 - .69 with .72 - .76 and .981 - 1.045 micrometers as the best 2 band pairs for the table look-up rule. Figure VII.1 shows the .72 - .76 micrometer band and Figure VII.2 shows the ground truth training data overlayed on this band. The alpha-beta thresholds were set at .3 and .021.

The contingency table (Table VII.1) for the best 2 band pairs classification with an alpha threshold of .3 and a beta threshold of .021 gave a misidentification error rate of 22% and a false identification error rate of 32%. There were 79,670 reserved assignments because of incompatible assignments between the first and second band pairs and 2,357 were reserved assignments because there was more than one possible assignment common to the two band pairs. The raw classified image is shown in Figure VII.3. The main cause of error is the confusion between category 1.3, shortleaf pine, and category 2.5, loblolly pine. This error is due to assigning category 1.3 when the true category is 2.5. A look at the timber stand map for edit #9 shows a patch of category 2.5, which is surrounded by category 1.3, in the lower right-hand corner. It is this area that gets mis-assigned the most.

If the classified image is filled so that all resolution cells whose category assignment was reserved is assigned to the category of its spatially nearest resolution cell neighbor which is assigned, the error rate remains substantially the same, about a 25% misidentification error rate and 32% false identification error rate (Figure VII.4 and Table VII.2) If we do 6 iterations of 4-fills and then do a 4-shrink and fill up, the resulting contingency table is Table VII.3. The misidentification and false identification error rates of 21% and 26% are lower than before, but the misidentification error rate category 2.5 went from 43% to 44% with category 1.3 still the problem.

The best 2 band pair results were obtained from doing a 4-shrink following the original classification and then filling (Figure VII.5). Table VII.4 shows a misidentification error rate of 14% and a false identification error rate of 17%, but still the misidentification of category 2.5 is the main cause of error. The
shrinking first does eliminate a significant amount of error between category 3.1, laurel oak, and category 4.2, low quality sweetgum. Neither procedure has trouble classifying category 2.5 on the left-side of the timber stand. Only on the right side where category 2.5 resembles category 1.3 spectrally is there confusion. This confusion could be ultimately due to sun angle.

The three best band pairs were:

1. .40 - .44 and .65 - .69 micrometers
2. .72 - .76 and .981 - 1.045 micrometers
3. .40 - .44 and 2.10 - 2.36 micrometers

Figure VII.6 shows a plot of the alpha threshold versus the number of reserved decisions. For the three best band pairs, the alpha and beta thresholds that minimized the number of reserved decisions was .6 and .042, respectively.

The raw classified image is shown in Figure VII.7. The contingency table indicates a misidentification error of 24% and a false identification error of 30% (Table VII.5).

After a complete filling, there was a 25% misidentification and 32% false identification error rate (Figure VII.8 and Table VII.6). If instead, our post processing consisted of a 4-fill, 8-fill, 4-shrink, 8-shrink and then a complete filling the misidentification error rate was 9% and the false identification error rate was 9% (Table VII.7 and Figure VII.9).
Figure VII.1 The .72 - .76 micrometer band.

Figure VII.2 The ground truth training data overlayed on the .72 - .76 micrometer band.
### Table VII.1
The contingency table of the best 2 band pairs for alpha-beta thresholds of .3 and .021.

<table>
<thead>
<tr>
<th>R DEC</th>
<th>1.3</th>
<th>2.3</th>
<th>2.5</th>
<th>2.6</th>
<th>3.1</th>
<th>4.2</th>
<th>7.2</th>
<th>TOTAL</th>
<th>#ERR</th>
<th>% ERR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>2952</td>
<td>5476</td>
<td>159</td>
<td>86</td>
<td>35</td>
<td>0</td>
<td>0</td>
<td>116183</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1.3</td>
<td>5394</td>
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<td>262</td>
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<td>2</td>
<td>0</td>
<td>0</td>
<td>2298</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>1.5</td>
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<td>1764</td>
<td>274</td>
<td>115</td>
<td>13</td>
<td>87</td>
<td>0</td>
<td>11679</td>
<td>43</td>
<td>43</td>
</tr>
<tr>
<td>1.6</td>
<td>1636</td>
<td>1764</td>
<td>274</td>
<td>115</td>
<td>13</td>
<td>87</td>
<td>0</td>
<td>11679</td>
<td>43</td>
<td>43</td>
</tr>
</tbody>
</table>

### Table VII.2
The contingency table of the best 2 band pairs after a complete filling.

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<tr>
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<th>2.3</th>
<th>2.5</th>
<th>2.6</th>
<th>3.1</th>
<th>4.2</th>
<th>7.2</th>
<th>TOTAL</th>
<th>#ERR</th>
<th>% ERR</th>
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</thead>
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<td>3657</td>
<td>44</td>
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<td>0</td>
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<td>1.3</td>
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<td>59</td>
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<td>35</td>
<td>16</td>
<td>144550</td>
<td>3832</td>
<td>22</td>
</tr>
</tbody>
</table>

### Table VII.3
The contingency table for SAMH3 GDT - 1 SMHSF1C71 - 1.
Figure VII.3 The classification of the best two band pairs for alpha-beta thresholds of .3 and .021.

Figure VII.4 The classified image of Figure VII.3 after a complete filling.
### Table VII.3
The contingency table of the best 2 band pairs after complete filling, 4-shrink, and complete filling operations.

<table>
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<tr>
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</thead>
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<td>R DEC 1:1</td>
<td>2:3</td>
</tr>
<tr>
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<tr>
<td>2:6</td>
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<tr>
<td>3:1</td>
<td>0</td>
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<tr>
<td>4:2</td>
<td>0</td>
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<tr>
<td>7:2</td>
<td>0</td>
</tr>
<tr>
<td>TOTAL</td>
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</tr>
<tr>
<td>ERR</td>
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</tr>
<tr>
<td>TOTAL ERR</td>
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</tr>
</tbody>
</table>

### Table VII.4
The contingency table of the best 2 band pairs after 4-shrink, and complete filling operations.

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</thead>
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<tr>
<td>ERR</td>
<td>0</td>
</tr>
<tr>
<td>TOTAL ERR</td>
<td>0</td>
</tr>
</tbody>
</table>
Figure VII.5 The classified image of Figure VII.3 after 4-shrink and complete filling operations.
Figure VII.6 A plot of the alpha thresholds versus number of reserved decisions
### Table VII.5

The contingency table of the best 3 band pairs for alpha-beta thresholds of .6 and .042.

<table>
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<th>ROW = TRUE CAT</th>
<th>R DEC 1.3</th>
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<th>2.5</th>
<th>2.6</th>
<th>3.1</th>
<th>4.2</th>
<th>7.2</th>
<th>TOTAL #ERR</th>
<th>% ERR</th>
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</thead>
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<td>54</td>
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<td>390</td>
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<td>7387</td>
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<td>14</td>
<td>47</td>
<td>30</td>
<td>39</td>
<td>21</td>
<td>32</td>
<td>12</td>
</tr>
</tbody>
</table>

Table VII.6 The contingency table of the best 3 band pairs after a complete filling.
Figure VII.7 The classification of the three best band pairs for alpha-beta thresholds of .6 and .042.

Figure VII.8 The classified image of Figure VII.7 after a complete filling.
Table VII.7 The contingency table of the best 3 band pairs after 4-fill, 8-fill, 4-shrink, 8-shrink, and complete filling operations.
Figure VII.9 The classified image of Figure VII.7 after 4-fill, 8-fill, 4-shrink, 8-shrink, and complete filling operations.
VIII Spectral Analysis: Edit 14

The same six spectral bands were chosen from edit #14 as were taken from edit #6 and edit #9. Figure VIII.1 shows the .72 - .76 micrometer band for edit 14 and Figure VIII.2 shows the selected ground truth training data. The selection procedure chose .40 - .44 and 2.10 - 2.36 with .588 - .643 and 2.10 - 2.36 micrometers as the best 2 band pairs for the table look-up rule. The alpha and beta thresholds were set at .3 and .021 respectively. The thresholds were too low and resulted in 56,320 reserved decisions in the contingency table for classification (Table VIII.1). The resulting misidentification error rate was 28% and false identification error rate was 29%. The result on the best 2 band pairs with 4-fill, 8-fill, 4-shrink, 8-shrink, and complete filling operations (Table VIII.2), was a misidentification error rate of 15% and a false identification error rate of 17%.

The feature selection procedure chose band pairs .40 - .44 and .65 - .69 micrometers, along with the best 2 band pairs for the best 3 band pairs. Using alpha and beta thresholds of .6 and .042, respectively, the number of reserved decisions was 43,236, with 25,794 points reserved because no assignment was possible and 17,442 reserved due to possible multiple assignments.

The largest cause of error for best 3 band pairs (Table VIII.3) was the confusion between categories 2.3 and 2.5, different ages of loblolly pine, and the confusion of each of these with category 4.1, low quality sweetgum. The misidentification and false identification error rates (46% and 48%) for category 4.1 are high but the number of points whose true category is 4.1 is small. Figure VIII.3 shows the resulting classification. There was such a small area of sweetgum, category 4.1, on the timber stand map that the ground truth may not be adequate to allow good spectral estimation.

The first post processing procedure we used was a complete filling (Table VIII.4 and Figure VIII.4). The errors were increased by the procedure, so one 4-shrink operation was performed on the image and this reduced the misidentification error to 9% and false identification error to 4% (Table VIII.5 and Figure VIII.5), but the low error rates were helped by the fact that there were 84,828 reserved decisions. Table VIII.5 does show that the confusion with category 4.1, was almost eliminated, though the misidentification error rate caused by assigning
2.3 to 2.5, 21% was still high. Completely filling the image resulted in a misidentification error rate of 17% and false identification error rate of 13% (Table VIII.6 and Figure VIII.6).

If on the raw classified image we do one 4-fill (Table VIII.7 and Figure VIII.7) and then one 8-fill, the resulting contingency table (Table VIII.8 and Figure VIII.8) is almost identical to Table VIII.3. The error rates on each are exactly the same. Then doing a 4-shrink (Table VIII.9 and Figure VIII.9) we find a contingency table almost identical to Table VIII.4. But if instead of filling we do an 8-shrink, we almost totally eliminate error (Table VIII.10 and Figure VIII.10). Only 2 points are incorrectly identified. Now if we completely fill the image we get our best results (Table VIII.11 and Figure VIII.11): 13% misidentification and 9% false identification error rates. Visual comparisons show the closeness of the two operations. Following the fills with a 4-shrink produces Figure VIII.5. Figure VIII.6 is the final classified image after complete filling, a 4-shrink and then a complete filling, while Figure VIII.11 is the final result of a 4-fill, 8-fill, 4-shrink, 8-shrink, and complete filling. From the figures, we can see that the extra shrink allowed the categories to be more dense. The contingency table of the image should show better results since the categories on the timber stand map tend to be dense, which is the case.

The results of the shrinking operations indicate that the errors that did occur were sparse enough to be wiped out with the shrinking. The reason that a shrink operation is not performed first on the image is that it tends to eliminate small area categories, even though correctly assigned, on the image.
Figure VIII.1  The .72 - .76 micrometer band.

Figure VIII.2  The ground truth training data overlayed on the .72 - .76 micrometer band.
### Table VIII.1
The contingency table of the best 2 band pairs for alpha-beta thresholds of .3 and .021.

<table>
<thead>
<tr>
<th>COL* = ASSIGN CAT</th>
<th>ROW = TRUE CAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEC</td>
<td></td>
</tr>
<tr>
<td>2*3</td>
<td>2*5</td>
</tr>
<tr>
<td>4*1</td>
<td>7*2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SCALE FACTOR 10**0</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>FRP</td>
<td></td>
</tr>
<tr>
<td>ERR</td>
<td></td>
</tr>
</tbody>
</table>

**Unknown**

<table>
<thead>
<tr>
<th></th>
<th>19856</th>
<th>17565</th>
<th>29402</th>
<th>123134</th>
<th>0</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>2*3</td>
<td>10554</td>
<td>719</td>
<td>515</td>
<td>209</td>
<td>40975</td>
<td>1469</td>
</tr>
<tr>
<td>2*5</td>
<td>958</td>
<td>196</td>
<td>3567</td>
<td>197</td>
<td>64</td>
<td>4978</td>
</tr>
<tr>
<td>4*1</td>
<td>765</td>
<td>233</td>
<td>147</td>
<td>594</td>
<td>10</td>
<td>1749</td>
</tr>
<tr>
<td>7*2</td>
<td>745</td>
<td>81</td>
<td>158</td>
<td>75</td>
<td>1855</td>
<td>2914</td>
</tr>
</tbody>
</table>

**Total**

<table>
<thead>
<tr>
<th></th>
<th>10491</th>
<th>24467</th>
<th>14942</th>
<th>31540</th>
<th>137750</th>
<th>2620</th>
</tr>
</thead>
<tbody>
<tr>
<td>FRP</td>
<td>0</td>
<td>517</td>
<td>1044</td>
<td>788</td>
<td>283</td>
<td>2670</td>
</tr>
<tr>
<td>ERR</td>
<td>0</td>
<td>25</td>
<td>23</td>
<td>57</td>
<td>13</td>
<td>29</td>
</tr>
</tbody>
</table>

Table VIII.2
The contingency table of the best 2 band pairs after 4-fill, 8-fill, 4-shrink, 8-shrink, and complete filling operations.
Table VIII.3  The contingency table of the best 3 band pairs for alpha - beta thresholds of .6 and .042.

<table>
<thead>
<tr>
<th>COL. = ASSIGN CAT</th>
<th>ROW = TRUE CAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>R DEC 2.3</td>
<td>2.5</td>
</tr>
<tr>
<td>UNKWN</td>
<td>39754</td>
</tr>
<tr>
<td>2.3</td>
<td>1568</td>
</tr>
<tr>
<td>2.5</td>
<td>717</td>
</tr>
<tr>
<td>4.1</td>
<td>664</td>
</tr>
<tr>
<td>7.2</td>
<td>933</td>
</tr>
<tr>
<td>TOTAL</td>
<td>43236</td>
</tr>
<tr>
<td>ERR</td>
<td>0</td>
</tr>
</tbody>
</table>

Table VIII.4  The contingency table of the best 3 band pairs after a complete filling.
Figure VIII.3  The classification of the three best band pairs for alpha-beta thresholds of .6 and .042.

Figure VIII.4  The classified image of Figure VIII.3 after a complete filling.
### Table VIII.5

The contingency table of the best 3 band pairs after complete filling and 4-shrink operations.

<table>
<thead>
<tr>
<th>R Dob.</th>
<th>Assign Cat</th>
<th>Row = True Cat</th>
<th>( \text{SFM} )</th>
<th>( \text{err} )</th>
<th>( \text{SD} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.3</td>
<td>18179</td>
<td>36805</td>
<td>12498</td>
<td>55542</td>
<td>123134</td>
</tr>
<tr>
<td>2.5</td>
<td>7289</td>
<td>849</td>
<td>75</td>
<td>323</td>
<td>4975</td>
</tr>
<tr>
<td>4.1</td>
<td>0</td>
<td>1301</td>
<td>10</td>
<td>289</td>
<td>0</td>
</tr>
<tr>
<td>7.2</td>
<td>0</td>
<td>500</td>
<td>329</td>
<td>2504</td>
<td>2914</td>
</tr>
<tr>
<td>Total</td>
<td>22695</td>
<td>42246</td>
<td>13751</td>
<td>58388</td>
<td>137750</td>
</tr>
</tbody>
</table>

### Table VIII.6

The contingency table of the best 3 band pairs after complete filling, 4-shrink, and complete filling operations.

<table>
<thead>
<tr>
<th>R Dob.</th>
<th>Assign Cat</th>
<th>Row = True Cat</th>
<th>( \text{SFM} )</th>
<th>( \text{err} )</th>
<th>( \text{SD} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.3</td>
<td>18179</td>
<td>36805</td>
<td>12498</td>
<td>55542</td>
<td>123134</td>
</tr>
<tr>
<td>2.5</td>
<td>7289</td>
<td>849</td>
<td>75</td>
<td>323</td>
<td>4975</td>
</tr>
<tr>
<td>4.1</td>
<td>0</td>
<td>1301</td>
<td>10</td>
<td>289</td>
<td>0</td>
</tr>
<tr>
<td>7.2</td>
<td>0</td>
<td>500</td>
<td>329</td>
<td>2504</td>
<td>2914</td>
</tr>
<tr>
<td>Total</td>
<td>22695</td>
<td>42246</td>
<td>13751</td>
<td>58388</td>
<td>137750</td>
</tr>
</tbody>
</table>
Figure VIII.5  The classified image of Figure VIII.4 after a 4-shrink operation.

Figure VIII.6  The classified image of Figure VIII.5 after a complete filling.
Table VIII.7 The contingency table of the best 3 band pairs after a 4-fill operation.

<table>
<thead>
<tr>
<th>COL* = ASSIGN CAT</th>
<th>ROW = TRUE CAT</th>
<th>R DEC 2*3</th>
<th>2*5</th>
<th>4*1</th>
<th>7*2</th>
<th>TOTAL ERR</th>
<th>ERR</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>UNKN</strong></td>
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<td>2375</td>
<td>2332</td>
<td>31476</td>
<td>16785</td>
<td>49202</td>
<td>123134</td>
<td>0</td>
</tr>
<tr>
<td><strong>23</strong></td>
<td></td>
<td>23</td>
<td>237111111</td>
<td>573</td>
<td>447</td>
<td>4975</td>
<td>2131</td>
<td>43</td>
</tr>
<tr>
<td><strong>25</strong></td>
<td></td>
<td>19</td>
<td>4754716154</td>
<td>94</td>
<td>4978</td>
<td>744</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td><strong>41</strong></td>
<td></td>
<td>16</td>
<td>522584572</td>
<td>31</td>
<td>1749</td>
<td>791</td>
<td>46</td>
<td>1</td>
</tr>
<tr>
<td><strong>72</strong></td>
<td></td>
<td>6</td>
<td>36326955</td>
<td>2201</td>
<td>2914</td>
<td>707</td>
<td>24</td>
<td>0</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td>2493</td>
<td>27483</td>
<td>37444</td>
<td>18500</td>
<td>51975</td>
<td>137750</td>
<td>4372</td>
</tr>
<tr>
<td><strong>FRR</strong></td>
<td></td>
<td>0</td>
<td>136</td>
<td>1658</td>
<td>787</td>
<td>572</td>
<td>4372</td>
<td>*****</td>
</tr>
<tr>
<td><strong>FRR</strong></td>
<td></td>
<td>0</td>
<td>33</td>
<td>28</td>
<td>45</td>
<td>21</td>
<td>31</td>
<td>*****</td>
</tr>
</tbody>
</table>

Table VIII.8 The contingency table of the best 3 band pairs after 4-fill, and 8-fill operations.
Figure VIII.7  The classified image of Figure VIII.3 after a 4-fill operation.

Figure VIII.8  The classified image of Figure VIII.3 after 4-fill and 8-fill operations.
CONTINGENCY TABLE FOR SAMH4 GDT = 1 SMH4<3B06 = 1 SCALE FACTOR 10** 0

<table>
<thead>
<tr>
<th>COL* = ASSIGN CAT</th>
<th>ROW = TRUE CAT</th>
<th>R DFC 2.3</th>
<th>2.5</th>
<th>4.1</th>
<th>7.2</th>
<th>TOTAL</th>
<th>ERP</th>
<th>ERR</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1**</td>
<td>49</td>
<td>164</td>
<td>10</td>
<td>61</td>
<td>284</td>
<td>284</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2**</td>
<td>7</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>6</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Table VIII.9 The contingency table of the best 3 band pairs after 4-fill, 8-fill and 4-shrink operations.

