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Image enhancement and analysis of leukocyte adhesion

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Abstract

Title of Thesis: **Image Enhancement and Analysis of**

Leukocyte Adhesion

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The image of leukocyte adhesion to microvascular walls in the isolated rat perfused heart model has been observed and processed. Some of the fluorescent labeled leukocytes are barely visible due to microscope focal plane and the motion of objects . The purpose of this thesis is to extract leukocyte from the image of the experimental data using image enhancement and analysis(segmentation) techniques and develop a program to handle automatically counting of leukocytes in a predefined scene.

Image Enhancement and Analysis of Leukocyte Adhesion

by
Yee-Ruh Lin

Thesis submitted to the Faculty of the Graduate School of
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Approval Sheet

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1 Introduction

1.1 Biological background

The adhesion of polymorphonuclear leukocytes (PMN's) to endothelium is an essential interaction in inflammatory and immunological responses. The control of these processes in the cell membrane of both endothelium and inflammatory cells is poorly understood. To know the nature of these processes well, the determination of PMN adhesion that after using different treatments, increasing or inhibiting adhesive activity, may evaluate the relative importance of endothelium as a regulator of neutrophil adhesion in an intact microcirculation.

In general, local injury immediately causes an influx of PMN's to the affected area involving a series of complex signaling and recognition processes. Some of the possible causes are local changes in calcium signaling or in membrane potential that may reversibly and instantaneously produce an endothelial pro-adhesive surface for PMN's at the injured site. Calcium entry into endothelium stimulates a variety of activities, such as the release of prostacyclin, ensothelium-derived relaxing factor, Von Willebrand factor, and platelet activating factor. Endothelial contraction and high permeability to macromolecules in microvessel may also induced by calcium entry.

There are some important findings revealed by Paul and Durán (inpreparation)[7] that in high potassium condition, the adhesive activity of endothelium to PMN's is

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greater than in normal potassium conditions in the coronary microcirculation. Pretreatment of the high potassium heart with calcium ionophore A23187 generates antiadhesive activity. They proposed that a rapidly synthesized endothelial leukocyte inhibitory molecule (ELAIM) would participate in the balance between adhesion and antiadhesion signal in the normal coronary microcirculation, and would serve as an endogenous anti-inflammatory substance by preventing or decreasing the number of leukocytes adhering to the endothelium. Their findings also suggest that shear rates, coronary resistance, and flow rate in coronary vessels did not change the adhesion significantly, indicating that hemodynamic factors are not important determinants of leukocyte adhesion.

1.2   Objective and Procedure

The objective of this work is the development of suitable image enhancement techniques to deblur and analyze the blured image of fluorescent labeled PMN's. The blur may in the form of sensor noise, microscope misfocus, relative object- microscope motion, and so on. In Paul and Durán's work, the researchers analyzed 40 frames in each heart with the help of a transparent overlay to determine the density of PMN's per unit area. Such kind of work demands great patience and concentration in analyzing the experimental data from the video tape .

The developments in this thesis incorporate software for analyzing the experiment data from videotapes frame by frame to release the uncertainty from scene of

the human eye and perseverance of analysis. This software includes techniques of histogram equalization, thresholding, modified interpolation, mathematical morphology and search technique in track to process the segment image. This enhancement process will offer us some important information hidden beneath the rugged surface of the epicardium and yield the PMN's number that appear on a predefined window.

2 Preparation and Experimental System

2.1 General Preparation

Male Wistar-Furth rat hearts were excised and set up as an isolated, perfused preparation. Blood was collected (10 ml/animal) by cardiac puncture in polystyrene tubes containing citrate, and the PMN's were separated from other components. PMN's were fluorescently labeled with 5-carboxy -fluorescein diacetate and infused the heart over 20 min . The number of adhering PMNs/mm^2 reached a plateu within the first 10 minutes. After a 10 min wash out period, the heart was placed on a specially designed lucite chamber and mounted on the stage of a Nikon Optiphot microscope for intravital microscopy observation. To determine the number of adhering PMN's per unit surface area, the entire left anterior surface of heart was scanned using a 6.3× objective following imaginary lines drawn between the left circumflex artery and apex. [7]

2.2 Experimental System

The fluorescent labeled PMN's were epilluminated through the microscope object using a 100 W mercury arc lamp with 488 um excitation filter and 515 barrier filter. The image was transmitted to a video camera (Model COHU 4410 SIT camera) and

displayed on a TV monitor and simultaneously transmitted to the memory of a video image digitizer DS20F (Quantex Corp). The output signal from the digitizer can be sent in analog form (EIA standard RS170 video) to a video cassette recorder(Sony 5600) or in digital form over an HP-IB (IEEE 488) bus to a Hewlett-Parkard 1000 series A-900 computer. Video frames in the digitizer can be controlled both manually and by computer.