CONTINGENCY TABLE FOR SAMH4 GDT = 1 SMH4<3B06 = 1 SCALE FACTOR 10** 0

<table>
<thead>
<tr>
<th>COL* = ASSIGN CAT</th>
<th>ROW = TRUE CAT</th>
<th>R DFC 2.3</th>
<th>2.5</th>
<th>4.1</th>
<th>7.2</th>
<th>TOTAL</th>
<th>ERP</th>
<th>ERR</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1**</td>
<td>65</td>
<td>3448</td>
<td>567</td>
<td>13030</td>
<td>123134</td>
<td>123134</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2.3</td>
<td>4967</td>
<td>R</td>
<td>U</td>
<td>0</td>
<td>0</td>
<td>4975</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2.5</td>
<td>3771</td>
<td>0</td>
<td>1270</td>
<td>0</td>
<td>0</td>
<td>4978</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>4.1</td>
<td>1737</td>
<td>U</td>
<td>U</td>
<td>12</td>
<td>0</td>
<td>1749</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>7.2</td>
<td>2271</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>642</td>
<td>2914</td>
<td>2</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Table VIII.10 The contingency table of the best 3 band pairs after 4-fill, 8-fill, 4-shrink, and 8-shrink operations.
Figure VIII.9 The classified image of Figure VIII.3 after 4-fill, 8-fill, and 4-shrink operations.

Figure VIII.10 The classified image of Figure VIII.3 after 4-fill, 8-fill, 4-shrink and 8-shrink operations.
<table>
<thead>
<tr>
<th>COL = ASSIGN CAT</th>
<th>ROW = TRUE CAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>R DEC 2.3 2.5 4.1 7.2 TOTAL ERR ERR SD</td>
<td></td>
</tr>
<tr>
<td>UNKN 9922 39868 11186 62158 123134 0 0 0</td>
<td></td>
</tr>
<tr>
<td>2.3 0 4488 314 173 0 4975 487 10 0</td>
<td></td>
</tr>
<tr>
<td>2.5 0 366 4672 0 0 4978 306 6 0</td>
<td></td>
</tr>
<tr>
<td>4.1 0 9 379 1379 0 1749 370 22 0</td>
<td></td>
</tr>
<tr>
<td>7.2 0 0 499 0 2415 2914 499 17 0</td>
<td></td>
</tr>
<tr>
<td>TOTAL 14716 45732 12729 64573 137750 1671 13 0</td>
<td></td>
</tr>
<tr>
<td>ERR 0 306 1192 173 0 1671 **** ***** *****</td>
<td></td>
</tr>
<tr>
<td>ERR 0 6 20 11 0 9 **** ***** *****</td>
<td></td>
</tr>
</tbody>
</table>

Table VIII.11 The contingency table of the best 3 band pairs after 4-fill, 8-fill, 4-shrink, 8-shrink and complete filling operations.
Spectral Analysis: Edit 3

As with the other edits, the same 6 spectral bands were chosen, .40 - .44, .588 - .643, .65 - .69, .72 - .76, .981 - 1.045, and 2.10 - 2.36 micrometers. Figure IX.1 shows the .72 - .76 micrometer band of edit 3 and Figure IX.2 shows the selected ground truth training data.

The feature extractor chose bands .40 - .44 and .588 - .643 with .588 - .643 and .65 - .69 micrometers as the best 2 band pairs. To minimize the total number of reserved decisions and to try and equalize the number of reserved decisions due to more than one assignment and no assignment, classification for the two best band pairs was done using a variety of alpha and beta thresholds. Figure IX.3 is a graph of the thresholds versus the number of reserved decisions.

Table IX.1 is the contingency table for best 2 band pairs with .3 and .021 alpha and beta thresholds, respectively. The resulting error rates of 36% misidentification and 38% false identification are better than the corresponding error rates of 37% and 41% for the classification with alpha, beta thresholds of .4, .028 (Table IX.2) and the corresponding error rates of 37% and 40% for the classification with alpha, beta thresholds of .5, .035 (Table IX.3). But the total number of reserved decisions for the .3 and .021 thresholds is 47,749. This is the highest number of reserved decisions and the lower error rates could be caused by lack of assignments. In this case, the fill operations would tend to propagate the error. Therefore, we chose .5 and .035 thresholds to work with. The raw classified image was post processed with 4-fill, 8-fill, 4-shrink, 8-shrink and complete filling operations. The resulting contingency table (Table IX.4) indicates an 18% misidentification error and 27% false identification error. The major confusion was poletimber immature shortleaf pine being classified as sawtimber immature shortleaf pine or poletimber immature loblolly pine.

The three best band pairs consisted of the two best band pairs plus band pair .40 - .44 and .65 - .69 micrometers. To minimize the total number of reserved decisions and to try to equalize the two causes for reserved decisions, classification was done for the three best band pairs using a variety of alpha beta thresholds. The resulting graph (Figure IX.4) indicates good alpha beta thresholds.
are .5 and .035. Contingency table (Table IX.5) shows a 34% misidentification rate and 38% false identification rate with 48,475 reserved decisions. Figure IX.5 shows the resulting classification. Category 1.2 was the largest cause of error. It was confused with category 1.3, sawtimber immature shortleaf pine and categories 2.4 and 2.6, two kinds of loblolly pine.

A 4-fill and an 8-fill operation reduces the misidentification error rate but propagates the false identification error rate (Table IX.6 and Figure IX.6). Doing a 4-shrink reduces the error rates to 18% and 23% for misidentification and false identification. This is as expected since fewer assignments are made to spatially uncertain categories but the misidentification error rate for category 2.1 was not reduced (Table IX.7 and Figure IX.7). The final 8-shrink and then fill all the way up results in a misidentification error rate of 14% and a false identification error rate of 25% (Table IX.8 and Figure IX.8). Most of the error is due to category 1.2 being confused with categories 1.3, 2.4, and 2.6. Thus, category 1.2 has a misidentification error rate of 60% compared to 6% for the next most highly confused category. Most of the confusion is between subclasses in the same class rather than between classes. Contingency table IX.9 shows the resulting classification when categories 1.2 and 1.3 are combined and categories 2.4 and 2.6 are combined. The misidentification error rate is 10% and the false identification error rate is 14%.
Figure IX.1  The .72 - .76 micrometer band.

Figure IX.2  The ground truth training data overlayed on the .72 - .76 micrometer band.
Figure IX. 3  Number of reserved decisions as a function of probability threshold alpha for best 2 band pairs, spectral only for edit #3.
Table IX.1 The contingency table of the best 2 band pairs for alpha - beta thresholds of .3 and .021.

<table>
<thead>
<tr>
<th>COL. = ASSIGN CAT</th>
<th>ROW = TRUTH CAT</th>
<th>2.6</th>
<th>7.1</th>
<th>TOTAL FRR</th>
<th>FRR SD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table IX.2 The contingency table of the best 2 band pairs for alpha - beta thresholds of .4 and .028.
CONTINGENCY TABLE FOR SAMH1 CAT = 1 SAMH1 R21 = 1 SCALE FACTOR 10** 0

COL. = ASSIGN CAT ROW = TRUE CAT

<table>
<thead>
<tr>
<th>R DEC</th>
<th>1.2</th>
<th>1.3</th>
<th>2.4</th>
<th>2.6</th>
<th>7.1</th>
<th>TOTAL</th>
<th>FRR</th>
<th>ERR</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNKN</td>
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<td>8018</td>
<td>25376</td>
<td>3425</td>
<td>21950</td>
<td>70355</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1.2</td>
<td>6041</td>
<td>2853</td>
<td>1727</td>
<td>412</td>
<td>835</td>
<td>1026</td>
<td>50</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>1.3</td>
<td>44</td>
<td>1760</td>
<td>59</td>
<td>0</td>
<td>0</td>
<td>1863</td>
<td>103</td>
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<td></td>
</tr>
<tr>
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<td>0</td>
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<td>0</td>
<td>496</td>
<td>9972</td>
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<tr>
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Table IX.3 The contingency table of the best 2 band pairs for alpha-beta thresholds of .5 and .035.

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Table IX.4 The contingency table of the best 2 band pairs for alpha-beta thresholds of .5 and .035 after a complete filling.
Figure IX.4  Number of reserved decisions as a function of probability threshold $\alpha$ for best 3 band pairs, spectral only for edit #3
### Table IX.5
The contingency table of the best 3 band pairs for alpha-beta thresholds of .5 and .035.

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</tr>
</tbody>
</table>

### Table IX.6
The contingency table of the best 3 band pairs after 4-fill and 8-fill operations.
Figure IX.5  The classification of the three best band pairs for alpha-beta thresholds of .5 and .035.

Figure IX.6  The classified image of Figure IX.5 after 4-fill and 8-fill operations.
Table IX.7 The contingency table of the best 3 band pairs after 4-fill, 8-fill and 4-shrink operations.

Table IX.8 The contingency table of the best 3 band pairs after 4-fill, 8-fill, 4-shrink, 8-shrink, and complete filling operations.
Figure IX.7  The classified image of Figure IX.5 after 4-fill, 8-fill and 4-shrink operations.

Figure IX.8  The classified image of Figure IX.5 after 4-fill, 8-fill, 4-shrink, 8-shrink and complete filling operations.
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Contingency Table Created by Combining Subclass Types of the Same Class

Table IX.9
X Spectral-Textural Analysis: Edit 6

We began the spectral-textural analysis of the edit #6 data by using five spectral bands and two texture bands and letting the feature selection procedure pick the best two and best three band pairs for the table look-up decision rule. The five spectral bands were:

.40 - .44 micrometers
.65 - .69 micrometers
.72 - .76 micrometers
.981 - 1.045 micrometers
2.10 - 2.36 micrometers

The textural transform was done on a 3x3 convolution of the .82 - .88 micrometer band. A second textural information band was created by doing a 3x3 convolution of the initial textural transform image.

The feature selection procedure selected the two best band pairs consisting of:

(1) .40 - .44 micrometer band with the 3x3 convolution before and after the textural transform of the .82 - .88 micrometer band
(2) .65 - .69 and .981 - 1.045 micrometer bands.

The alpha-beta thresholds were set at .3 and .021, respectively. This threshold selection was too low for of the 159,500 points to be classified, 74,326 were reserved assignments because of incompatible category assignments between the first and second band pairs and 1,904 were reserved assignment because there was more than one possible assignment common to the two band pairs. The resulting contingency table, (Table X.1 and Figure X.1) shows a misidentification error rate of 36% and a false identification error rate of 37%. After filling the classified image to remove all reserved assignments, the misidentification error rate was 38% and false identification error rate was 39%, Table X.2 and Figure X.2. This is worse than the best two band pair spectral results indicating that either the alpha-beta thresholds used created such a high number of reserved decisions that the classification accuracy was lowered or that a feature selection procedure which minimizes a lower bound on the error rate does not necessarily produce the features of the best classification.

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Spatial processing can improve the identification accuracy of the initially classified image. For example, if the completely filled image is shrunk for one iteration with a 4-shrink operator and then filled again, the misidentification and false identification error rates improve to 33%, Table X.3 and Figure X.3. The biggest cause of errors was category 2.4 being assigned to category 1.3 and category 2.6 being assigned to categories 1.3, 2.3 and 2.5. A still greater increase in identification accuracy results if the initially classified image with reserved decisions is operated on with a 4-fill, then 8-fill, then 4-shrink, then 8-shrink operations and then filled up completely (Figure X.4). The resulting contingency table, Table X.4, shows a 32% misidentification error rate and 7% false identification error rate. This is about the same as the best two-band spectral results.

Doing two iterations of a 4-shrink followed by an 8-shrink (Figure X.5) instead of just one iteration as described for the previous classification produces not as good results. Table X.5 shows a 34% misidentification error rate and 7% false identification error rate.

Repeating the 2 band experiment with an alpha threshold of .5 and a beta threshold of .035 reduces the number of reserved decisions to 42,226 with 25,173 reserved decisions due to no assignment and 17,053 reserved decisions due to multiple assignments. The resulting classification (Table X.6 and Figure X.6) gives a misidentification error rate of 37% and a false identification error rate of 38%.

A complete filling of the image (Table X.7 and Figure X.7) gives a misidentification error rate of 38% and 39%. The main cause of error is assigning category 1.3 when the true category is 2.4 and assigning 2.5 when the true category is 2.6. If we do a 4-shrink on the filled image and then completely fill it again (Table X.8 and Figure X.8) we get a misidentification error rate of 32% and a false identification error rate of 36%, but now categories 2.4 and 2.6 are completely misidentified. If instead we do a 4-fill, 8-fill, 4-shrink, 8-shrink and then completely fill up the raw classification (Table X.9 and Figure X.9) we get a misidentification error rate of 30% and a false identification error rate of only 5%. This improvement over the (.3 and .021) result is due to better thresholding. So, even though the raw classification using an alpha threshold of .3 was a few percentage points better than the raw classification using an alpha threshold of .5, the large number of reserved decisions hindered classification accuracy with the fill and shrink operations.
We also did a 4-fill, 8-fill, 4-shrink and complete filling (Table X.10 and Figure X.10) on the raw classification using alpha threshold of .5 to see if we were doing too much shrinking. The resulting misidentification error rate of 32% and false identification error rate of 36% indicates that we were not.

The best 3 band pairs results did significantly increase the accuracy over the two best spectral band pair accuracy and the two best spectral-textural band pair results. The band pairs selected by the feature selection procedure were:

1. .40 - .44 micrometer band with the 3x3 convolution before and after the textural transform of the .82 - .88 micrometer band
2. .65 - .69 and 2.10 - 2.36 micrometer bands
3. .72 - .76 and .981 - 1.045 micrometer bands.

The alpha-beta thresholds were set at .7 and .049, respectively. This resulted in 25,590 reserved decisions due to no common category assignment and 43,889 reserved decisions because of more than one possible category assignment. The thresholds were set just a little too high.

The contingency table of the initially classified image with reserved decisions is shown in Table X.11. It indicates a 35% misidentification error rate and 37% false identification error rate. Completely filling the initially classified image with reserved decisions yields a misidentification error rate of 38% and false identification error rate of 37%. This identification accuracy (Table X.12) is just below the best 3 band pair spectral results.

If the completely filled image is operated on with one iteration of a 4-shrink operation and then completely filled, the misidentification error rate improves to 29% and false identification error rate improves to 30% (Table X.13 and Figure X.11). The results indicate that almost all resolution cells originally assigned to category 2.4 were neighboring resolution cells of a different category. Hence, the 4-shrink operation eliminated most of the assignments to category 2.4.

The basically scattered assignments to category 2.4 was manifest in the next experiment in which we did a 4-fill, then an 8-fill, then a 4-shrink, then an 8-shrink and a complete filling of the initially classified image with reserved decisions. The contingency table (Table X.14 and Figure X.12) shows a 23% misidentification error rate and a 6% false identification error rate. These results
are definitely better than the corresponding three best spectral band pair results. The main reason for the identification accuracy increase is that most of category 2.6 was assigned to category 2.6; only some of category 2.6 was assigned to category 2.5 and hardly any at all to category 1.3. All of category 2.4, however, was misidentified as category 1.3.

Following the pattern of the previous results, if a double 4-shrink and then 8-shrink operation is applied instead of a single 4-shrink and then 8-shrink, the classification results are not quite as good: a 39% misidentification error rate and 12% false identification error rate. As shown in Table X.15, category 2.4 is misidentified as category 1.3 and category 2.6 is misidentified as category 2.3 and category 2.5.
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Table X.1 The contingency table of the best 2 band pairs for alpha-beta thresholds of .3 and .021.

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Table X.2 The contingency table of the best 2 band pairs for alpha-beta thresholds of .3 and .021 after a complete filling.
Figure X.1  The classification of the best 2 band pairs for alpha-beta thresholds of .3 and .021.

Figure X.2  The classified image of Figure X.1 after a complete filling.
Table X.3  The contingency table of the best 2 band pairs for alpha - beta thresholds of .3 and .021 after complete filling, 4-shrink, and complete filling operations.

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Table X.4  The contingency table of the best 2 band pairs for alpha - beta thresholds of .3 and .021 after 4-fill, 8-fill, 4-shrink, 8-shrink, and complete filling operations.
Figure X.3  The classified image of Figure X.1 after complete filling, 4-shrink, and complete filling operations.

Figure X.4  The classified image of Figure X.1 after 4-fill, 8-fill, 4-shrink, 8-shrink and complete filling operations.
CONTINGENCY TABLE FOR  SMM12G01  - 1  SMM2G03 - 1  SCALE FACTOR 10** 0

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<td>6956 0</td>
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<td>2 2459 169 0 0</td>
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<td>2.4</td>
<td>679 0</td>
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<td>28 1416 0 2596</td>
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<td>2.6</td>
<td>7 825 0 609</td>
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<td>ERR</td>
<td>659 19</td>
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Table X.5 The contingency table of the best 2 band pairs for alpha - beta thresholds of .3 and .021 after 4-fill, 8-fill, 4-shrink, 8-shrink, 4-shrink, 8-shrink, and complete filling operations.

CONTINGENCY TABLE FOR  SMM12G01  - 1  SMM2B15 - 1  SCALE FACTOR 10** 0

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<td>1.3</td>
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<td>1.4</td>
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<td>2.4</td>
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<td>2.5</td>
<td>1064 465 44 190 26 2106 131 8 4034 864 29</td>
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<td>2.6</td>
<td>502 157 11 155 5 534 60 10 1434 872 94</td>
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<tr>
<td>ERR</td>
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Table X.6 The contingency table of the best 2 band pairs for alpha - beta thresholds of .5 and .035.
Figure X.5  The classified image of Figure X.1 after 4-fill, 8-fill, 4-shrink, 8-shrink, 4-shrink, 8-shrink and complete filling operations.

Figure X.6  The classification of the best 2 band pairs for alpha - beta thresholds of .5 and .035.
Table X.7
The contingency table of the best 2 band pairs for alpha-beta thresholds of .5 and .035 after a complete filling.

Table X.8
The contingency table of the best 2 band pairs for alpha-beta thresholds of .5 and .035 after complete filling, 4-shrink, and complete filling operations.
Figure X.7 The classified image of Figure X.6 after a complete filling.

Figure X.8 The classified image of Figure X.6 after complete filling, 4-shrink and complete filling operations.
Table X.9 The contingency table of the best 2 band pairs for alpha - beta thresholds of .5 and .035 after 4-fill, 8-fill, 4-shrink, 8-shrink, and complete filling operations.

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<td>0 12 498 47</td>
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<td>2.3</td>
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<td>0 387 10 154</td>
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<td>0 130 0 330</td>
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<td>2.7</td>
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</tr>
<tr>
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<tr>
<td>IERR</td>
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</tr>
<tr>
<td>% ERR</td>
<td>0 16 7 7 100 28 100 0 36 100</td>
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Table X.10 The contingency table of the best 2 band pairs for alpha - beta thresholds of .5 and .035 after 4-fill, 8-fill, 4-shrink, 8-shrink, and complete filling operations.
Figure X.9  The classified image of Figure X.6 after 4-fill, 8-fill, 4-shrink, 8-shrink, and complete filling operations.

Figure X.10  The classified image of Figure X.6 after 4-fill, 8-fill, 4-shrink and complete filling operations.
### Table X.11

The contingency table of the best 3 band pairs for alpha-beta thresholds of .7 and .049.

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<th>2.6</th>
<th>7.2</th>
<th>TOTAL</th>
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<td>199</td>
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<td>4</td>
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<td>34</td>
<td>28</td>
<td>629</td>
<td>700</td>
<td>94</td>
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</tr>
</tbody>
</table>

| 2               | 2367           | 217      | 14    | 91   | 12  | 1038  | 290   | 5     | 4034  | 629  | 38  |
| 2.1             | 781            | 53       | 7     | 93   | 1   | 242   | 241   | 16    | 1434  | 412  | 63  |
| 2.2             | 1428           | 255      | 209   | 42   | 18  | 5     | 9     | 3659  | 5625  | 538  | 13  |
| 2.3             | 69479          | 10763    | 20077 | 8321  | 13117 | 9260  | 13512  | 156096 | 3834  | 35  |
| 2.4             | 0              | 873      | 327   | 285  | 118 | 769   | 997   | 170   | 3534  | ***  | **** |

| TOTAL           | 0              | 36517    | 19048 | 10763 | 20077 | 8321  | 13117 | 9260  | 13512  | 156096 | 3534  | 35  |
| 2.5             | 0              | 511      | 34    | 189  | 31   | 2556  | 706   | 7     | 4034  | 1478  | 37  |
| 2.6             | 0              | 441      | 377   | 468  | 33   | 1317  | 4686  | 5625  | 539   | 17   |
| 7.2             | 0              | 1777     | 625   | 541  | 228 | 1635  | 2007  | 315   | 7063  | ***  | **** |

| 3.1             | 0              | 39       | 85    | 85   | 85   | 39    | 85    | 410   | 13512  | 156096 | 3534  | 35  |

Table X.12

The contingency table of the best 3 band pairs after a complete filling.

---

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**ORIGINAL PAGE IS OF POOR QUALITY**
The contingency table of the best 3 band pairs after complete filling, 4-shrink, and complete filling operations.

Table X.13

The contingency table of the best 3 band pairs after 4-fill, 8-fill, 4-shrink, 8-shrink and complete filling operations.

Table X.14
Figure X.11  The classification of the best 3 band pairs for alpha - beta thresholds of .7 and .049 after complete filling, 4-shrink, and complete filling operations.

Figure X.12  The classification of the best 3 band pairs for alpha - beta thresholds of .7 and .049 after 4-fill, 8-fill, 4-shrink, 8-shrink, and complete filling operations.
Table X.15 The contingency table of the best 3 band pairs after 4-fill, 8-fill, 4-shrink, 8-shrink, 4-shrink, 8-shrink, and complete filling operations.
Spectral-Textural Analysis: Edit 9

With this edit we experimented to find the best texture transforms. The .82 - .88 micrometer band was chosen as the band having the most spatial information (Figure XI.1). Figure XI.2 is a 2x2 rectangular convolution of the .82 - .88 micrometer band and Figure XI.3 is a 3x3 rectangular convolution of the band. Each of these bands were used as inputs into the texture transform. The resulting textural transform images are shown in Figures XI.4, XI.5 and XI.6. Each of these were convoluted with a 2x2 window size (shown in Figures XI.7, XI.8, XI.9). Finally the textural transforms were convoluted with a 3x3 convolution window giving us 3 more texture images (Figures XI.10, XI.11 and XI.12). Using our own visual discretion we chose the textural transform with a 3x3 rectangular convolution after the textural transform as the two texture bands with the most information (these are shown in Figures XI.10 and XI.12).

We combined these 2 texture bands with the spectral bands and the feature selector chose band pairs .40 - .44 micrometers and the 3x3 rectangular convolution before and after the textural transform with .65 - .69 and 2.10 - 2.36 micrometers as the 2 best band pairs for classification. Band pair .72 - .76 and .981 - 1.045 micrometers was selected with the other two for the best 3 band pairs. Figure XI.13 and XI.14 show the graphs of the threshold alpha against the number of reserved decisions. For best 3 band pairs the best alpha threshold was .7 with a beta threshold of .049.

To check the choice of thresholds we checked several results using different thresholds. The best 3 band pairs classification with alpha, beta thresholds of .3 and .021 gave us a misidentification error rate of 20% and a false identification error rate of 20% (Table XI.1 and Figure XI.15). The error rate was low but the total number of reserved decisions 104,531 is high. Only 89 of these points were reserved due to more than one assignment, while 104,443 points were reserved because of no assignment. The largest cause of error was due to misidentification of category 2.6 as category 2.5, both subclasses of loblolly pine.
Post processing with a 4-shrink and then a complete filling we obtained misidentification and false identification error rates of 36% and 20%. Both category 2.6 and category 3.1, laurel oak, had misidentification error rates of 100% (Table XI.2 and Figure XI.16). Though the shrink operation usually reduces error, if a sparse category is assigned correctly, the shrink operation here tended to wipe out the category. Table XI.2 shows us that this happened to category 2.6 and category 3.1. If instead of a shrink we first did a 4-fill, then a 4-shrink and then a complete filling, the resulting contingency table is Table XI.3 (Figure XI.17). The misidentification error rate was 18% and the false identification error rate was 16%, but the misidentification error rate for category 2.6 was still high at 41%. The main cause of error is the confusion of 2.6 and 2.5. The only way left to eliminate the confusion is to change thresholds.

Values of .6 and .042 for the alpha, beta thresholds resulted in a misidentification error rate of 25% and a false identification error rate of 28% (Table XI.4). The misidentification error rate for categories 2.5 and 2.6 were 31% and 34%, respectively. If .7 and .049 are chosen for the alpha and beta thresholds we get error rates of 25% and 31%, but the misidentification error rate for category 2.6 is only 24% and the misidentification error rate of category 2.5 is 31% (Table XI.5). The number of reserved decisions is 71,919 with 43,045 points being reserved because of more than one assignment and 28,874 points reserved because of no assignment. With thresholds for alpha and beta of .8 and .063, the misidentification and false identification error rates were 28% and 32%, respectively (Table XI.6). Though the misidentification error rate for category 2.6 has been reduced to 19% and for category 2.5 it was reduced to 21%, the misidentification and false identification error rates for category 3.1 have grown to 62% and 62%, and for category 4.2 the rates have gone up to 52% and 45%. In addition the number of reserved decisions has risen to 121,716 indicating that the thresholds have gotten too high.

Since the error rates for Table XI.4 and Table XI.5 were almost the same, the results from the classification with thresholds of .7 and .049 should be better for post processing. The main cause of error had been with categories 2.5 and 2.5 and this classification showed lower error rates for these categories.
If we fill up the image with alternating 4-fill and 8-fills we get a misidentification error rate of 27% and a false identification error rate of 33% (Table XI.7). This is no improvement on the raw classification so the shrink operation is needed to eliminate incorrect assignments. Post processing with a 4-fill and an 8-fill so the shrink operations do not wipe out sparsely populated categories, then doing a 4-shrink and 8-shrink and finally a complete filling, we obtain a misidentification error rate of 8% and a false identification error rate of 11% (Table XI.8 and Figure XI.18). The misidentification error rate for category 2.6 was reduced to 0 and the confusion between category 3.1 and 4.2 was small. As was the case with the spectral analysis the misidentification of category 2.5 with 1.3 is the main cause of error. Though the texture analysis gives better overall results, it cannot overcome the inability of the decision rise to separate categories 2.5 and 1.3 in the lower right hand corner of the timber stand map.

The results of the best 2 band pairs classification were not as good. The contingency table resulting from alpha, beta thresholds of .3 and .021 resulted in a misidentification error rate of 25% and a false identification error rate of 31% (Table XI.9 and Figure XI.19). If we do a 4-fill, 4-shrink and fill up we get error rates of 23% and 29% (Table XI.10 and Figure XI.20). If we shrink first and then fill up, the results showed improvement with a misidentification error rate of 15% and a false identification error rate of 20% (Table XI.11 and Figure XI.21).
Figure XI.1  The .82 - .88 micrometer band used for the texture transform.

Figure XI.2  Shows Figure XI.1 after a 2x2 rectangular convolution.
Figure XI.3  Shows Figure XI.1 after a 3x3 rectangular convolution.

Figure XI.4  The texture transform of Figure XI.1.
Figure XI.5  The texture transform of Figure XI.2.

Figure XI.6  The texture transform of Figure XI.3.
Figure XI.7 Shows Figure XI.4 after a 2x2 rectangular convolution.

Figure XI.8 Shows Figure XI.5 after a 2x2 rectangular convolution.
Figure XI.9  Shows Figure XI.6 after a 2x2 rectangular convolution.

Figure XI.10  Shows Figure XI.4 after a 3x3 rectangular convolution.
Figure XI.11  Shows Figure XI.5 after a 3x3 rectangular convolution.

Figure XI.12  Shows Figure XI.6 after a 3x3 rectangular convolution.
Figure XI.13  Number of reserved decisions as a function of probability threshold alpha for best 2 band pairs with texture for edit #9
Figure XI.14  Number of reserved decisions as a function of probability threshold alpha for best 3 band pairs spectral only for edit #9
--- CONTINGENCY TABLE FOR SAMH33GTD —- SMH33R01 —- 1 ---

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<tr>
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</thead>
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<td></td>
</tr>
</tbody>
</table>

| UNKWN | 9814 | 643 | 8838 | 1952 | 1028 | 1686 | 3979 | 112859 | 0 | 0 |
| 1.3 | 4281 | 4323 | 10 | 65 | 5 | 0 | 1 | 0 | 8685 | 81 | 2 |
| 2.0 | 259 | 7 | 212 | 1 | 4 | 0 | 0 | 6 | 925 | 16 | 8 |
| 2.6 | 7017 | 1101 | 8 | 3388 | 153 | 1 | 4 | 7 | 11769 | 1274 | 27 |
| 2.6 | 2251 | 1 | 7 | 167 | 205 | 1 | 10 | 3 | 2645 | 189 | 48 |

| 3.1 | 1249 | 0 | 0 | 0 | 1 | 207 | 61 | 9 | 1527 | 71 | 26 |
| 4.2 | 1407 | 0 | 0 | 6 | 9 | 62 | 209 | 8 | 1701 | 85 | 29 |
| 7.2 | 712 | 0 | 1 | 0 | 1 | 1 | 2 | 488 | 1205 | 5 | 1 |
| TOTAL | 1050 | 15246 | 881 | 10465 | 2330 | 1300 | 1973 | 4500 | 141226 | 1723 | 20 |
| ERR | 0 | 1109 | 26 | 239 | 173 | 65 | 78 | 33 | 1723 | 4450 |

--- Table XI.1 The contingency table of the best 3 band pairs for alpha-beta thresholds of .3 and .021. ---

--- CONTINGENCY TABLE FOR SAMH33GTD —- SMH33R01 —- 1 ---

| R DEC 1.3 2.3 2.5 2.6 3.1 4.2 7.2 TOTAL ERR ERR |

| UNKWN | 30028 | 1405 | 32582 | 4508 | 0 | 3121 | 41215 | 112859 | 0 | 0 |
| 1.3 | 0 | 8645 | 0 | 0 | 0 | 0 | 0 | 0 | 8685 | 0 | 0 |
| 2.5 | 0 | 12 | 913 | 0 | 0 | 0 | 0 | 0 | 925 | 12 | 1 |
| 2.6 | 4773 | 0 | 6906 | 0 | 0 | 0 | 0 | 0 | 4773 | 4773 | 47 |
| 7.1 | 0 | 0 | 0 | 1160 | 0 | 0 | 1485 | 2645 | 2645 | 100 |
| 4.2 | 0 | 0 | 0 | 265 | 0 | 0 | 1436 | 1701 | 265 | 16 |
| 7.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1205 | 1205 | 0 | 0 |
| TOTAL | 43498 | 2318 | 40913 | 4508 | 0 | 5029 | 44960 | 141226 | 9222 | 36 |
| ERR | 0 | 4785 | 0 | 1425 | 0 | 0 | 472 | 2540 | 9222 | 0 |

| ERR | 0 | 36 | 0 | 17 | 0 | 0 | 25 | 68 | 20 |

--- Table XI.2 The contingency table of the best 3 band pairs for alpha-beta thresholds of .3 and .021 after 4-shrink and complete filling operations. ---
Figure XI.15  The classification of the best 3 band pairs for alpha-beta thresholds of .3 and .021.

Figure XI.16  The classified image of Figure XI.15 after 4-shrink and complete filling operations.
Table XI.3 The contingency table of the best 3 band pairs for alpha-beta thresholds of .3 and .021 after 4-fill, 4-shrink, and complete filling operations.

Table XI.4 The contingency table of the best 3 band pairs for alpha-beta thresholds of .6 and .042.
Figure XI.17  The classified image of Figure XI.15 after 4-fill, 4-shrink and complete filling operations.

Figure XI.18  The classification of the best 3 band pairs for alpha - beta thresholds of .7 and .049 after 4-fill, 8-fill, 4-shrink, 8-shrink, and complete filling operations.
Table XI.5 The contingency table of the best 3 band pairs for alpha-beta thresholds of .7 and .049.

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</table>

Table XI.6 The contingency table of the best 3 band pairs for alpha-beta thresholds of .8 and .063.
### Table XI.7
The contingency table of the best 3 band pairs for alpha-beta thresholds of .7 and .049 after a complete filling.

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</tr>
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<td>7.2</td>
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<td>0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>31644</td>
<td>654431284</td>
</tr>
<tr>
<td>ERR</td>
<td>0</td>
<td>2677</td>
</tr>
</tbody>
</table>

### Table XI.8
The contingency table of the best 3 band pairs for alpha-beta thresholds of .7 and .049 after 4-fill, 8-fill, 4-shrink, 8-shrink, and complete filling operations.

<table>
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<tr>
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</tr>
</thead>
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<td>7.5</td>
</tr>
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</tr>
<tr>
<td>1.8</td>
<td>819</td>
<td>819</td>
</tr>
<tr>
<td>2.3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2.6</td>
<td>0</td>
<td>2677</td>
</tr>
<tr>
<td>3.1</td>
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<td>4.2</td>
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<td>0</td>
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<tr>
<td>7.2</td>
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<tr>
<td>ERR</td>
<td>0</td>
<td>2677</td>
</tr>
</tbody>
</table>
### Table XI.9

The contingency table of the best 2 band pairs for alpha-beta thresholds of .3 and .021.