The DS20F digital video processor provides the capability of digitizing and storing TV images in one field or one frame (33ms) time. Image digitized by the DS20F can originate from any source providing standard RS 170 such as video cameras or video tape recorders. Each video image is resolved into a 512 × 512 matrix of picture elements. The gray scale range is 8 bits per picture element (256 gray scale). The experimental system is shown on fig.1.[4]

Videotapes of fluorescent label PMN's played back frame by frame through the digitizer memory. Digital images of selected frames are then further processed using several image processing techniques. Program IMAG89 was revised to I2 to provide specific usage for leukocyte adhesion image. Processed image can then be recorded on videotape or stored in digital form on the high speed disk (HP 7958,10 M Bytes) attached to the A-900 computer.
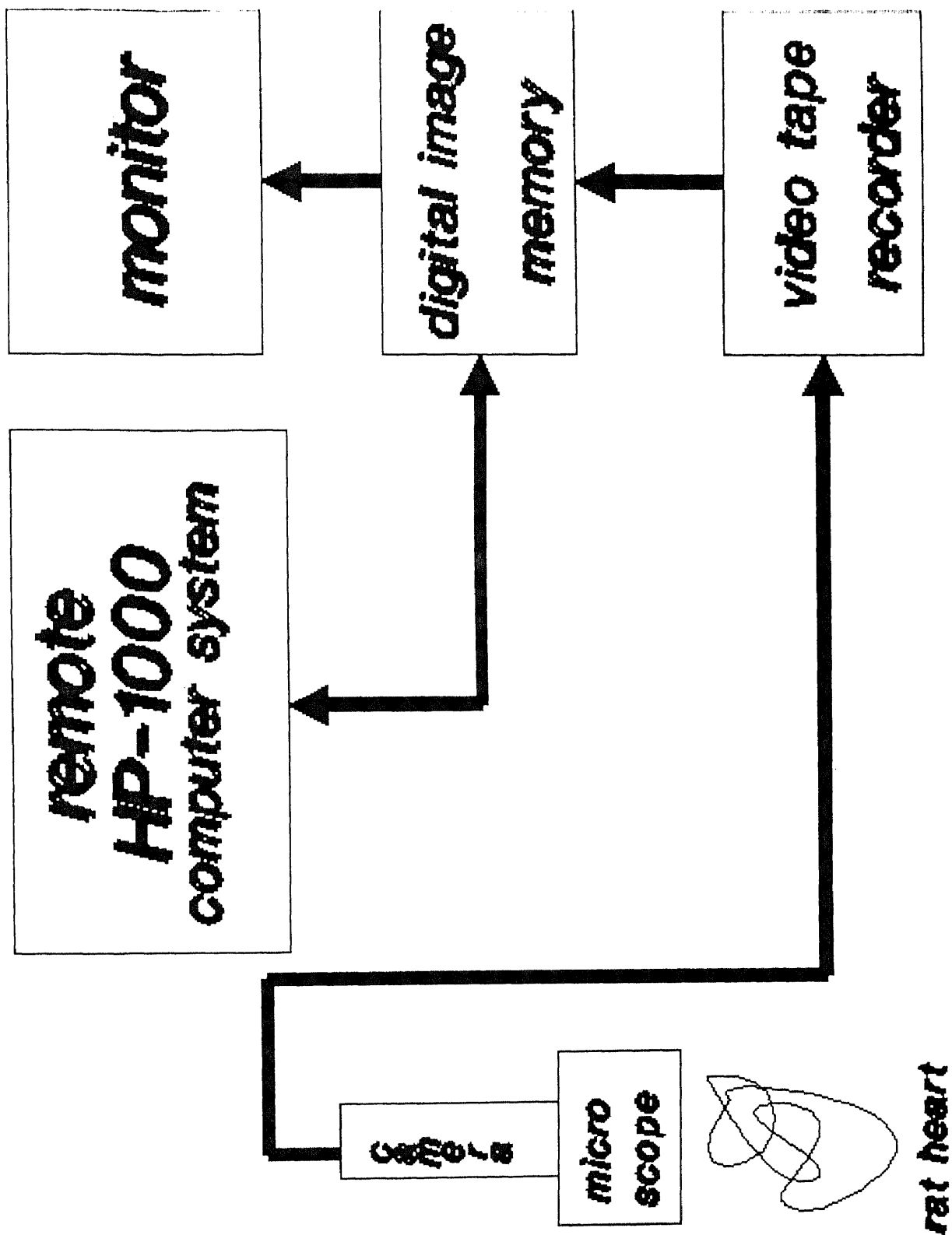
Figure 1: The experimental system