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<th>2.6</th>
<th>3.1</th>
<th>4.1</th>
<th>7.1</th>
<th>TOTAL</th>
<th>ERR</th>
<th>ERR</th>
</tr>
</thead>
<tbody>
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<td>19961</td>
<td>17645</td>
<td>15074</td>
<td>17061</td>
<td>112859</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1.3</td>
<td>8255</td>
<td>9</td>
<td>246</td>
<td>114</td>
<td>2</td>
<td>21</td>
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<td>8685</td>
<td>430</td>
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<td></td>
</tr>
<tr>
<td>2.5</td>
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<td>2</td>
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<td>18</td>
<td>79</td>
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<td>72</td>
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<td>235</td>
<td>25</td>
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<td>3371</td>
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<td>6561</td>
<td>1357</td>
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<td>234</td>
<td>43</td>
<td>11679</td>
<td>5118</td>
<td>44</td>
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<tr>
<td>3.1</td>
<td>0</td>
<td>8</td>
<td>238</td>
<td>340</td>
<td>1619</td>
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<td>1299</td>
<td>150</td>
<td>24</td>
<td>1527</td>
<td>228</td>
<td>15</td>
</tr>
<tr>
<td>7.1</td>
<td>0</td>
<td>24</td>
<td>0</td>
<td>2</td>
<td>106</td>
<td>9</td>
<td>1064</td>
<td>1205</td>
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<td>12</td>
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<td>TOTAL</td>
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<td>10354</td>
<td>141226</td>
<td>7866</td>
<td>23</td>
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<td>38</td>
<td>9</td>
<td>50</td>
<td>28</td>
<td>36</td>
<td>18</td>
<td>29</td>
<td>******</td>
<td>*****</td>
</tr>
</tbody>
</table>
```

**Table XI.10**  The contingency table of the best 2 band pairs after 4-fill, 4-shrink, and complete filling operations.
Figure XI.19  The classification of the best 2 band pairs for alpha-beta thresholds of .3 and .021.

Figure XI.20  The classified image of Figure XI.19 after 4-fill, 4-shrink, and complete filling operations.
### Table XI.11

The contingency table of the best 2 band pairs after 4-shrink and complete filling operations.
Figure XI.21  The classified image of Figure XI.19 after 4-shrink and complete filling operations
The spectral texture analysis of edit #14 began just like that of the other edits except the feature selection did not choose a texture band as one of the best 2 or best 3 band pairs. We, nevertheless, did an experiment with 2 band pairs. We chose bands .40 - .44 and .72 - .76 with bands .72 - .76 and the texture transform image. The texture image was the result of a 3x3 convolution of the .82 - .88 micrometer band as input into the texture transform and a 3x3 convolution after the texture transform. The alpha and beta thresholds were .3 and .021, respectively. Figure XII.1 shows the .82 - .88 micrometer band used for the texture transform. The texture transformed image that was used for processing is shown in Figure XII.2. Figure XII.3 shows the texture transform result with no convolution before transforming and with a 3x3 convolution after. The feature selector did not choose this band and visually we can see that it has much less spatial information than the texture transform that was chosen.

The contingency table that resulted from the table look-up rule (Table XII.1) shows a 43% misidentification error rate and a 44% false identification error rate. This is not nearly as good as the spectral results. There were a large number of reserved decisions, 72,804, due to too low thresholds.

The main reason for the larger error was increased confusion between all categories and category 7.2, not site prepared. These errors were small on the spectral analysis.

Using the same spatial post processing that we used in the spectral analysis we reduced the error most of the time but not always. After a 4-fill, 8-fill, 4-shrink, 8-shrink, we eliminated almost all errors in the spectral analysis (Section VIII) but with this spectral-textural analysis (Table XII.2) we increase misidentification error on category 4.1 to 91%, and on category 2.3 it was about the same (59%) as before post processing.

The final filling of the image (Table XII.3) reduced the error rates to 35% and 31% but did not come close to the 85% classification accuracy of the 2-band spectral results. This might have been due to the texture function used or to the fact that there was little textural distribution between the categories in this image.
Figure XII.1  The .82 - .88 micrometer band used for the texture transform.

Figure XII.2  The texture transform of Figure XII.1 with a 3x3 rectangular convolution before the texture transform and a 3x3 rectangular convolution after.
Figure XII.3  The texture transform of Figure XII.1 with no rectangular convolution before the texture transform and a 3x3 rectangular convolution after.
### Table XII.1
The contingency table of the best 2 band pairs for alpha-beta thresholds of 0.3 and 0.021.

<table>
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<th>4.1</th>
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<th>TOTAL</th>
<th>ERR</th>
<th>ERR</th>
<th>SD</th>
</tr>
</thead>
<tbody>
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<td>11622</td>
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<td>0</td>
</tr>
<tr>
<td>2.3</td>
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<td>281</td>
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<td>4975</td>
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<td>52</td>
</tr>
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<td>115</td>
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<td>4978</td>
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<td>18</td>
</tr>
<tr>
<td>4.1</td>
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<td>216</td>
<td>105</td>
<td>212</td>
<td>110</td>
<td>1749</td>
<td>431</td>
<td>67</td>
</tr>
<tr>
<td>7.2</td>
<td>1542</td>
<td>229</td>
<td>133</td>
<td>112</td>
<td>898</td>
<td>2914</td>
<td>474</td>
<td>35</td>
</tr>
<tr>
<td>TOTAL</td>
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<td>9201</td>
<td>16134</td>
<td>12342</td>
<td>24081</td>
<td>134562</td>
<td>2564</td>
<td>43</td>
</tr>
</tbody>
</table>

### Table XII.2
The contingency table of the best 2 band pairs after 4-fill, 8-fill, 4-shrink, and 8-shrink operations.

<table>
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<tr>
<th>DEC</th>
<th>2.3</th>
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<th>4.1</th>
<th>7.2</th>
<th>TOTAL</th>
<th>ERR</th>
<th>ERR</th>
<th>SD</th>
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</thead>
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</tr>
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<td>4</td>
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<tr>
<td>4.1</td>
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<td>1749</td>
<td>43</td>
<td>91</td>
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<td>2914</td>
<td>56</td>
<td>11</td>
</tr>
<tr>
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<td>2971</td>
<td>10984</td>
<td>134562</td>
<td>274</td>
<td>40</td>
<td>0</td>
</tr>
</tbody>
</table>

### CORRECTION
The table presents the contingency analysis results for two sets of band pairs with specified alpha-beta thresholds. The contingency is categorized by different bands and their corresponding error rates, showing the effectiveness of the operations applied.
CONTINGENCY TABLE FOR SAPH42GDT - 1 SMH4F5003 - 1 SCALE FACTOR 1000

<table>
<thead>
<tr>
<th>COL: = ASSIGN CAT</th>
<th>ROW: = TRUE CAT</th>
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<th>4.1</th>
<th>7.2</th>
<th>TOTAL</th>
<th>ERR</th>
<th>SD</th>
</tr>
</thead>
<tbody>
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<td>52738</td>
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</tr>
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<td>374</td>
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</tr>
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<td>1749</td>
<td>1211</td>
<td>69</td>
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<td>*****</td>
</tr>
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<td>ERR</td>
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<td>18</td>
<td>37</td>
<td>38</td>
<td>31</td>
<td>*****</td>
<td>*****</td>
</tr>
</tbody>
</table>

Table XII.3  The contingency table of the best 2 band pairs after 4-fill, 8-fill, 4-shrink, 8-shrink and complete filling operations.
In addition to the six spectral bands, we provided the feature selector with two textural transform bands. The texture bands were created from the .82 - .88 micrometer spectral bands as before. We used a 3x3 convolution before and after textural transform and no convolution before and 3x3 convolution after textural transform. The feature selector chose bands .40 - .44 and .588 - .643 micrometers with .40 - .44 micrometers and no convolution before and 3x3 convolution after texture bands for the best 2 band pairs. Figure XIII.1 shows how the alpha and beta thresholds were chosen in an attempt to minimize the total number of reserved decisions and to equalize the number of reserved decisions due to no assignment and the number of reserved decisions due to multiple assignments.

For the best 2 band pairs the alpha threshold was set at .5 and the beta threshold at .035. Table XIII.1 shows the resulting contingency table for the best 2 band pairs. There are 49,130 reserved decisions with 18,083 due to no assignment and 31,047 due to multiple assignment. The misidentification error rate was 42% and the false identification error rate was 43%. The largest cause of error was the misidentification error rate (90%) of category 1.3, shortleaf pine, mostly caused by assigning category 1.2, another subclass of shortleaf pine. Post processing with a 4-fill, 8-fill, 4-shrink, 8-shrink and a complete filling results in a misidentification error rate of 34% and a false identification error rate of 20% (Table XIII.2).

The band pairs used for the best 2 along with the .588 - .643 and .65 - .69 micrometer band pair were chosen by the feature selector as the best 3 band pairs. Figure XIII.2 shows the graph of the threshold alpha against the number of reserved decisions. For the best 3 band pairs the alpha threshold was set at .6 and the beta threshold was set at .042. It is interesting to note, that the number of reserved decisions due to no assignment was 25,878, and the number of reserved decisions due to more than one assignment was 26,566 which are very close indicating good thresholds.

Table XIII.3 shows the resulting contingency table for the best 3 band pairs. The misidentification error rate was 38% and the false identification
error rate was 41%. The greatest cause of confusion is the misidentification of category 1.3 and the false identification of category 1.3, a subclass of shortleaf pine. As with the spectral analysis of edit #3 (Chapter IX), the confusion is mostly within class types. Confusion between category 1.2 and category 1.3, subclasses of shortleaf pine, and confusion between category 2.4 and category 2.6 cause most of the error. Figure XIII.3 shows the best 3 band pairs classification.

Post processing with a 4-fill and an 8-fill (Table XIII.4 and Figure XII.4) did not really change the error rates. The misidentification error rate is 40% and the false identification error rate is 44%. A 4-shrink (Table XIII.5 and Figure XIII.5) and an 8-shrink (Table XIII.6) eliminate almost all of the confusion between class types, but the error within class type 1 is still high. This confusion within class type 1 was also present in the spectral analysis (Chapter IX). The final post processing, a complete filling, resulted in a contingency table (Table XIII.7 and Figure XIII.6) having a misidentification error rate of 25% and a false identification error rate of 29%.

Note that the results of 4-fill, 8-fill, 4-shrink, 8-shrink, and complete filling operations for the best 3 band pairs (Table XIII.7 and Figure XIII.6) and the results of 4-fill, 8-fill, 4-shrink, 8-shrink and complete filling operations for best 3 band pairs using the spectral analysis (Chapter IX, Table IX.7 and Figure IX.8) shows less error in the spectral results. Yet, comparison of Figure XIII.6 and Figure IX.8 show that the figure from the texture analysis is actually truer to the timber stand and compartment map for edit #3 than the spectral figure. It seems this is due to the area covered by the ground truth overlay (Figure IX.2), so that more ground truth would have resulted in better classification accuracy for the texture analysis.
Figure XIII.1  Number of reserved decisions as a function of probability threshold alpha for best 2 band pairs with texture for edit #3
### Table XIII.1
The contingency table of the best 2 band pairs for alpha-beta thresholds of .5 and .035.

<table>
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<th>ROW: True Cat</th>
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<th>1.3</th>
<th>2.4</th>
<th>2.6</th>
<th>7.1</th>
<th>TOTAL</th>
<th>ERR % ERR</th>
<th>SD</th>
</tr>
</thead>
<tbody>
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<td></td>
</tr>
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</tr>
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<td>4020</td>
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</tr>
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</tr>
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</tr>
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<td>45</td>
<td>21</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table XIII.2
The contingency table of the best 2 band pairs after 4-fill, 8-fill, 4-shrink, 8-shrink and complete filling operations.
Figure XIII.2 Number of reserved decisions as a function of probability threshold \( \alpha \) for best 3 band pairs with texture for edit #3.
### Table XIII.3
The contingency table of the best 3 band pairs for alpha-beta thresholds of .6 and .042.

<table>
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<th>7.1</th>
<th>TOTAL</th>
<th>% ERR</th>
<th>% SD</th>
</tr>
</thead>
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<td>1326</td>
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<td>9972</td>
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</tr>
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</table>

- **# ERR**: 0
- **% ERR**: 0
- **% SD**: 0

### Table XIII.4
The contingency table of the best 3 band pairs after 4-fill and 8-fill operations.

<table>
<thead>
<tr>
<th>COL. = ASSIGN CAT</th>
<th>ROW = TRUE CAT</th>
<th>1.2</th>
<th>1.3</th>
<th>2.4</th>
<th>2.6</th>
<th>7.1</th>
<th>TOTAL</th>
<th>% ERR</th>
<th>% SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNKWN</td>
<td>96</td>
<td>1478</td>
<td>5624</td>
<td>16474</td>
<td>19209</td>
<td>11449</td>
<td>67633</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.2</td>
<td>5</td>
<td>6241</td>
<td>1873</td>
<td>1326</td>
<td>1976</td>
<td>582</td>
<td>12003</td>
<td>5757</td>
<td>48</td>
</tr>
<tr>
<td>1.3</td>
<td>2</td>
<td>907</td>
<td>666</td>
<td>68</td>
<td>220</td>
<td>0</td>
<td>1863</td>
<td>1195</td>
<td>64</td>
</tr>
<tr>
<td>2.4</td>
<td>13</td>
<td>1420</td>
<td>340</td>
<td>5281</td>
<td>2453</td>
<td>465</td>
<td>9972</td>
<td>4678</td>
<td>47</td>
</tr>
<tr>
<td>2.6</td>
<td>0</td>
<td>1075</td>
<td>117</td>
<td>808</td>
<td>4270</td>
<td>135</td>
<td>6405</td>
<td>2135</td>
<td>33</td>
</tr>
<tr>
<td>TOTAL</td>
<td>116</td>
<td>24424</td>
<td>6628</td>
<td>24281</td>
<td>28172</td>
<td>16275</td>
<td>101896</td>
<td>6009</td>
<td>48</td>
</tr>
</tbody>
</table>

- **# ERR**: 0
- **% ERR**: 0
- **% SD**: 0
Figure XIII.3  The classification of the three best band pairs for alpha-beta thresholds of .6 and .042.

Figure XIII.4  The classified image of Figure XIII.3 after 4-fill and 8-fill operations.
### Table XIII.5
The contingency table of the best 3 band pairs after 4-fill, 8-fill, and 4-shrink operations.

<table>
<thead>
<tr>
<th>COL. = ASSIGN CAT</th>
<th>ROW = TRUE CAT</th>
<th>R DEC</th>
<th>1.2</th>
<th>1.3</th>
<th>2.4</th>
<th>2.6</th>
<th>7.1</th>
<th>TOTAL #ERR</th>
<th>% ERR</th>
<th>% SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNKNWN62426</td>
<td>910 299 287 440 3271 67633</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1.2 10897</td>
<td>800 185 24 13 79 12003</td>
<td>301</td>
<td>27</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1863 66</td>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td>1.3 1732</td>
<td>66 45 0 0 0 10053</td>
<td>66</td>
<td>50</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>211 13</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>2.4 8622</td>
<td>5 0 341 3 1 9972</td>
<td>9</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>101896 399</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>2.6 6181</td>
<td>13 0 211 0 0 6405</td>
<td>13</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7.1 1140</td>
<td>0 0 10 0 2870 4020</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>TOTAL 91998</td>
<td>1799 549 662 667 6221 101896</td>
<td>399</td>
<td>17</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>% ERR</td>
<td>0 84 185 34 16 80 399</td>
<td>20</td>
<td>17</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>% ERR</td>
<td>0 9 74 9 7 3 20</td>
<td>20</td>
<td>17</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### Table XIII.6
The contingency table of the best 3 band pairs after 4-fill, 8-fill, 4-shrink and 8-shrink operations.
Table XIII.7 The contingency table of the best 3 band pairs after 4-fill, 8-fill, 4-shrink, 8-shrink and complete filling operations.
Figure XIII.5  The classified image of Figure XIII.3 after 4-fill, 8-fill and 4-shrink operations.

Figure XIII.6  The classified image of Figure XIII.3 after 4-fill, 8-fill, 4-shrink, 8-shrink, and complete filling operations.
XIV Conclusions

Use of textural features and spatial post processing has been shown to cut the average classification error to less than half its initial value while tending to increase and equalize the equally weighted average misidentification error and equally weighted false identification error. The classified images resulting from spatial and textural processing have a more cartographic map-like quality than the typically salt and pepper classified images using no textural features or spatial post-processing.

The simultaneous decrease in average classification error and increase in both equally weighted average misidentification error and false identification error means that more pixels whose true category identification is of a frequently occurring category get reassigned correctly by the spatial post-processing than of an infrequently occurring category. This is a natural consequence of the fact that the spatial processing is more of a syntactic operation than a semantic one. Spatial processing operations which use category labels instead of just sameness or difference of category labels could be designed which do not favor the larger categories over the smaller categories.

Because of the strong interaction between average error, average misidentification error, average false identification error, and classified image appearance and complexity, it is clear that further work can bear much fruit by analysis of these interaction effects. In particular, we recommend that textural and spatial post-processing concepts be developed using classified image’s local neighborhood contexts as the independent variable and classification error as the dependent variable.
REFERENCES


Table of Contents

I. User Interaction
II. Internal Program Description
III. Non-Standard Subroutines
IV. Subroutine Documentations
V. Listing
1. **User Interaction**

User parameters are input by the routine TXINPT which asks for parameters by name:

- **NFUNC = 1** use subroutine FUNC 1
- **NFUNC = 2** use subroutine FUNC 2
- **NFUNC = 3** use subroutine FUNC 3
- **NFUNC = 4** use subroutine FUNC 4
- **NFUNC = 5** use subroutine FUNC 5

- **NDIS** = distance between spaces of neighboring cells
- **IBOUT** = logical unit number to output error messages
- **PCLCT** = percent of point to count in FPLXIT
- **FILNMP** = input filename
- **FILNMQ** = output filename
II. Internal Program Description

The texture programs are set up so that after the call to TXINPT at the beginning of execution the user does not interact anymore with the computer.

The user must know which function he wants to use. The user inputs 1, 2, 3, 4, or 5 corresponding to FUNC1, FUNC2, FUNC3, FUNC4, and FUNC5 respectively; where:

- **FUNC1** - computes the sum probability feature of the image
- **FUNC2** - computes the gradient entropy feature of the image
- **FUNC3** - computes the entropy feature of the image
- **FUNC4** - computes the gradient feature of the image
- **FUNC5** - prepares normalized lex arrays which have been equal probability quantized according to their diagonal elements.

The parameter NDIS is the distance between spaces of neighboring cells. The texture transform works on the co-occurrence of grey levels on neighboring cells. Each cell has a $0^\circ$ neighbor, a $90^\circ$ neighbor, a $135^\circ$ neighbor, and a $45^\circ$ neighbor. This covers all the cells, since a cell's $180^\circ$ neighbor has that cell as a $0^\circ$ neighbor. Thus, for each grey level, there is a count of the co-occurrences of grey levels as one of the four specified neighbors. The parameter NDIS is the distance the algorithm gives to look for the neighboring cells. If the user wants to perform the texture transform using all co-occurrence counts, then the parameter PCLCT should be 1.00. If the user only wants to count 80% of the cells, the PCLCT should be set to 0.80, and so on.

The mainline TXJDM calls the ASCII I/O routine TXINPT for input parameters. The TXJDM transfers control to TXTMN. This routine sets up the work area, allocating core to those arrays that need it. FPLXIT is then called to compute the lex arrays where:

- **LEX1** - array containing count over all grey levels of vertically adjacent (90-degree) neighbor;
- **LEX2** - array containing count over all grey levels of horizontally adjacent (0-degree) neighbor;
- **LEX3** - array containing count over all grey levels of left diagonally adjacent (135-degree) neighbor;
- **LEX4** - array containing count over all grey levels of right diagonally adjacent (45-degree neighbor).
When these counts have finished, control is returned to TXTMN, which transfers control to the appropriate function as specified by the user. The FUNC array which is passed as an argument to the FUNC routines is equivalenced to the lex arrays. For example:

```
  FUNC (1,1) = LEX1 (1)
  FUNC (1,2) = LEX2 (1)
  FUNC (1,3) = LEX3 (1)
  FUNC (1,4) = LEX4 (1)
```

After the appropriate function has been applied, control is again returned to TXTMN. TXTMN then calls in PLXIT. PLXIT reads in the image data and determines the corresponding eight neighbors and applies the texture transform.

Let \( Z_r \times Z_c \) be the set of resolution cells of an image \( I \) (by row-column coordinates). Let \( G \) be the set of grey tones possible to appear on image \( I \). Then \( I: Z_r \times Z_c \rightarrow G \). Let \( R \) be a binary relation on \( Z_r \times Z_c \) pairing together all those resolution cells in the desired spatial relation. The co-occurrence matrix \( P: G \times G \rightarrow [0,1] \), for image \( I \) and binary relation \( R \) is defined by

\[
P(i,j) = \frac{\# \{(a,b),(c,d) \in R | I(a,b) = i \text{ and } I(c,d) = j\}}{\#R}
\]

The textural transform \( J: Z_r \times Z_c \rightarrow \mathbb{R} \), of image \( I \) relative to function \( f \), is defined by

\[
J(y,x) = \sum_{(a,b) \in R(y,x)} \frac{1}{\#R(y,x)} f[P(I(y,x),I(a,b))]
\]

Assuming \( f \) to be the identity function, the meaning of \( J(y,x) \) is as follows. The set \( R(y,x) \) is the set of all those resolution cells in \( Z_r \times Z_c \) in the desired spatial relation to resolution cell \( (y,x) \). For any resolution cell \( (a,b) \in R(y,x) \), \( P(I(y,x),I(a,b)) \) is the relative frequency by which the grey tone \( I(y,x) \), appearing at resolution cell \( (y,x) \), and the grey tone \( I(a,b) \), appearing at resolution cell \( (a,b) \), co-occur together in the desired spatial relation on the entire image. The sum

\[
\sum_{(a,b) \in R(y,x)} P(I(y,x),I(a,b))
\]

is just the sum of the relative frequencies of grey tone co-occurrence over
all resolution cells in the specified relation to resolution cell \((y,x)\).

The factor \(\frac{1}{\#R(y, x)}\), the reciprocal of the number of resolution cells in the
desired spatial relation to \((y,x)\) is just a normalizing factor.

These data values are then written out in the corresponding place on
the output texture transformed image. When PLXIT exits, the texture trans-
form has been created. Control goes to TXTMN, which exits back to the
mainline TXTDM. This program returns to the beginning and brings back the
ASCII I/O routines to get the parameters for the next texture transform. If
none are desired, a carriage return will terminate the processing.

All ASCII I/O on our PDP-15 is 5/7 ASCII in double integer words. The
PDP-15 has 36 bits in one double integer word.

See Figure 1 for the program flow.
III. Non-Standard Subroutines

ADJI
ADJ2 Dynamic core allocation routines
ADJ3

The program can allocate memory by performing what essentially amounts to a dynamic Fortran equivalence and dimension

KDPUSH - Ignore (delete)

Error stack processing used in KANDIDATES.

SDKINL - KANDIDATS sequential file opener

Opens files for KANDIDATS routines. Uses Seek and Enter (STANDARD Fortran routines) and can be modified to fit your file structure.

SKPDSC - skip descriptor records

KANDIDATS creates descriptor records, containing processing history information, before the image date. Since the file is sequential, these must be skipped. If the user has random access on images, this can be ignored. If not, be sure that image record numbers are advanced to first image data record.

IMTRXP - Matrix print-out routine

Any standard Matrix print routine will work.

SREAD - sequential read (uses Fortran reads)

SWRITE - sequential write (uses Fortran write)

Starting on the next page is an explanation of the "ADJ routines and several ideas on how to get around them."
The included program segment may be compared to the following example:

1. INTEGER ARRAY (500), X(1)
2. REAL Y(1)
3. INTEGER XSIZE, YSIZE, YSTART, TTLSZE
4. READ (5, 100) XSIZE, YSIZE
5. TTLSZE = XSIZE + YSIZE
6. IF (TTLSZE .GT. 500) CALL ERROR
7. YSTART = XSIZE + 1
8. CALL ADJ1 (X, ARRAY (1))
9. CALL ADJ1 (Y, ARRAY (YSTART))
10. . . . TASK CODE
11. STOP
12. END

Within the task code, X and Y may be referenced as vectors with respective types, integer and real. In addition references to X will access the first XSIZE elements of ARRAY and references to Y will access the last YSIZE elements of ARRAY.
If X and Y are used only in contexts that functions may be used in, then the program segment may be recoded using statement functions. (Check your particular implementation of FORTRAN for applicability.)

1. INTEGER ARRAY (500)
2. REAL RL
3. INTEGER XSIZE, YSIZE, TTLSZE
4. X(I) = ARRAY (I)
5. Y(I) = RL(ARRAY (I + XSIZE))
6. READ (5, 100) XSIZE, YSIZE
7. TTLSZE = XSIZE + YSIZE
8. IF (TTLSZE .GT. 500) CALL ERROR
9. ... TASK CODE
10. STOP
11. END

Where the function RL is coded as follows.

1. REAL FUNCTION RL(ARG)
2. REAL ARG
3. RL = ARG
4. RETURN
5. END

Within the task code, X and Y will have respective types integer and real and will access those specified locations of ARRAY.

However, X and Y may only be used as functions.
In the context of subroutine calls, adjustable dimensions is a standard feature of FORTRAN as in the following example:

1. INTEGER ARRAY (500)
2. INTEGER XSIZE, YSIZE, YSTART, TTLSZE
3. READ (5, 100) XSIZE, YSIZE
4. TTLSZE = XSIZE + YSIZE
5. IF (TTLSZE .GT. 500) CALL ERROR
6. YSTART = XSIZE + 1
7. CALL SUB (ARRAY(1), ARRAY (YSTART), XSIZE, YSIZE)
8. STOP
9. END

Where SUB is coded as follows:

1. SUBROUTINE SUB (X, Y, XSIZE, YSIZE)
2. INTEGER XSIZE, YSIZE
3. INTEGER X(XSIZE)
4. REAL Y(YSIZE)
5. . . . TASK CODE
6. RETURN

This approach necessitates a division of storage allocation code and task code.
Alternatively X and Y may be dimensioned independently and given a reasonable but sufficient size.

1. INTEGER X (250)
2. REAL Y(250)
3. READ (5, 100) XSIZE, YSIZE
4. IF (XSIZE .GT. 250). OR.
5. (Y SIZE .GT. 250) CALL ERROR
6. ... TASK CODE
7. STOP
8. END
Check the output of the FORTRAN compiler being used.
If the compiler generates and uses dope vectors it would be possible to produce user written ADJ routines.
Keep in mind that all recoding must preserve the size, shape, type and usage of the involved data elements.
IV. Subroutine Documentations
GENERAL MATRIX PRINTOUT PROGRAM

PROGRAM TITLE: SUBROUTINE IMTRXP
DATE OF LISTING: February 13, 1973
PROGRAMMER: Dinesh Goel
DOCUMENTED BY: Dinesh Goel
PROGRAM LANGUAGE: FORTRAN IV
COMPUTER REQUIRED: PDP 15/20

PURPOSE:
This subroutine divides an integer matrix into sections suitable for printer output and prints the matrix with matrix title, column designation, row designation, and column and row labels.

CALLING SEQUENCE:
CALL IMTRXP (IA, NROW, NCOL, NRWDIM, TTL1, TTL2, TTL3, CLBL, RLBL, ISTR)

INPUT ARGUMENTS:
IA Input array of matrix to be printed out.
NROW Number of rows in the printed matrix.
NCOL Number of columns in the printed matrix.
NRWDIM Row dimension of the entire matrix which is stored by columns.
TTL1 Matrix title of 13 words.
TTL2 Column title of 2 words.
TTL3 Row title of 2 words.
CLBL Array of column labels.
RLBL Array of row lables.
ISTR This is an option
    if 1, matrix will be printed as such.
    if 2, transposed matrix will be printed out.
    if 3, matrix is assumed to be symmetric having long to short storage in IA.

150
if 4, matrix is assumed to be symmetric having short to long storage in 1A.

OUTPUT ARGUMENTS:
None.

OTHER PARAMETERS AND ARRAYS:
IROW Array for any one row of matrix as finally printed out.

COMMENTS:
If the printed matrix has large number of columns which cannot fit on one page of printer output, it will be separated into blocks, each of which is small enough to fit on one page. The rows are printed in the blocks of 5. This program takes only the integer numbers, for real numbers RMTRXP can be used. File code 17 octal has been used for printing the matrix which must be assigned to teletype or IBM printer in the beginning as desired.
Sequential Read

PROGRAM TITLE: SREAD
VERSION: B
DATE: June 22, 1973
UPDATE: April 29, 1975
AUTHOR: Robert M. Haralick
DOCUMENTED BY: Robert M. Haralick
PROGRAM LANGUAGE: FORTRAN IV
IMPLEMENTED ON: PDP 15/20

PURPOSE:
This subroutine reads a set of lines on a file of single image data stored in standard bit compacted form. SREAD assumes that SDKINL has already been called to open the file on IDAT.

ENTRY POINT:
SPREAD (IDAT, IARRAY, IDY, IDENT, IEV, ERRRET)

ARGUMENT LIST:
IDAT the file code on which the image resides
IARRAY 2-dimensional array (row x column) which subimage is returned in
IDY number of records in subimage. The number of rows and columns for a record will be taken from IDENT (14) and IDENT (13), respectively
IDENT identification array of 20 words,
IEV integer event variable
IEV = 1 success
IEV = -2001 illegal file code
IEV = -2006/10/too small
IEV = -2007 EOF
IEV = -2009 READ ERROR
IEV = 2012 illegal data mode
ERRRET alternate return taken if an error occurs.

SUBROUTING REQUIRED:
ADJ1
KDPOP
KDPUSH
UNPACK

COMMENTS:
IARRAY must be a two dimensional array
IDENT (13)* IDENT (14) must not be greater than 256
unless the user has a block data program to allocate more
memory to labeled common area /10/. 
Skip Descriptor Records

PROGRAM TITLE: SKPDSC
VERSION: A
DATE: July 10, 1973
UPDATE: October 15, 1974
AUTHOR: Robert M. Haralick
DOCUMENTED BY: Robert M. Haralick
PROGRAM LANGUAGE: FORTRAN IV
IMPLEMENTED ON: PDP 15/20
PURPOSE:

This program skips the descriptor records of images stored in standard bit compacted form. SKPDSC assumes that SDKINL has been called previously.

ENTRY POINT:

SKPDSC (IDATP, IDENT, IEV, ERRRET)

ARGUMENT LIST:

IDATP file code on which the image resides.
IDENT identification array of 20 words for the image.
IEV 
  = 1 success
  = -2001 illegal file code
  = -2007 EOF
  = -2009 read error
ERRRET Alternate return taken if error occurs

SUBROUTINES REQUIRED:

KDPOP
KDPUSH
Sequential Disc Initializer

PROGRAM TITLE: SDKINL
VERSION: B
DATE: June 30, 1973
UPDATE: October 15, 1974
AUTHOR: Robert M. Haralick
DOCUMENTED BY: Robert M. Haralick
PROGRAM LANGUAGE: FORTRAN IV
IMPLEMENTED ON: PDP 15/20

PURPOSE: This subroutine initializes a PDP 15/20 sequential disc file for input or output. The file is used to store image data in standard bit compacted form. The number of data words will be written in a logical record of at least 20 and the number of bits per data word should not be more than 18.

ENTRY POINT:

SDKINL: (IDAT, FILNM, IDENT, IRDWRT, IEV, ERRRET)

ARGUMENT LIST:

IDAT file code on which file resides.
FILNM array containing the file name.
IDENT identification array of 20 words.
IRDWRT read/write indicator.
   IRDWRT =1 initialize as input file.
   IRDWRT =2 initialize as output file
IEV integer event variable.
   = 1 Success
   = -2001 Illegal file code
   = -2002 Number of bits per point has a illegal value
   = -2003 Frame coordinate and image dimension information not specified in-Ident-array
   = -2004 Illegal request
ERRRET
ALTERNATE RETURN TAKEN IF A ERROR OCCURS

SUBROUTINES REQUIRED:
ENTER
FSTAT
ICEIL
KDPOP
KDPUSH
MAXG
SEEK

= -2005 file does not exist
= -2011 illegal min/max/NZL/nbits combination
= -2012 illegal data mode
Sequential Write

PROGRAM TITLE: SWRITE
VERSION: C
DATE: June 22, 1973
UPDATE: October 15, 1974
AUTHOR: Robert M. Haralick
DOCUMENTED BY: Robert M. Haralick
IMPLEMENTED ON: PDP 15/20

PURPOSE:
This program writes a set of lines or a file of single image data stored in standard bit compacted format. SWRITE assumes that SDKINL has also been called to initialize the file on IDAT.

ENTRY POINT:
SWRITE (IDAT, IARRAY, IDY, IDENT, IEV, ERRRET)

ARGUMENT LIST:
IDAT file code on which 1 image resides.
IARRAY 2-dimensional array (row x column) in which subimage is transferred to program.
IDY number of records for subimage. The number of rows and columns for a record will be taken from IDENT (13) and IDENT (14).
IDENT identification array of 20 words.
IEV integer event variable
IEV = 1 success
IEV = -2001 illegal file code
IEV = -2006 /10/ too small
IEV = -2007 EOF
IEV = -2008 WRITE ERROR
IEV = -2012 illegal data mode
ERRRET ATTENATE RETURN TAKEN IF ERROR OCCURS
SUBROUTINE REQUIRED:

```
ADJ1          KDPUSH
KDPOP         PACK
```

COMMENTS:

IARRAY must be a two dimensional array.
IDENT (13)* IDENT (14) must not be greater than 256
unless the user has a block data program to allocate more
memory to labeled common area /10/.
V. Listing
CERROR  E-R-R-O-R

ASCII ERROR I/O FOR TEXTURE PROGRAM

PROGRAM TITLE          ERROR
VERSION                A
AUTHOR                 CHIN-HUANG CHEN
DATE                   FEBRUARY 1975
UPDATE
PROGRAM LANGUAGE       FORTRAN IV
IMPLEMENTED ON          PDP 15
DOCUMENTED BY           CHIN-HUANG CHEN

PURPOSE

THIS ROUTINE TELLS THE USER EITHER LSTID OR TXTMN IS
IN ERROR ON .DAT SLOT IOU! OR IBOUT

ENTRY POINT           ERROR(IERR, IEV, IOU!, IBOUT)

ARGUMENT LIST
IERR  PARAMETER USED TO DETERMINE EITHER LSTID
      OR TXTMN IS IN ERROR
IEV   INTEGER EVENT VARIABLE
IOU   ERROR MESSAGE OUTPUT .DAT SLOT
IBOUT ALTERNATE ERROR MESSAGE OUTPUT .DAT SLOT

SUBROUTINE ERROR(IERR, IEV, IOU!, IBOUT)
DOUBLE INTEGER FDATE(3)

GO TO (304, 310), IERR
CALL ADATE(FDATE)
WRITE(IOU!, 405) FDATE
405    FORMAT(I1, 3A5)
      IF(IBOUT.NE.IOU!) WRITE(IBOUT, 405) FDATE
      GO TO 200

304    WRITE(IOU!, 305) IEV
      IF(IOU!.NE.IBOUT) WRITE(IBOUT, 305) IEV
305    FORMAT('LSTID ERROR', 15)
      GO TO 400

310    WRITE(IBOUT, 311) IEV
      IF(IBOUT.NE.IOU!) WRITE(IBOUT, 311) IEV
311    FORMAT('TXTMN ERROR IEV=', 15)
400    CALL CLOSE(IBOUT)
200    RETURN
END
PROGRAM SUBROUTINE FPLXIT

TITLE

PROGRAMMER A. SINGH NOVEMBER 1972
UPDATE ROBERT M HARALICK FEBRUARY 1974
GE MONAGHAN 9/20/74
RM HARALICK 10/10/74
CHIN-HUANG CHEN 2/22/75

PURPOSE ADD PCLCT IN ARGUMENT LIST
CHANGE LEX ARRAY TO SINGLE INTEGER
ADD OVERFLOW CHECK ON LEX ARRAY

DOCUMENTATION A. SINGH

COMPUTER REQUIRED ANY

PROGRAM LANGUAGE FORTRAN IV

PURPOSE FPLXIT COMPUTES THE FOUR NEIGHBOUR GRAY TONE MATRICES LEX1, LEX2, LEX3 AND LEX4 FOR ANGLES 90, 0, 135 AND 45 DEGREES RESPECTIVELY. IT WORKS FOR ALL DISTANCES.

METHOD FPLXIT CHECKS THE GRAY LEVELS OF THE NEIGHBOURS OF A CELL, AND INCREMENTS THE CORRESPONDING ELEMENT IN THE ASSOCIATED LEX ARRAY. THE NEIGHBOURS UNDER CONSIDERATION ARE A DISTANCE D & AWAY, WHERE D IS THE DISTANCE FOR THAT RUN OF FPLXIT.

CALLING SEQUENCE CALL FPLXIT(IDATI, IDATA, LEX1, LEX2, LEX3, LEX4, IPT, IDENT, MM1, PCLCT, IEV, IERR1)

ARGUMENTS
IDATI INPUT FILE CODE
IDATA SCRATCH ARRAY FOR MM1 LINES OF THE IMAGE

IMAGE
LEX1, LEX2, LEX3 AND LEX4 ARE THE FOUR LEX ARRAYS FOR THE GRAY TONE MATRICES.

IPT ARRAY WHICH CONTAINS THE POINTERS FOR THE IDATA ARRAY.

IDENT IDENTIFICATION ARRAY FOR THE IMAGE

MM1 SPATIAL DISTANCE + 1

PCLCT PERCENT OF LINES COUNTED

IEV INTEGER EVENT VARIABLE

IEV=-5011 IF NUMPL OR NUMLIN IS LESS THAN TWICE SPATIAL DISTANCE PARAMETER.

IEV=-5010 IF LEX ARRAY IS OVERFLOW

IERR1 ALTERNATE RETURN TAKEN IF ERROR OCCURS
PARAMETERS NUMLIN NUMBER OF LINES IN THE IMAGE
NUMPPL NUMBER OF POINTS PER LINE IN THE IMAGE
IMAX LARGEST GRAY TONE
IMIN LEAST GRAY TONE
LEAST1 =IMIN-1. LEAST1 IS USED FOR NORMALISING
THE GRAY TONES.
NOBL NUMBER OF GRAY TONES
NOBL=IMAX-IMIN+1
NBUBL SIZE OF A LEX ARRAY
NBUBL=NOBL*(NOBL+1)/2

INPUT AND IMAGE READ IN FROM FILE (02).
OUTPUT

RETURNS NORMAL AND ALTERNATE ERROR RETURNS

SUBPROGRAMS INDEX
REQUERED

CALLED BY TXTMN

COMMENTS FPLXIT WORKS FOR ALL SPATIAL DISTANCES. IT DOES THIS
BY HAVING NDIS+1 LINES OF IDATA IN CORE, WHERE NDIS
IS THE SPATIAL DISTANCE PARAMETER.

SUBROUTINE FPLXIT(IDATI, IDATA, LEX1, LEX2, LEX3, LEX4, IPT,
IDENT, MM1, IMNGO, PCLCT, IARRAY, IEV, IERR1)
DOUBLE INTEGER INT, LEX1, LEX2, LEX3, LEX4
DIMENSION IDATA(1,1), LEX1(1), LEX2(1), LEX3(1), LEX4(1), IPT(1)
DIMENSION IDENT(20), IARRAY(1,1,1)

IDATA(NUMPPL, MM1), IPT(MM1)

STACK SUBROUTINE NAME IN ERROR STACK

CALL KPUSH('FPLXIT', 'T')

SET PARAMETERS

NUMPPL=IDENT(6)
NUMLIN=IDENT(7)
IMIN=IDENT(15)
IMAX=IDENT(16)
LEAST1=IMIN-1
NOBL=IMAX-LEAST1
NBUBL=NOBL*(NOBL+1)/2

INITIALISE THE LEX ARRAYS TO ZERO

DO 14 I=1, NBUBL
LEX1(I)=0
LEX2(I)=0
LEX3(I)=0
LEX4(I)=0

CHECK IF SIZE OF IMAGE IS TOO SMALL,
RELATIVE TO THE DISTANCE PARAMETER MM

MM=MM1-1
MM2=MM*2
IEV=-5011
IF(NUMPPL.LT.MM2 OR. NUMLIN.LT.MM2) GO TO 9999

NUMPMM=NUMPPL-MM
NUMLMM=NUMLIN-MM

READ IN THE FIRST MM1 LINES OF THE IMAGE
AND SET UP POINTERS

DO 110 IY=1,MM1
IPT(IY)=IY
CALL RREAD(IDAT1,ARRAY,IMGNO,IY,1,IDENT,IEV,ERR1)
DO 111 LY=1,NUMPPL
111 IDATA(LY,IY)= ARRAY(1,1,LY)
110 CONTINUE

SETTING UP POINTERS FOR THE FIRST AND
LAST ROWS OF THE IMAGE ARRAYS

IST=IPT(1)
LST=IPT(MM1)

GO THROUGH ALL BUT MM ROWS OF IMAGE

NOVFLO=131017
INT=3856347531

NEXT=MM1+1

DO 105 LCNT = NEXT,NUMLIN
IF(RCM(INT).GT.PCLCT) GO TO 105

SKIP LINES RANDOMLY BY USING RANDOM NUMBER
GENERATOR RCM EXTERNAL FUNCTION

GO THROUGH EACH ROW MM TIMES. THE FIRST
SET OF MM COLUMNS ARE HANDLED SEPARATELY

DO 120 IRW=1,MM
IRM = IRW + MM

Set I, L, J and K equal to the (normalised) values of gray tones of resolution cells in positions A, B, C and D as in the diagram --

A C
B D

Where A initially is the upper left corner cell. The cells are a distance MM apart.

I = IDATA(IRW, IST) - LEAST1
L = IDATA(IRW, LST) - LEAST1
K = IDATA(IRM, LST) - LEAST1
J = IDATA(IRM, IST) - LEAST1

Put the two dimensional information into one dimensional form. The function needed to convert a double subscripted array, IMM(X,Y), into a single subscripted array, IMM(Z), is of the form G(X) + F(Y), where G(X) = (X-1)*X/2 and F(Y) = Y. Therefore

Z = (X-1)*X/2 + Y

This is done in the program by the external function INDEX(X,Y).

Since the order of occurrence of the gray tones belonging to a resolution cell pair is immaterial, the arrays are symmetric. We let the larger of the two have the first subscript, i.e., the array is stored in lower triangular form. The order of the subscripting is as follows:

IMM(1,1) = IMM(1),
IMM(2,1) = IMM(2),
IMM(2,2) = IMM(3),
IMM(3,1) = IMM(4),

IMM(NOBL, NOBL) = IMM(NBUBL).

The scanning procedure, that is the method by which the pairwise comparisons are made, is described below for the general case. Consider a resolution cell with spatial coordinates (M,N), and call this cell I. The scanning operation begins in the upper left hand corner of the image and it then proceeds by comparing the gray
TONES OF &I& WITH AT MOST FOUR GRAY TONES
OF ITS NEIGHBOURING RESOLUTION CELLS.

THAT &I& NEVER NEEDS TO CONSIDER MORE
THAN FOUR NEIGHBOURS CAN BE SEEN FROM
THE DIAGRAM OF THE SEARCH PATTERN SHOWN
BLOW --

```
I J
M L K
```

ON A GIVEN ITERATION, &I& WILL LOOK FIRST
AT ITS VERTICAL NEIGHBOUR (&L&), NEXT
AT ITS HORIZONTAL NEIGHBOUR (&J&), THIRD
AT ITS LOWER RIGHT NEIGHBOUR (&K&) AND
FOURTH AT ITS LOWER LEFT DIAGONAL
NEIGHBOUR (&M&). &I& THEN MOVES INTO
THE POSITION OF THE RIGHT RESOLUTION
CELL OF THE PREVIOUSLY SCANNED FIRST
ROW (THE POSITION OCCUPIED BY &J&).

THE OPERATION IS REPEATED UNTIL ALL
NEIGHBOURING PAIRS OF RESOLUTION CELLS
HAVE BEEN EXAMINED. THE PROCEDURE IS
FURTHER REPEATED FOR CELLS SKIPPED OVER
IF THE SPATIAL DISTANCE IS GREATER THAN
ONE, TILL ALL CELLS HAVE BEEN EXHAUSTED.