3   Principles, Methods, and Results

3.1   Image Pattern of Leukocyte Adhesion

In image compression or enhancement, the desired output is a picture, an approx-
imation to , or an improved version of, the input picture. Another major branch of
picture processing deals with image analysis or scene analysis; here the input is still
pictorial, but the desired output is a description of the given picture or scene.[16]

The objective of this work is to use image analysis techniques to develop some
software to recognize the fluorescent labeled PMN's on the screen and determine the
number of PMN's within a predefined window. The softwares generated description
refers to specific objects in the picture; thus, it is necessary to segment the picture of
leukocyte adhesion and the background must be "scissored out". In order to extract
an object from a picture explicitly after image enhancement and segmentation, the
objects needed to be clearly defined to discriminate objects from noise. After com-
pleting segmentation and filtering, the standard pattern recognition can be applied
to the processed image. Fig.2 shows the procedures to process the image model of
leukocyte adhesion.

The following are the principles and concepts of digital image techniques that were
applied to this analysis.
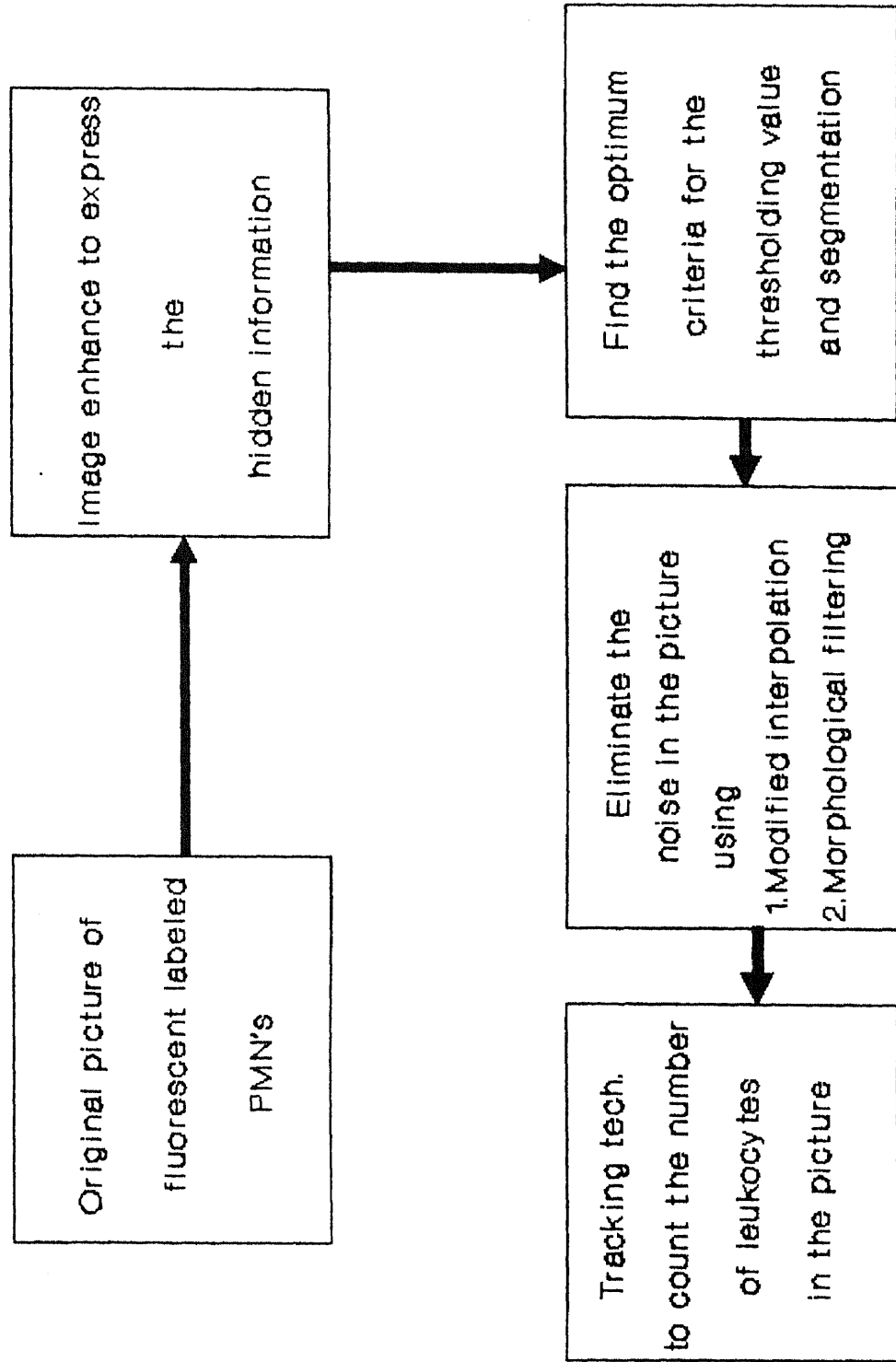
Figure 2: Flow chart of the procedure to enhances images of leukocyte adhesion