```
IL=INDEX(I,L)
```

COUNT VERTICALLY ADJACENT (90-DEGREE)
NEIGHBOUR

```
LEX1(IL)=LEX1(IL)+1
I,J=INDEX(I,J)
```

COUNT HORIZONTALLY ADJACENT (0-DEGREE)
NEIGHBOUR

```
LEX2(IJ)=LEX2(IJ)+1
I,K=INDEX(I,K)
```

COUNT LEFT DIAGONALLY ADJACENT
(135-DEGREE) NEIGHBOUR

```
LEX3(IK)=LEX3(IK)+1
```

NOW ITERATE DOWN THE ROW

```
DO 130 N=IRM, NUMPMM, MM
NMM=N+MM
I=J
```

165
M=L
L=K

J=IDATA(NMM, IST) - LEAST1
K=IDATA(NMM, LST) - LEAST1

IL=INDEX(I, L)

COUNT VERTICALLY ADJACENT (90-DEGREE) NEIGHBOUR

LEX1(IL)=LEX1(IL)+1

IJ=INDEX(I, J)

COUNT HORIZONTALLY ADJACENT (0-DEGREE) NEIGHBOUR

LEX2(IJ)=LEX2(IJ)+1

IK=INDEX(I, K)

COUNT LEFT DIAGONALLY ADJACENT (135-DEGREE) NEIGHBOUR

LEX3(IK)=LEX3(IK)+1

IM=INDEX(I, M)

COUNT RIGHT DIAGONALLY ADJACENT (45-DEGREE) NEIGHBOUR

LEX4(IM)=LEX4(IM)+1

130 CONTINUE

COMPUTE THE LAST SET OF MM COLUMNS SEPARATELY

I=J
M=L
L=K

IL=INDEX(I, L)

COUNT VERTICALLY ADJACENT (90-DEGREE) NEIGHBOUR

LEX1(IL)=LEX1(IL)+1

IM=INDEX(I, M)

COUNT RIGHT DIAGONALLY ADJACENT (45-DEGREE) NEIGHBOUR
LEX4(IM) = LEX4(IM) + 1

120 CONTINUE
C
C SHIFT THE POINTERS FOR THE TWO ARRAYS.
C THIS IS DONE BY A CYCLIC ROTATION.
C THE POINTER ARRAYS IPT IS SUCH THAT AT ANY
C TIME THE ITH LOCATION OF IPT CONTAINS
C THE POINTER TO THE ITH POSITION OF THE
C LINE IN IDATA OR JDATA ARRAY. FOR
C EXAMPLE, IF IPT(2) = 4 THEN THE FOURTH LINE
C OF THE PHYSICAL JDATA ARRAY IS ACTUALLY
C THE SECOND LINE, AT THAT MOMENT.
C
IF (LCNT .EQ. NUMLIM) GO TO 105
C
C ROTATE IN A CYCLIC MANNER
C
ITEMP = IPT(1)
DO 135 IB = 1, MM
135 IPT(IB) = IPT(IB + 1)
IPT(MM1) = ITEMP
C
SET UP THE POINTERS TO THE FIRST AND
LAST ROWS OF THE TWO IMAGE ARRAYS
C
IST = IPT(1)
LST = IPT(MM1)
C
READ IN A NEW LINE INTO THE IDATA ARRAY
C
CALL RREAD(IDATI, IARRAY, IMGNO, LCNT, 1, IDENT, IEV, ERR1)
\DO 112 LY = I/NUMPPL
112 IDATA(LY, LST) = IARRAY(1, 1, LY)
IF (LEX1(IL).GT.NOVFLO) GO TO 106
IF (LEX2(IJ).GT.NOVFLO) GO TO 106
IF (LEX3(IK).GT.NOVFLO) GO TO 106
IF (LEX4(IM).GT.NOVFLO) GO TO 106
C
105 CONTINUE
GO TO 108
106 IEV = -5010
RETURN ERR1
C
C THE LAST MM ROWS ARE COMPUTED SEPARATELY
C
108 DO 140 LR = 1, MM
ISR = IPT(LR + 1)
C
DO 142 IRW = 1, MM
I = IDATA(IRW, ISR) - LEAST1

ORIGINAL PAGE IS OF POOR QUALITY
DO LOOP TO WORK DOWN A ROW, COMPUTING
THE 0-DEGREE NEIGHBOUR ONLY

DO 144 N=IRW, NUMPMM, MM
NMM=N+MM
J=IDATA(NMM, ISR)-LEAST1
IJ=INDEX(I, J)

COUNT HORIZONTALLY ADJACENT (0-DEGREE)
NEIGHBOUR

LEX2(IJ)=LEX2(IJ)+1

144 I=J
142 CONTINUE
140 CONTINUE

DOUBLE THE DIAGONAL TO MAKE EVERYTHING
COME OUT RIGHT

NOBL=IMAX-IMIN+1
DO 12 I=1, NOBL
II=INDEX(I, I)
LEX1(II)=LEX1(II)*2
LEX2(II)=LEX2(II)*2
LEX3(II)=LEX3(II)*2
LEX4(II)=LEX4(II)*2
12 CONTINUE

CALL CLOSE(IDATI)
CALL KDPOP
RETURN

ERROR

9999 CALL CLOSE(IDATI)
RETURN IERR1

END
SUBROUTINE FUNC1

PROGRAM SUBROUTINE FUNC1

TITLE

PROGRAMMER A. SINGH OCTOBER 1972

UPDATE ROBERT M HARALICK FEBRUARY 1974

CHIN-HUANG CHEN FEBRUARY 22, 1975

DOCUMENTATION A. SINGH

COMPUTER REQUIRED ANY

PROGRAM LANGUAGE FORTRAN IV

PURPOSE FUNC1 COMPUTES THE SUM PROBABILITY FEATURE OF THE IMAGE.


CALLING SEQUENCE CALL FUNC1(LEX1, LEX2, LEX3, LEX4, FUNC, NBUBL)

ARGUMENTS LEX1, LEX2, LEX3 AND LEX4 ARE THE FOUR TRIANGULAR GRAY TONE MATRICES.

FUNCTIONS THIS IS A TWO DIMENSIONAL ARRAY WHERE THE RESULTS OF SUBROUTINE FUNC1 ARE STORED. THESE ARE STORED IN TRIANGULAR FORM LIKE THE LEX ARRAYS. THE SECOND SUBSCRIPT CORRESPONDS TO THE DIRECTION (K=1, 2, 3 OR 4 IS 90, 0, 135 OR 45 DEGREES RESPECTIVELY), WHILE THE FIRST SUBSCRIPT, IJ=INDEX(I, J), IS THE LOCATION OF THE GRAY TONE PAIR (I, J) AS IN THE LEX ARRAYS.

PARAMETERS NOBL NUMBER OF GRAY TONES

AND ARRAYS R1, R2, R3, R4 ARE THE RECIPROCAL OF THE TOTAL NUMBER OF GRAY TONE PAIRS FOR EACH OF THE FOUR DIRECTIONS.

INPUT AND NONE

OUTPUT RETURN NO ERROR RETURNS
SUBPROGRAMS  INDEX
REQUIRED
CALLED BY  TXTMN

SUBROUTINE FJSINC (LEX1, LEX2, LEX3, LEX4, FUNC, NBUBL, NOBL)
   DOUBLE INTEGER FUNC, LEX1, LEX2, LEX3, LEX4

   DIMENSION LEX1(1), LEX2(1), LEX3(1), LEX4(1), FUNC(1,4)

   FUNC(NBUBL, 4)

NOW COMPUTE FUNC
TO DETERMINE THE TOTAL NUMBER OF PAIRS IN A GIVEN DIRECTION

   R1=0.
   R2=0.
   R3=0.
   R4=0.

   DO 5 I=1, NOBL
       DO 5 J=1, NOBL
           IJ=INDEX(I, J)
           TEMP=LEX1(IJ)
           R1=R1+TEMP
           TEMP=LEX2(IJ)
           R2=R2+TEMP
           TEMP=LEX3(IJ)
           R3=R3+TEMP
           TEMP=LEX4(IJ)
           R4=R4+TEMP
           CONTINUE

   TO COMPUTE AVERAGE

   AVG1=0.
   AVG2=0.
   AVG3=0.
   AVG4=0.

   DO 6 I=1, NOBL
       DO 6 J=1, NOBL
           IJ=INDEX(I, J)
           TEMP=LEX1(IJ)
           AVG1=AVG1+TEMP
           TEMP=LEX2(IJ)
           AVG2=AVG2+TEMP
           TEMP=LEX3(IJ)
           AVG3=AVG3+TEMP

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TEMP = LEX4(I, J)
AVG4 = AVG4 + TEMP * TEMP
CONTINUE

AVG1 = AVG1 / R1
AVG2 = AVG2 / R2
AVG3 = AVG3 / R3
AVG4 = AVG4 / R4

DO 7 I = 1, NOBL
DO 7 J = I, NOBL
IJ = INDEX(I, J)
TEMP = LEX1(I, J)
FUNC(I, J, 1) = (TEMP - AVG1) * 1000. / R1
TEMP = LEX2(I, J)
FUNC(I, J, 2) = (TEMP - AVG2) * 1000. / R2
TEMP = LEX3(I, J)
FUNC(I, J, 3) = (TEMP - AVG3) * 1000. / R3
TEMP = LEX4(I, J)
FUNC(I, J, 4) = (TEMP - AVG4) * 1000. / R4
7 CONTINUE

RETURN
END
PROGRAM SUBROUTINE FUNC2

TITLE

PROGRAMMER A. SINGH OCTOBER 1972
UPDATE ROBERT M HARALICK FEBRUARY 1974
GE MONAGHAN OCTOBER 1974
CHIN-HUANG CHEN FEBRUARY 22, 1975

DOCUMENTATION A. SINGH

COMPUTER REQUIRED ANY

PROGRAM LANGUAGE FORTRAN IV

PURPOSE FUNC2 COMPUTES THE GRADIENT ENTROPY FEATURE OF THE IMAGE.

METHOD FUNC2 FIRST COMPUTES THE TOTAL NUMBER OF PAIRS FOR EACH DIRECTION. THE GRADIENT ENTROPY COMPONENT IS

\[ \text{A} \log(1 + |I - J|) \times \text{A} \log(P(I, J)) \], WHERE THE PROBABILITY IS \( P(I, J) = \text{LEX}(IJ)/\text{TOTAL NUMBER OF PAIRS FOR THE K LEX ARRAY} \). IJ = INDEX(I, J).

CALLING SEQUENCE CALL FUNC2(LEX1, LEX2, LEX3, LEX4, FUNC, NBUBL)

ARGUMENTS LEX1, LEX2, LEX3 AND LEX4 ARE THE FOUR TRIANGULAR GRAY TONE MATRICES.

FUNCTION THIS IS A TWO DIMENSIONAL ARRAY WHERE THE RESULTS OF SUBROUTINE FUNC2 ARE STORED.

 THESE ARE STORED IN TRIANGULAR FORM LIKE THE LEX ARRAYS. THE SECOND SUBSCRIPT CORRESPONDS TO THE DIRECTION (K=1, 2, 3 OR 4 IS 90, 0, 135 OR 45 DEGREES RESPECTIVELY), WHILE THE FIRST SUBSCRIPT, IJ=INDEX(I, J), IS THE LOCATION OF THE GRAY TONE PAIR (I, J) AS IN THE LEX ARRAYS.

NBUBL SIZE OF A LEX ARRAY
NBUBL=NOBL*(NOBL+1)/2

PARAMETERS AND ARRAYS NOBL NUMBER OF GRAY TONES
R1, R2, R3, R4 ARE THE RECIPROCAL OF THE TOTAL NUMBER OF GRAY TONE PAIRS FOR EACH OF THE FOUR DIRECTIONS.

RL1, 2, 3, 4 ARE THE PROBABILITIES P(I, J), FOR THE FOUR DIRECTIONS, FOR GRAY TONE I TO OCCUR NEXT TO GRAY TONE J IN A PARTICULAR DIRECTION.
INPUT AND  
OUTPUT  
RETURNS  
NO ERROR RETURNS  
SUBPROGRAMS  
INDEX  
REQUIRED  
CALLED BY  
TXTMN

SUBROUTINE FUNC2(LEX1, LEX2, LEX3, LEX4, FUNC, NBU7L, NOBL)

DOUBLE INTEGER FUNC, LEX1, LEX2, LEX3, LEX4
DIMENSION LEX1(1), LEX2(1), LEX3(1), LEX4(1), FUNC(1, 4)

FUNC(NBU7L, 4)

NOW COMPUTE FUNC

TO DETERMINE THE TOTAL NUMBER OF PAIRS IN A GIVEN DIRECTION

R1=0
R2=0
R3=0
R4=0.

DO 5 I=1, NOBL
   DO 5 J=1, NOBL
      IJ=INDEX(I, J):
      TEMP=LEX1(IJ)
      R1=R1+TEMP
      TEMP=LEX2(IJ)
      R2=R2+TEMP
      TEMP=LEX3(IJ)
      R3=R3+TEMP
      TEMP=LEX4(IJ)
      R4=R4+TEMP
  5 CONTINUE

TO GET R1, R2, R3, R4 TO SAVE DIVISION?

R1=1./R1
R2=1./R2
R3=1./R3
R4=1./R4
TO COMPUTE ANGULAR MOMENTUM COMPONENT

DO 2 I=1, NOBL
DO 2 J =1, NOBL
I,J=INDEX(I, J)
TEMP=LEX1(I,J)
RL1=TEMP*R1
TEMP=LEX2(I,J)
RL2=TEMP*R2
TEMP=LEX3(I,J)
RL3=TEMP*R3
TEMP=LEX4(I,J)
RL4=TEMP*R4
FUNC(I,J,1)=ALOG(1. +ABS(FLOAT(I-J)))*ALOG(1. E-9+RL1)*200.
FUNC(I,J,2)=ALOG(1. +ABS(FLOAT(I-J)))*ALOG(1. E-9+RL2)*200.
FUNC(I,J,3)=ALOG(1. +ABS(FLOAT(I-J)))*ALOG(1. E-9+RL3)*200.
FUNC(I,J,4)=ALOG(1. +ABS(FLOAT(I-J)))*ALOG(1. E-9+RL4)*200.

2 CONTINUE

RETURN
END
FUNCTION

PROGRAM SUBROUTINE FUNC3

TITLE

PROGRAMMER A. SINGH OCTOBER 1972

UPDATE ROBERT N HARALICK FEBRUARY 1974

GE MONAGHAN OCTOBER 1974

CHIN-HUANG CHEN FEBRUARY 22, 1975

DOCUMENTATION A. SINGH

COMPUTER REQUIRED ANY

PROGRAM LANGUAGE FORTRAN IV

PURPOSE FUNC3 COMPUTES THE ENTROPY FEATURE OF THE IMAGE.

METHOD

FUNC3 FIRST COMPUTES THE TOTAL NUMBER OF PAIRS FOR EACH DIRECTION. THE ENTROPY COMPONENT IS THEN

\[ -P(I, J) \times \text{ALOG}(P(I, J)) \]

WHERE THE PROBABILITY P(I, J) IS

\[ P(I, J) = \text{LEXK}(IJ)/(\text{TOTAL NUMBER OF PAIRS FOR THE K LEX ARRAY}) \]

IJI = INDEX(I, J)

CALLING SEQUENCE CALL FUNC3(LEX1, LEX2, LEX3, LEX4, FUNC, NBUBL)

ARGUMENTS LEX1, LEX2, LEX3 AND LEX4 ARE THE FOUR TRIANGULAR GRAY TONE MATRICES.

FUNC THIS IS A TWO DIMENSIONAL ARRAY WHERE THE RESULTS OF SUBROUTINE FUNC3 ARE STORED. THESE ARE STORED IN TRIANGULAR FORM LIKE THE LEX ARRAYS. THE SECOND SUBSCRIPT CORRESPONDS TO THE DIRECTION (K=1, 2, 3 OR 4 IS 90, 0, 135 OR 45 DEGREES RESPECTIVELY).

WHILE THE FIRST SUBSCRIPT, IJI=INDEX(I, J), IS THE LOCATION OF THE GRAY TONE PAIR (I, J) AS IN THE LEX ARRAYS.

NBUBL SIZE OF A LEX ARRAY

NBUBL=NOBL*(NOBL+1)/2

PARAMETERS NOBL NUMBER OF GRAY TONES

AND ARRAYS R1, R2, R3, R4 ARE THE RECIPROCAL THE TOTAL NUMBER OF GRAY TONE PAIRS FOR EACH OF THE FOUR DIRECTIONS.

RL1,2,3,4 ARE THE PROBABILITIES P(I, J), FOR THE FOUR DIRECTIONS, FOR GRAY TONE I TO OCCUR NEXT TO GRAY TONE J IN A PARTICULAR DIRECTION.

INPUT AND NONE
OUTPUT

RETURNS NO ERROR RETURNS

SUBPROGRAMS REQUIRED

CALLED BY TXTMN

SUBROUTINE FUNC3(LEX1, LEX2, LEX3, LEX4, FUNC, NBUBL, NOBL)

DOUBLE INTEGER FUNC, LEX1, LEX2, LEX3, LEX4

DIMENSION LEX1(1), LEX2(1), LEX3(1), LEX4(1), FUNC(1, 4)

NOW COMPUTE FUNC

TO DETERMINE THE TOTAL NUMBER OF PAIRS IN A GIVEN DIRECTION

R1=0.
R2=0.
R3=0.
R4=0.

DO 5 I=1, NOBL
DO 5 _I=1, NOBL
   I J=INDEX(I, _I)
   TEMP=LEX1(I J)
   R1=R1+TEMP
   TEMP=LEX2(I J)
   R2=R2+TEMP
   TEMP=LEX3(I J)
   R3=R3+TEMP
   TEMP=LEX4(I J)
   R4=R4+TEMP
   5 CONTINUE

TO GET R1, R2, R3, R4 TO SAVE DIVISIONS

R1=1./R1
R2=1./R2
R3=1./R3
R4=1./R4

TO COMPUTE ENTROPY COMPONENTS

DO 2 I=1, NOBL
DO 2 _I=1, NOBL
   I J=INDEX(I, _I)

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TEMP = LEX1(IJ)
RL1 = TEMP*R1
TEMP = LEX2(IJ)
RL2 = TEMP*R2
TEMP = LEX3(IJ)
RL3 = TEMP*R3
TEMP = LEX4(IJ)
RL4 = TEMP*R4

C

IF(RL1 LT 0.000001) GO TO 31
FUNCTION(I,J,1) = (-RL1*ALOG(RL1))#200.
31 IF(RL2 LT 0.000001) GO TO 32
FUNCTION(I,J,2) = (-RL2*ALOG(RL2))#200.
32 IF(RL3 LT 0.000001) GO TO 33
FUNCTION(I,J,3) = (-RL3*ALOG(RL3))#200.
33 IF(RL4 LT 0.000001) GO TO 2
FUNCTION(I,J,4) = (-RL4*ALOG(RL4))#200.
2 CONTINUE
C
RETURN
END
SUBROUTINE FUNC4

ROBERT M HARALICK MAY 1973
GE MONAGHAN OCTOBER 1974
CHIN-HUANG CHEN FEBRUARY 22, 1975

FORTRAN IV

FUNC4 COMPUTES THE GRADIENT FEATURE OF THE IMAGE.

CALL FUNC4(LEX1, LEX2, LEX3, LEX4, FUNC, N8U8L)

LEX1, LEX2, LEX3 AND LEX4 ARE THE FOUR TRIANGULAR GRAY TONE MATRICES.
FUNC THIS IS A TWO DIMENSIONAL ARRAY WHERE THE RESULTS OF SUBROUTINE FUNC4 ARE STORED.
LEX ARRAYS THE SECOND SUBSCRIPT CORRESPONDS TO THE DIRECTION (K=1,2,3 OR 4 IS 90,0,135 OR 45 DEGREES RESPECTIVELY),
WHILE THE FIRST SUBSCRIPT, IJ=INDEX(I,J), IS THE LOCATION OF THE GRAY TONE PAIR (I,J) AS IN THE LEX ARRAYS.
N8U8L SIZE OF A LEX ARRAY
N8U8L=NO8L*(NO8L+1)/2

NO8L NUMBER OF GRAY TONES
R1, R2, R3, R4 ARE THE RECIPROCAL OF THE TOTAL NUMBER OF GRAY TONE PAIRS FOR EACH OF THE FOUR DIRECTIONS
RL1, 2, 3, 4 ARE THE PROBABILITIES P(I,J), FOR THE FOUR DIRECTIONS, FOR GRAY TONE I TO OCCUR NEXT TO GRAY TONE J IN A PARTICULAR DIRECTION.
INPUT AND NONE
OUTPUT
RETURNS NO ERROR RETURNS
SUBPROGRAMS INDEX
REQUIRED
CALLED BY TXTMN

SUBROUTINE FUN04(LEX1, LEX2, LEX3, LEX4, FUNC, N8U8L, NO8L)
DOUBLE INTEGER FUNC, LEX1, LEX2, LEX3, LEX4

DIMENSION LEX1(1), LEX2(1), LEX3(1), LEX4(1), FUNC(1, 4)

FUNCTION(N8U8L, 4)

AF=1./FLOAT(N8U8L)

NOW COMPUTE FUNC
TO DETERMINE THE TOTAL NUMBER OF PAIRS IN A GIVEN DIRECTION

R1=0.
R2=0.
R3=0.
R4=0.
DO 5 I=1, NO8L
DO 5 J=1, NOEL.
IJ=INDEX(I, J)
TEMP=LEX1(IJ)
R1=R1+TEMP
TEMP=LEX2(IJ)
R2=R2+TEMP
TEMP=LEX3(IJ)
R3=R3+TEMP
TEMP=LEX4(IJ)
R4=R4+TEMP
5 CONTINUE

TO GET R1, R2, R3, R4 TO SAVE DIVISIONS
R1=1./R1
R2=1./R2
R3=1./R3
R4=1./R4

TO COMPUTE ANGULAR MOMENTUM COMPONENT

DO 2 I=1, NO8L
DO 2 J-I, NOEL.
IJ=INDEX(I, J)
TEMP = LEX1(I,J)
TEMP = LEX2(I,J)
FUNC(I,J,1) = (ABS(FLOAT(I-J))/(AF+TEMP*R1)) * 200.
TEMP = LEX3(I,J)
FUNC(I,J,2) = (ABS(FLOAT(I-J))/(AF+TEMP*R2)) * 200.
TEMP = LEX4(I,J)
FUNC(I,J,3) = (ABS(FLOAT(I-J))/(AF+TEMP*R3)) * 200.

2 CONTINUE
C
RETURN
C
END
PROGRAM TITLE:        FUNCT
VERSION:               A
DATE:                   NOVEMBER 23, 1973
AUTHOR:                 ROBERT M HARALICK
UPDATE:                 CHIN-HUANG CHEN 2/22/75
DOCUMENTED BY:          ROBERT M HARALICK
IMPLEMENTED ON:         PDP 15
LANGUAGE:               FORTRAN

PURPOSE:
THIS SUBROUTINE PREPARES NORMALIZED LEX
ARRAYS WHICH HAVE BEEN EQUAL PROBABILITY QUANTIZED ACCORDING
TO THEIR DIAGONAL ELEMENTS AND PUTS THE RESULTS IN FUNC ARRAY.

ENTRY POINT:          FUNCT(LEX1, LEX2, LEX3, LEX4, FUNC, NBUBL)

ARGUMENT LIST:
LEX1 IS VERTICAL CO-OCCURENCE MATRIX
LEX2 IS HORIZONTAL CO-OCCURENCE MATRIX
LEX3 IS 135 DEGREE CO-OCCURENCE MATRIX
LEX4 IS 45 DEGREE CO-OCCURENCE MATRIX
FUNC IS THE NORMALIZED AND QUANTIZED
CO-OCCURENCE MATRICES
NBUBL IS THE SIZE OF THE LEX ARRAYS

SUBROUTINE FUNCT(LEX1, LEX2, LEX3, LEX4, FUNC, NBUBL, NOBL)
DOUBLE INTEGER FUNC, LEX1, LEX2, LEX3, LEX4, F

DIMENSION LEX1(1), LEX2(1), LEX3(1), LEX4(1), FUNC(1, 4), F(1)
DATA INTVD /8/

CALL ADJ1(F, FUNC(1, 1))
CALL LEXEQP(LEX4, NOBL, INTVD, F)
DO 12 I=1, NBUBL
12       FUNC(1, 4)=F(I)
CALL LEXEQP(LEX3, NOBL, INTVD, F)
DO 13 I=1, NBUBL
13       FUNC(1, 3)=F(I)
CALL LEXEQP(LEX2, NOBL, INTVD, F)
DO 14 I=1, NBUBL
14       FUNC(1, 2)=F(I)
CALL LEXEQP(LEX1, NOBL, INTVD, F)
RETURN
DO 15 I=1, NBUBL

ORIGINAL PAGE IS
OF POOR QUALITY.
15 FUNC(I, I) = F(I)
END
EQUAL PROBABILITY QUANTIZE THE DIAGONAL OF THE LEX ARRAY

ENTRY POINT: LEXEQP(LEX, NOBL, INTVD, FUNC)

ARGUMENT LIST:
LEX IS THE LEX ARRAY
NOBL IS THE NUMBER OF BRIGHTNESS LEVELS
INTVD IS THE NUMBER OF DESIRED QUANTIZED LEVELS
FUNC IS THE NORMALIZED AND QUANTIZED LEX ARRAY.

SUBROUTINE LEXEQP(LEX, NOBL, INTVD, FUNC)
DOUBLE INTEGER FUNC, LEX

DIMENSION LEX(1), FUNC(1)
COMMON /IO/NSIZE,F(16),FLQ(16), MEX(136), IT(176)

PUT CUMULATIVE DISTRIBUTION OF DIAGONAL ELEMENTS OF LEX ARRAY INTO F.
## Construct the Quantized Lex Matrix

**ROBL**=FLOAT(NOBL)
CALL EQPQNT(NOBL, INTVD, F, FLQ, ROBL, O, O1)

**CONSTRUCT THE QUANTIZED LEX MATRIX**

\[ \text{J1}=1 \]
\[ \text{DO 4 J}=1, \text{INTVD} \]
\[ \text{IF(J, EQ. 1) GO TO 12} \]
\[ \text{J1}=\text{FLQ}(\text{J-1})+1. \]
\[ \text{12 CONTINUE} \]
\[ \text{J2}=\text{FLQ}(\text{J}) \]
\[ \text{K1}=1 \]
\[ \text{DO 7 K}=1, \text{J} \]
\[ \text{IF(K, EQ. 1) GO TO 13} \]
\[ \text{K1}=\text{FLQ}(\text{K-1})+1. \]
\[ \text{13 CONTINUE} \]
\[ \text{K2}=\text{FLQ}(\text{K}) \]
\[ \text{MM}=\text{INDEX}(\text{J, K}) \]
\[ \text{MEX(MM)}=0 \]
\[ \text{DO 10 JJ}=\text{J1}, \text{J2} \]
\[ \text{DO 10 KK}=\text{K1}, \text{K2} \]
\[ \text{LL}=\text{INDEX}(\text{JJ, KK}) \]
\[ \text{MEX(MM)}=\text{MEX(MM)}+\text{LEX(LL)} \]
\[ \text{10 CONTINUE} \]
\[ \text{CONTINUE} \]
\[ \text{CONTINUE} \]

**DEFINE THE QUANTIZING FUNCTION**

\[ \text{J}=1 \]
\[ \text{DO 3 I}=1, \text{NOBL} \]
\[ \text{IF(FLOAT(I). LE. FLQ(J)) GO TO 5} \]

**GREY TONE I BELONGS TO THE NEXT QUANTIZING INTERVAL.**

\[ \text{J}=\text{J+1} \]

**GREY TONE I BELONGS TO THE JTH QUANTIZING INTERVAL.**

\[ \text{5 IT(I)}=\text{J} \]
\[ \text{3 CONTINUE} \]

**TRANSFER IT TO FUNC.**

\[ \text{DO 11 I}=1, \text{NOBL} \]
\[ \text{II}=\text{IT(I)} \]
\[ \text{DO 11 J}=1, \text{NOBL} \]
\[ \text{JJ}=\text{IT(J)} \]
\[ \text{N}=\text{INDEX}(\text{I, J}) \]
\[ \text{MM}=\text{INDEX}(\text{II, JJ}) \]
\[ \text{TEMP}=\text{MEX(MM)} \]
11 CONTINUE
   FUNC(N)=TEMP*S*1000.
   RETURN
   END
CPLXIT

PROGRAM SUBROUTINE PLXIT

TITLE

PROGRAMMER A. SINGH NOVEMBER 8/72

MODIFIED 5/14/73 ROBERT M HARALICK
7/10/73
2/2/74
8/10/74 GE MONAGHAN
10/10/74 RM HARALICK
2/22/75 CHIN-HUANG CHEN

DOCUMENTATION A. SINGH

COMPUTER PDP 15

REQUIRED

PROGRAM FORTRAN IV

LANGUAGE

PURPOSE PLXIT COMPUTES THE JDATA IMAGE

METHOD PLXIT COMPUTES THE JDATA IMAGE UTILISING THE RESULTS
OF FPLXIT AND FUNC. LET G(I,J) BE THE GRAY LEVEL OF
THE JTH RESOLUTION CELL IN THE ITH LINE OF THE
CONSIDERED IMAGE (IDATA), AND LET V(I,J) BE THE JTH
RESOLUTION CELL IN THE ITH LINE OF THE JDATA IMAGE.
THEN --

V(I,J) = FUNC(G(I,J+L),G(I-L,J+L),G(I-L,J),G(I-L,J-L),
G(I,J-L),G(I+L,J-L),G(I+L,J),G(I+L,J+L)),

WHERE FUNC IS A FUNCTION (SUCH AS FUNC1, FUNC2 OR
FUNC3) PROVIDED BY THE USER.
L = 1,2,3..., IS THE
SEPARATION BETWEEN CELLS. L=1, MEANS NEAREST
NEIGHBOUR, L=2, MEANS NEXT TO NEAREST NEIGHBOUR ETC.
PLXIT WORKS FOR ALL POSITIVE L.

ENTRY POINT PLXIT(IDATI, IDATJ, IDATA, JDATA, IDENT, FUNC, IPT
NBUBL, MM1, NXMIN, NXMAX, JDENT, IEV, IERR1)

ARGUMENTS IDATI DAT SLOT WHERE ORIGINAL IMAGE RESIDES
IDATJ DAT SLOT FOR JDATA IMAGE
IDATA SCRATCH ARRAY WHERE THE ORIGINAL IMAGE IS
READ IN.
JDATA INTEGER ARRAY WHERE THE JDATA IMAGE IS
GENERATED AND STORED BEFORE BEING WRITTEN
ONT0 THE TAPE (03).
IDENT IDENTIFICATION ARRAY OF IDATA
JDENT IDENTIFICATION ARRAY OF JDATA
FUNC A TWO DIMENSION ARRAY CONTAINING THE
RESULTS OF THE EXTERNAL FUNCTION PROGRAM.

THE SECOND INDEX DETERMINES THE DIRECTION,
WHILE THE FIRST ONE CORRESPONDS TO THE
ELEMENT IN THE ASSOCIATED LEX ARRAY.

IPT
ARRAY WHICH CONTAINS THE POINTERS FOR
THE IDATA AND THE JDATA ARRAYS

NBUBL
SIZE OF A LEX ARRAY

NBUBL=NOBL*(NOBL+1)/2, WHERE NOBL IS THE
NUMBER OF GRAY TONES.

MM1
SPATIAL DISTANCE + 1

NXMIN
MINIMUM JDATA VALUE

NXMAX
MAXIMUM JDATA VALUE

IEV
INTEGER EVENT VARIABLE

IEV=-5011 IF NUMPPL OR NUMLIN IS LESS THAN
TWICE MM.

PARAMETERS
NUMPPL
NUMBER OF POINTS PER LINE IN THE INPUT IMAGE

AND ARRAYS
IMAX
LARGEST GRAY TONE ON INPUT FILE

IMIN
LEAST GRAY TONE ON INPUT FILE

LEAST1
IMIN-1. LEAST1 IS USED FOR NORMALIZING
THE GRAY TONES.

NOBL
NUMBER OF GRAY TONES

NOBL=IMAX-IMIN+1

RETURNS
NO ERROR RETURNS

SUBPROGRAMS
INDEX

REQUIRED
TXTMN

CALLED BY

COMMENTS
PLXIT WORKS FOR ALL SPATIAL DISTANCES. IT DOES
THIS BY HAVING MM + 1 LINES OF IDATA IN THE CORE,
WHERE MM IS THE SPATIAL DISTANCE PARAMETER.

SUBROUTINE PLXIT(IDATI, IDATJ, IDATA, JDATA, IDENT, FUNC, IPT, NBUBL, MM1, I)

IMINO, NXMIN, NXMAX, JIDENT, IARRAY, IEV, IERR1)

DOUBLE INTEGER FUNC

DIMENSION IDATA(1,1), JDATA(1,1), FUNC(1,1), IPT(1), IDENT(20)

DIMENSION JIDENT(20), IARRAY(1,1,1)

IDATA(NUMPPL, MM1), JDATA(NUMPPL, MM1), FUNC(NBUBL, 4), IPT(MM1)

STACK SUBROUTINE NAME IN ERROR STACK

CALL KDPUSH(‘PLXIT’, ‘‘)

SET PARAMETERS
NUMPPPL=IDENT(6)  
NUMLIN=IDENT(7)  
IMIN=IDENT(15)  
IMAX=IDENT(16)  
LEAST1=IMIN-1  
NOBL=IMAX-LEAST1  
NBUBL=NOBL*(NOBL+1)/2  

NXMIN=131000  
NXMAX=-131000  

CHECK IF SIZE OF IMAGE IS TOO SMALL,  
RELATIVE TO THE SPATIAL DISTANCE  
PARAMETER.  

MM=MM1-1  
MM2=MMX2  
IF(NUMPPPL.LT.MM2.OR.NUMLIN.LT.MM2) GO TO 9999  

ZERO OUT THE JDATA ARRAY  

NUMPMM=NUMPPPL-MM  
NUMLMM=NUMLIN-MM  
DO 100 I=1,NUMPPPL  
DO 100 J=1,MM1  
100 JDATA(I,J)=0  

READ IN THE FIRST MM1 LINES OF THE IMAGE  
AND SET UP POINTERS  

DO 110 IY=1,MM1  
IPT(IY)=IY  
CALL RREAD(IDATI,IARRAY,IMGNO,IY,1,IDENT,IEV,ERR1)  
DO 111 LY=1,NUMPPPL  
111 IDATA(LY,IY)=IARRAY(1,1,LY)  
110 CONTINUE  

SETTING UP POINTERS FOR THE FIRST AND  
LAST ROWS OF THE IMAGE ARRAYS  

IST=IPT(1)  
LST=IPT(MM1)  

GO THROUGH ALL BUT MM ROWS OF IMAGE  

NEXT=MM1+1  

DO 105 LCNT=1,NUMLIN  
105 CONTINUE
SET OF MM COLUMNS ARE HANDLED SEPARATELY

DO 120 IRW=1, MM
IRM=IRW+MM

SET I, L, J AND K EQUAL TO THE
NORMALISED) VALUES OF GRAY TONES OF
RESOLUTION CELLS IN POSITIONS A, B, C
AND D AS IN THE DIAGRAM --

A C
B D

WHERE A INITIALLY IS THE UPPER LEFT
CORNER CELL. THE CELLS ARE A DISTANCE
MM APART.

I=IDATA(IRW, IST)-LEAST1
L=IDATA(IRW, LST)-LEAST1
K=IDATA(IRM, LST)-LEAST1
J=IDATA(IRM, IST)-LEAST1

PUT THE TWO DIMENSIONAL INFORMATION
INTO ONE DIMENSIONAL FORM. THE FUNCTION
NEEDED TO CONVERT A DOUBLE SUBSCRIPTED
ARRAY, IMM(X,Y), INTO A SINGLE
SUBSCRIPTED ARRAY, IMM(Z), IS OF THE
FORM G(X) + F(Y), WHERE G(X) = (X-1)*X/2
AND F(Y) = Y. THEREFORE
Z = (X-1)*X/2.

THIS IS DONE IN THE PROGRAM BY THE
EXTERNAL FUNCTION INDEX(X,Y).

SINCE THE ORDER OF OCCURRENCE OF THE
GRAY TONES BELONGING TO A RESOLUTION
CELL PAIR IS IMMATERIAL, THE ARRAYS ARE
SYMmetric. WE LET THE LARGER OF THE TWO
HAVE THE FIRST SUBSCRIPT, I.E., THE ARRAY
IS STORED IN LOWER TRIANGULAR FORM. THE
ORDER OF THE SUBSCRIPTING IS AS FOLLOWS -
IMM(1,1) = IMM(1),
IMM(2,1) = IMM(2),
IMM(2,2) = IMM(3),
IMM(3,1) = IMM(4),

IMM(NOBL,NOBL) = IMM(NBUBL).

THE SCANNING PROCEDURE, THAT IS THE
METHOD BY WHICH THE PAIRWISE COMPARISONS
ARE MADE, IS DESCRIBED BELOW FOR THE
GENERAL CASE.

consider a resolution cell with spatial
COORDINATES (M,N), AND CALL THIS CELL I. THE SCANNING OPERATION BEGINS IN THE UPPER LEFT HAND CORNER OF THE IMAGE AND IT THEN PROCEEDS BY COMPARING THE GRAY TONE OF &I& WITH AT MOST FOUR GRAY TONES OF ITS NEIGHBOURING RESOLUTION CELLS. THAT &I& NEVER NEEDS TO CONSIDER MORE THAN FOUR NEIGHBOURS CAN BE SEEN FROM THE DIAGRAM OF THE SEARCH PATTERN SHOWN BELOW --

\[
\begin{array}{cccc}
I & J & M & L & K \\
\end{array}
\]

ON A GIVEN ITERATION, &I& WILL LOOK FIRST AT ITS VERTICAL NEIGHBOUR (&L&), NEXT AT ITS HORIZONTAL NEIGHBOUR (&J&), THIRD AT ITS LOWER RIGHT NEIGHBOUR (&K&), AND FOURTH AT ITS LOWER LEFT DIAGONAL NEIGHBOUR (&M&). &I& THEN MOVES INTO THE POSITION OF THE LEFT-MOST RESOLUTION CELL OF THE PREVIOUSLY SCANNED SECOND ROW (THE POSITION OCCUPIED BY &M&). THE OPERATION IS REPEATED UNTIL ALL NEIGHBOURING PAIRS OF RESOLUTION CELLS HAVE BEEN EXAMINED. THE PROCEDURE IS FURTHER REPEATED FOR CELLS SKIPPED OVER IF THE SPATIAL DISTANCE IS GREATER THAN ONE, TILL ALL CELLS HAVE BEEN EXHAUSTED.

IL=INDEX(I,L)
ADD FUNC(IL,1) TO CENTER CELL AND 90-DEGREE NEIGHBOUR

JDATA(IRW,IST) = JDATA(IRW,IST) + FUNC(IL,1)
JDATA(IRW,LST) = JDATA(IRW,LST) + FUNC(IL,1)

IJ=INDEX(I,J)
ADD FUNC(IJ,2) TO CENTER CELL AND 0-DEGREE NEIGHBOUR

JDATA(IRW,IST) = JDATA(IRW,IST) + FUNC(IJ,2)
JDATA(IRM,IST) = JDATA(IRM,IST) + FUNC(IJ,2)

IK=INDEX(I,K)
ADD FUNC(IK,3) TO CENTER CELL AND 135-DEGREE NEIGHBOUR

JDATA(IRW,IST) = JDATA(IRW,IST) + FUNC(IK,3)
JDATA(IRM,LST) = JDATA(IRM,LST) + FUNC(IK,3)
NI=IRW

NOW ITERATE DOWN THE ROW

DO 130 N=IRM, NUMPMM, MM
  NMM=N+MM
  NNN=N-MM
  NI=N
  I=J
  M=L
  L=K

  J=JDATA(NMM, IST)-LEAST1
  K=JDATA(NMM, LST)-LEAST1

  IL=INDEX(I, L)

  ADD FUNC(IL, 1) TO CENTER CELL AND 90-DEGREE NEIGHBOUR

  JDATA(N, IST) = JDATA(N, IST) + FUNC(IL, 1)
  JDATA(N, LST) = JDATA(N, LST) + FUNC(IL, 1)

  IJ=INDEX(I, J)

  ADD FUNC(IJ, 2) TO CENTER CELL AND 0-DEGREE NEIGHBOUR

  JDATA(N, IST) = JDATA(N, IST) + FUNC(IJ, 2)
  JDATA(NMM, IST) = JDATA(NMM, IST) + FUNC(IJ, 2)

  IK=INDEX(I, K)

  ADD FUNC(IK, 3) TO CENTER CELL AND 135-DEGREE NEIGHBOUR

  JDATA(N, IST) = JDATA(N, IST) + FUNC(IK, 3)
  JDATA(NMM, LST) = JDATA(NMM, LST) + FUNC(IK, 3)

  IM=INDEX(I, M)

  ADD FUNC(IM, 4) TO CENTER CELL AND 45-DEGREE NEIGHBOUR

  JDATA(N, IST) = JDATA(N, IST) + FUNC(IM, 4)
  JDATA(NMM, LST) = JDATA(NMM, LST) + FUNC(IM, 4)

130 CONTINUE

COMPUTE THE LAST SET OF MM COLUMNS SEPARATELY

NI=NI+MM
I=J
M=L
L=I
IL=INDEX(I,L)

ADD FUNC(IL,1) TO CENTER CELL AND
90-DEGREE NEIGHBOUR

JDATA(NIM,IST) = JDATA(NIM,IST) + FUNC(IL,1)
JDATA(NIM,LST) = JDATA(NIM,LST) + FUNC(IL,1)

IM=INDEX(I,M)

ADD FUNC(IM,4) TO CENTER CELL AND
45-DEGREE NEIGHBOUR

JDATA(NIM,IST) = JDATA(NIM,IST) + FUNC(IM,4)
JDATA(NI,LST) = JDATA(NI,LST) + FUNC(IM,4)

120 CONTINUE

TO WRITE OUT THE COMPLETED LINE OF THE
JDATA IMAGE

DO 699 J=1,MM
IXM=NUMPPL-J+1
JDATA(J,IST)=(JDATA(J,IST)*8)/5
JDATA(IXM,IST)=(JDATA(IXM,IST)*8)/5
699 CONTINUE

IF(LCNT.NE.1) GO TO 695

DO 694 J=1,NUMPPL
IARRAY(1,1,J)=(JDATA(J,IST)*5)/3
694 CONTINUE
GO TO 798

695 CONTINUE
DO 797 J=1,NUMPPL
IARRAY(1,1,J)=JDATA(J,IST)
797 CONTINUE

798 CONTINUE

LINE=LCNT-MM1

CALL RWRITE(IDAT,J,IARRAY,1,LINE,1,JDENT,IEV,ERR1)

DO 700 IXM=1,NUMPMM
IF(JDATA(IXM,IST).LT.NXMIN) NXMIN=JDATA(IXM,IST)
IF(JDATA(IXM,IST).GT.NXMAX) NXMAX=JDATA(IXM,IST)
700 CONTINUE

SHIFT THE POINTERS FOR THE TWO ARRAYS.
THIS IS DONE BY A CYCLIC ROTATION.
The pointer array IPT is such that at any
time the Ith location of IPT contains
the pointer to the Ith position of the
LINE IN IDATA OR JDATA ARRAY. FOR EXAMPLE, IF IPT(2)=4 THEN THE FOURTH LINE
OF THE PHYSICAL JDATA ARRAY IS ACTUALLY THE SECOND LINE, AT THAT MOMENT.

IF(LCNT EQ. NUMLIN) GO TO 105

ROTATE IN A CYCLIC MANNER

ITEMP=IPT(1)
DO 135 IB=1,MM
135 IPT(IB)=IPT(IB+1)
IPT(MM1)=ITEMP

SET UP THE POINTERS TO THE FIRST AND LAST ROWS OF THE TWO IMAGE ARRAYS

IST=IPT(1)
LST=IPT(MM1)

READ IN A NEW LINE INTO THE IDATA ARRAY

CALL I:READ(IDATI, IARRAY, IMGNO, LCNT, 1, IDENT, IEV, ERR1)
DO 112 LY=1, NUMPPL
112 IDATA(LY, LST)=IARRAY(1, 1, LY)

ZERO OUT THE LAST LINE OF THE JDATA ARRAY

DO 145 JJ=1, NUMPPL
145 JDATA(JJ, LST)=0

THE LAST MM ROWS ARE COMPUTED SEPARATELY

DO LOOP TO GO THROUGH THE MM ROWS

ILINE=LINE
DO 140 LR=1, MM
ISR=IPT(LR+17)

DO LOOP TO GO THROUGH EACH ROW MM TIMES

DO 142 IRW=1, MM
I=IDATA(IRW, ISR)-LEAST1

DO LOOP TO WORK DOWN A ROW, COMPUTING THE 0-DEGREE NEIGHBOUR ONLY

DO 144 N=IRW, NUMPMM, MM
NMM=N+MM
J=IDATA(NMM, ISR)-LEAST1
IJ=INDEX(I, J)
ADD FUNC(I,J,2) TO CENTER CELL AND 0-DEGREE NEIGHBOUR

JDATA( N, ISR) = JDATA( N, ISR) + FUNC(I,J,2)  
JDATA(NMM, ISR) = JDATA(NMM, ISR) + FUNC(I,J,2)

144 I=J
142 CONTINUE

WRITE OUT THE COMPLETED JDATA LINE

DO 698 J=1, MM
   IXM=NUMPPL-J+1
   JDATA(J, ISR)=JDATA(J, ISR)*8)/5
   JDATA(IXM, ISR)=JDATA(IXM, ISR)*8)/5
698 CONTINUE

IF(LR. NE. MM) GO TO 670

DO 696 J=1, NUMPPL
   IARRAY(1, 1, J)=JDATA(J, ISR)*8)/3
696 CONTINUE
GO TO 896

670 CONTINUE

DO 897 J=1, NUMPPL
   IARRAY(1, 1, J)=JDATA(J, ISR)
897 CONTINUE

896 CONTINUE

LINE=ILINE+LR
CALL RWRITE(IDATJ, IARRAY, 1, LINE, 1, JDENT, IEV, ERR1)
DO 701 IXM=1, NUMPMM
   IF(JDATA(IXM, ISR), LT, NXMIN) NXMIN=JDATA(IXM, ISR)
   IF(JDATA(IXM, ISR), GT, NXMAX) NXMAX=JDATA(IXM, ISR)
701 CONTINUE

140 CONTINUE

CALL CLOSE(IDATJ)
CALL CLOSE(IDATI)
CALL KDPOL
RETURN

ERROR RETURN

9999 CONTINUE
CALL CLOSE(IDATI)
CALL CLOSE(IDATJ)
RETURN IERR1
END
DESCRIPTION

THIS ROUTINE GETS THE NECESSARY PARAMETERS FOR THE TEXTURE TRANSFORM PACKAGE

ENTRY POINT

T-X-INPT(NFUNC, NDIS, FILNMP, FILNMQ, IBOUT, PCLCT)

ARGUMENT LIST

NFUNC
PARAMETER USED TO DETERMINE WHICH FUNCTION Computes the JDATA IMAGE
NFUNC=1 FOR SUM PROBABILITY FEATURE
NFUNC=2 FOR ANGULAR MOMENTUM FEATURE
NFUNC=3 FOR ENTROPY FEATURE
NFUNC=4 FOR GRADIENT FEATURE
NFUNC=5 FOR NORMALIZED ARRAY WHICH HAS BEEN EQUAL PROBABILITY QUANTIZED
NDIS
SPATIAL DISTANCE TO BE USED TO GENERATE LEX ARRAYS
FILNMP
INPUT FILE NAME
FILNMQ
OUTPUT FILE NAME
IBOUT
ERROR MESSAGE OUTPUT . DAT SLOT
PCLCT
PERCENT OF LINES COUNTED IN GENERATING THE FOUR NEIGHBOR GRAY TONE MATRICES (LEX ARRAYS)

SUBROUTINE T-X-INPT(NFUNC, NDIS, FILNMP, FILNMQ, IBOUT, PCLCT)
DOUBLE INTEGER FILNMP, FILNMQ, FDATE
DIMENSION FILNMP(2), FILNMQ(2), FDATE(3)
IOU T = 6
IDIN = 4

GET PARAMETERS

WRITE(IOU T, 100)
100 FORMAT(' T-YPE NFUNC, NDIS, IBOUT, PCLCT, I/O FILE NAMES')
WRITE(IOU T, 110)
110 FORMAT(' (FORMAT IS 3I5, F4. 2, A9, A9)')
READ(IDIN, 101) NFUNC, NDIS, IBOUT, PCLCT, FILNMP, FILNMQ
101 FORMAT(3I5, F4. 2, A5, A4, A5, A4)
WRITE(IOU T, 102) NFUNC, NDIS, IBOUT, PCLCT, FILNMP, FILNMQ
IF(IBOUT. NE. IOU T) WRITE(IBOUT, 102) NFUNC, NDIS, IBOUT, FILNMP, FILNMQ
2FILNMQ
102 FORMAT(1X, 3I5, 2X, F4. 2, 2X, A5, A4, 2X, A5, A4)

CALL ADA T(EFDATE)
WRITE(IOU T, 405) FDATE
IF(IBOUT .NE. IOUT) WRITE(IBOUT, 405) FDATE
405 FORMAT(1X, 3A5)
RETURN
END
PROGRAM TITLE: TXJDM
VERSION: A
AUTHOR: ROBERT M HARALICK
DATE NOVEMBER 1974
UPDATE FEBRUARY 1975
CHIN-HUANG CHEN
PROGRAM LANGUAGE: FORTRAN IV
IMPLEMENTED ON: PDP 15

PURPOSE:

THIS ROUTINE IS THE MAIN LINE FOR THE JDATA GENERATION DISPLAY. INPUT PARAMETERS ARE FUNCTION TYPE, SPATIAL DISTANCE RELATIONSHIP, ERROR MESSAGE OUTPUT, DAT SLOT, PERCENT OF LINES COUNTED IN GENERATING THE FOUR NEIGHBOR GRAY TONE MATRICES, INPUT FILE NAME, AND OUTPUT FILE NAME.

SUBROUTINES CALLED:
TXINPT
ERROR
TXTMN
SDKINL
SKPDSC
FPLXIT
SREAD
INDEX
FUCI1
FUCI2
FUCI3
FUCI4
FUCI5
EQPONT
LEXEQP
PLXIT
INDEX
SREAD

DOUBLE INTEGER NPPCAL, NTOTAL, FILNMP, FILNMQ
DIMENSION FILNMQ(2), FILNMP(2)
COMMON IWORK(8000), IWRK(7000)
COMMON /DFA/ NG, F(50)
COMMON /DFB/ AMEAN, VAR, NPPCAL, NTOTAL, START, END, NCALL, NNTERS, DANGE
COMMON /IO/ NSIZE, IDUM(2048)
COMMON /TXT/ ITXT(10)
DATA IOUT, IDATK, IDAT0, NDIM/6, 2, 1, 15000/
NSIZE = 1024
200 CONTINUE

GET INPUT PARAMETERS
CALL TXINPT(NFUNC, NDIS, FILNMP, FILNMQ, IBOUT, PCLCT)

WRITE THE INPUT IMAGE IDENTIFICATION BLOCK

CALL LSTID(IDATK, FILNMP, IBOUT, 1, IEV, @304)

COMPUTE THE INTEGER TEXTURE IMAGE

CALL TXTMN(IWORK, NDIM, FILNMP, FILNMQ, NDIS, NFUNC, 2NXMIN, NXMAX, PCLCT, IEV, @310)

WRITE THE OUTPUT IMAGE IDENTIFICATION BLOCK

CALL LSTID(IDATQ, FILNMQ, IBOUT, 1, IEV, @304)

CALL CLOSE(IBOUT)
GO TO 200

304   IERR=1
GO TO 500

310   IERR=2

500   CALL ERROR(IERR, IEV, IOUT, IBOUT)
GO TO 200
END
T-X-T-M-N

PROGRAM SUBROUTINE TXTMN

TITLE

PROGRAMMER MODIFIED BY A. SINGH, OCTOBER  &72
MODIFIED FOR PDP BY ROBERT M HARALICK 5/1/73
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DOCUMENTATION
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COMPUTER REQUIRED
PDP-15

PROGRAM LANGUAGE
FORTRAN IV

PURPOSE
TXTMN IS THE MAINLINE SUBROUTINE FOR THE TEXTURE
ROUTINE PACKAGE TO COMPUTE THE JDATA IMAGE.

METHOD
TXTMN DOES THE FOLLOWING -
TAKES IN LABELS AND PARAMETERS FROM ARGUMENT LIST,
READS IN THE IMAGE FROM FILE (02),
SETS THE MAXIMUM AND MINIMUM GRAY LEVELS,
SETS UP DYNAMIC ALLOCATION OF PARAMETERS AND
CALLS THE REST OF THE SUBROUTINES.

ENTRY POINT CALL TXTMN(IWORK,NDIM,S,T,NDIS,IFUNC,
NXMIN,NXMAX,PCLCT,IEV,ERR1)

ARGUMENTS IWORK
SCRATCH ARRAY WHERE THE IMAGE IS READ IN
AND THEN LATER IT IS USED FOR DYNAMIC
ALLOCATION.

NDIM
SIZE OF SCRATCH ARRAY. NDIM SHOULD BE
EITHER NUMPPL*NUMLIN OR
2*(M*(A+1)+1)+4*B*(B+1), WHICH EVER ONE
IS LARGER.
A IS THE NUMBER OF POINTS/LINE IN THE
IMAGE, B IS THE MAXIMUM NUMBER OF GRAY
LEVELS POSSIBLE AND M IS THE LARGEST
REDUCTION DISTANCE THE PROGRAM WILL RUN
WITH.

S
NAME OF FILE THE IMAGE IS ON

T
NAME OF FILE WHERE THE JDATA IMAGE IS CREATED

NDIS
SPACING BETWEEN NEIGHBORLY RESOLUTION CELLS

IFUNC
PARAMETER USED TO DETERMINE WHICH FUNCTION
COMPUTES THE JDATA IMAGE.
IFUNC=1 FOR SUM PROBABILITY
IFUNC=2 FOR ANGULAR MOMENTUM FEATURE
IFUNC=3 FOR ENTROPY FEATURE
IFUNC=4 FOR GRADIENT FEATURE OF THE IMAGE
IFUNC=5 FOR NORMALIZED LEX ARRAY WHICH HAS BEEN
EQUALLY PROBABILITY QUANTIZED

NXMIN IS THE MINIMUM ON THE JDATA IMAGE
NXMAX IS THE MAXIMUM ON THE JDATA IMAGE
PCLCT IS THE PERCENT OF LINES COUNTED
IEV INTEGER EVENT VARIABLE
ERR1 ALTERNATE ERROR RETURN

PARAMETERS
AND ARRAYS
NUMLIN NUMBER OF LINES IN THE INPUT IMAGE
NUMPL NUMBER OF POINTS PER LINE IN THE INPUT IMAGE
IMAX MAXIMUM GRAY LEVEL
IMIN MINIMUM GRAY LEVEL
LEAST1 =IMIN-1
NOBL NUMBER OF GRAY LEVELS
NBUBL =NOBL*(NOBL+1)/2 IS THE SIZE OF A LEX ARRAY
NIDATA, NJDATA, NLEX1,2,3,4, NFUNC AND NTOT ARE POINTERS
FOR DYNAMIC ALLOCATION IN IWORK.

INPUT AND OUTPUT
READ IN FROM FILE (02)
ERROR FOR INCORRECT SIZE OF IWORK,
ERROR IF PARAMETER IFUNC HAS BEEN
INITIALIZED INCORRECTLY.
INPUT IMAGE ON FILE CODE IDATI.
WRITE, JDATA IMAGE ON FILE CODE IDATJ.

SUBPROGRAMS FPLXIT, PLXIT, INDEX, FUNC1, FUNC2, FUNC3, FUNC4, FUNC5
SEEK SYSTEM LIBRARY
CLOSE SYSTEM LIBRARY

REQUIRED

RETURNS NORMAL AND ALTERNATE
PROGRAM TERMINATED FOR INCORRECT
SIZE OF IWORK, ERROR IF IFUNC
INITIALIZED INCORRECTLY.

CALLED BY MAIN LINE PROGRAM TXJDM

SUBROUTINE TXTMN(IWORK, NDIM, S, T, NDIS, IFUNC, NXMIN,
2NXMAX, PCLCT, IEV, ERR1)

INTEGER ERR1
DOUBLE INTEGER FUNC
DOUBLE INTEGER FDATE, S, T, A, B
DOUBLE INTEGER LEX, C1, R1, C2, R2

DIMENSION IWORK(1), LEX1(1), LEX2(1), LEX3(1), LEX4(1), IDATA(1,1), T(2)
DIMENSION IDENT(20), S(2), JDENT(20), FDATE(3)
DIMENSION JDATA(1, 1), IPT(1), FUNC(1, 1)
  DIMENSION CC1(8), RR1(8), LEX(13), C1(2), R1(2)

  IDATA(NUMPPL, MM1), JDATA(NUMPPL, MM1), LEX1(NBUBL), LEX2(NBUBL),
  LEX3(NBUBL), LEX4(NBUBL), IPT(MMAX), FUNCT(NBUBL, 4)

COMMON /TXT/ IMAX, IMIN, NUMPPL, NUMLIN, NBUBL, NOBL, LEAST1
DATA A, B, I, Z, IONE, ITWO, 'TXTMN', 0, 1, 2/
DATA IDATI, IDATJ/2, 3/
DATA LEX, 'LEX', 'ARRAY', 11*/ /
DATA CC1, R1/ 'COL', 'ROW' /
DATA CC1, 'C1', 'C2', 'C3', 'C4', 'C5', 'C6', 'C7', 'C8'/
DATA RR1, 'R1', 'R2', 'R3', 'R4', 'R5', 'R6', 'R7', 'R8'/

  CALL KDPSUB(A, B)
  CALL SDKINL(IDATI, S, IDENT, 1, IEV, ERR1)
NUMPPL=IDENT(6)
NUMLIN=IDENT(7)
IMAX=IDENT(15)
IMAX=IDENT(16)

LEAST1=IMIN-1
NOBL=IMAX-LEAST1
NBUBL=NOBL*(NOBL+1)/2

SET DYNAMIC ALLOCATION PARAMETERS

  SINCE THE SIZE OF IDATA, JDATA AND IPT ARE DIFFERENT FOR DIFFERENT
  REDUCTIONS, THE MAXIMUM SPACE THEY WILL REQUIRE HAS TO BE
  RESERVED. IDATA AND JDATA THIS WILL BE (NDIS+1)*NUMPPL, AND FOR
  IPT JUST NDIM+1.

  MM1=NDIS+1
  NIDATA=1
  NJDATA=NIDATA+NUMPPL*MM1
  NLEX1=NJDATA+NUMPPL*MM1
  NLEX2=NLEX1+NBUBL
  NLEX3=NLEX2+NBUBL
  NLEX4=NLEX3+NBUBL
  NFUNC=NLEX1
  NIPT=(NLEX4+NBUBL)*2
  NTOT=NIPT+MM1

  CHECKING IF THE SIZE OF IWORK IS ENOUGH
  IF(NTOT.GT.NDIM) GO TO 78
  NBIG=NDIM-NTOT
ADJUST THE DIMENSIONS

CALL ADJ2(IDATA, IWORK(NIDATA), NUMPPL)
CALL ADJ2(JDATA, IWORK(NJDATA), NUMPPL)
CALL ADJ1(LEX1, IWORK(NLEX1))
CALL ADJ1(LEX2, IWORK(NLEX2))
CALL ADJ1(LEX3, IWORK(NLEX3))
CALL ADJ1(LEX4, IWORK(NLEX4))
CALL ADJ2(FUNC, IWORK(NFUNC), NBUCL)
CALL ADJ1(IPT, IWORK(NIPT))

ZERO OUT THE SCRATCH AREA

DO 30 JLINK=1, NDIM
  IWORK(JLINK)=0
30

SKIP THE DESCRIPTOR RECORDS

CALL SKPDSC(IDATI, IDENT, IEV, ERR1)

COMPUTE THE FOUR LEX ARRAYS

CALL FPLXIT(IDATI, IDATA, LEX1, LEX2, LEX3, LEX4, IPT, IDENT, MM1, 2PCLCT, IEV, ERR1)

WRITE OUT THE LEX ARRAYS

CALL IMTRXP(LEX1, 8, 8, LEX, C1, R1, CC1, RR1, 4)
CALL IMTRXP(LEX2, 8, 8, LEX, C1, R1, CC1, RR1, 4)
CALL IMTRXP(LEX3, 8, 8, LEX, C1, R1, CC1, RR1, 4)
CALL IMTRXP(LEX4, 8, 8, LEX, C1, R1, CC1, RR1, 4)

CALL PROPER FUNCTION SUBPROGRAM

IEV=-5011
IF(IFUNC.EQ.1) CALL FUNC1(LEX1, LEX2, LEX3, LEX4, FUNC, NBUCL)
IF(IFUNC.EQ.2) CALL FUNC2(LEX1, LEX2, LEX3, LEX4, FUNC, NBUCL)
IF(IFUNC.EQ.3) CALL FUNC3(LEX1, LEX2, LEX3, LEX4, FUNC, NBUCL)
IF(IFUNC.EQ.4) CALL FUNC4(LEX1, LEX2, LEX3, LEX4, FUNC, NBUCL)
IF(IFUNC.EQ.5) CALL FUNC5(LEX1, LEX2, LEX3, LEX4, FUNC, NBUCL)
IF(IFUNC.LE.0. OR. IFUNC.GE.6) RETURN ERR1
DO 79 I=1,20
  JDENT(I)=IDENT(I)
79 CONTINUE

JDENT(5)=10
JDENT(19)=1
JDENT(10)=3
JDENT(11)=512
JDENT(15)=-256
JDENT(16)=255
CALL CPYDSC(IDATI, S, IDATJ, T, JDENT, IEV, ERR1)
CALL ADATE(FDATE)
NW=JDENT(12)*2
WRITE(IDATJ) A, B, FDATE, S, (IZ, I=15, NW)
WRITE(IDATJ) IONE, (IZ, I=2, NW)
WRITE(IDATJ) ITWO, IFUNC, NDIS, (IZ, I=3, NW)
CALL PLXIT(IDATI, IDATJ, IDATA, JDATA, IDENT, FUNC, IPT, NBUBL, MM1,
2NXMIN, NXMAX, JDENT, IEV, ERR1)
4 CONTINUE
CALL KDPOP
RETURN
C
C  ERROR RETURN FOR NOT ENOUGH WORK SPACE
C
78  IEV=-5010
RETURN ERR1
C
END