3.2 Image Enhancement by Histogram Equalization Technique

Let the variable r represent the gray level of the pixels in the fluorescent labeled PMN's image to be enhanced and they lie in the range

$$0 \leq r \leq 255$$

with r=0 representing black and r=255 representing white in the gray scale. For any r in the interval[0,255], attention will be focused on a transformation of the form

$$s = T(r) \tag{1}$$

which produce a level s for every pixel value r in the original image, and assuming eq(1) satisfies the conditions

(a) T(r) is single-valued and monotonically increasing in the interval $0 \leq r \leq 255$

(b) $0 \leq T(r) \leq 255$ for $0 \leq r \leq 255$

where condition (a) preserves the order from black to white in the gray scale, and condition(b) guarantees a mapping that is consistent with the allowed range of pixel values.

The inverse transformation from s back to r will be denoted by

$$r = T^{-1}(s) \qquad \text{for } 0 \leq s \leq 255 \tag{2}$$

where it is assumed that $T^{-1}(s)$ also satisfies conditions (a) and (b) with respect to the variables . The gray levels in an image are random quantities in the interval[0,255]. Assuming for a moment that they are continuous variables, the original

and transformed gray levels can be characterized by their probability density function $P_r(r)$ and $P_s(s)$ respectively.

It follows from elementary probability theory that if $P_r(r)$ and T(r) are known, and $T^{-1}(s)$ satisfies condition(a), then the probability density function of the transformed gray level is given by the relation

$$P_s(s) = [P_r(r)\frac{dr}{ds}]_{r=T^{-1}(s)} \tag{3}$$

Now let's consider the transformation function

$$s = T(r) = \int_0^r P_r(w)dw \tag{4}$$

where w is a dummy variable of integration. The rightmost side of eq(4) is recognized as the cumulative distribution function of r. Then from eq(4) the derivative of s with respect to r is given by

$$\frac{ds}{dr} = P_r(r) \tag{5}$$

substituting $\frac{dr}{ds}$ into eq(3)

$$
\begin{aligned}
P_s(s) &= [P_r(r)\frac{1}{P_r(r)}]_{r=T^{-1}(s)} \\
&= [1]_{r=T^{-1}(s)} \\
&= 1 \qquad 0 \le s \le 255
\end{aligned} \tag{6}
$$

which is a uniform density in the interval of definition of the transformed variable s, using a transformation function equal to the cumulative distribution of r produces an image whose gray levels have a uniform density.

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In order to be useful for digital image processing, the concept developed above must be formulated in discrete form. For gray levels that assume discrete values we deal with probabilities given by the relation

$$P_r(r_k) = \frac{n_k}{n} \quad 0 \leq r_k \leq 255 \quad k = 0, \cdots, 255 \qquad (7)$$

$P_r(r_k)$ is the probability of kth gray level, n_k is the number of pixels in the image.

The discrete form of eq(1) is given by the relation

$$s_k = T(r_k) = \sum_{j=0}^{k} \frac{n_j}{n} = \sum_{j=0}^{k} P_r(r_j) \quad 0 \leq r \leq 255 \quad 0 \leq k \leq 255 \qquad (8)$$

The inverse transformation is denoted by

$$r_k = T^{-1}(s_k) \quad 0 \leq s_k \leq 255 \qquad (9)$$

As a practical illustration of histogram equalization, we applied the subroutine HSTEQ in I2.(see Appendix) Consider the original image of fluorescent labeled PMN's shown in fig. 3(a) which is influenced by microscope misfocus and relative motion, so that some leukocytes are barely visible. The narrow range of values occupied by the pixels of this image is evident in the histogram shown in fig.3(b). The equalized histogram is shown in fig.4(b), and the processed image in fig.4(a); while the equalized histogram is not perfectly flat throughout the full range of gray levels as expected, considerable improvement over the original image was achieved by the spreading effect of the histogram-equalization technique.[9]

The result display explicitly some of the hidden valuable information. With the information of the enhanced image, that offers us a criteria to perform the segmentation.

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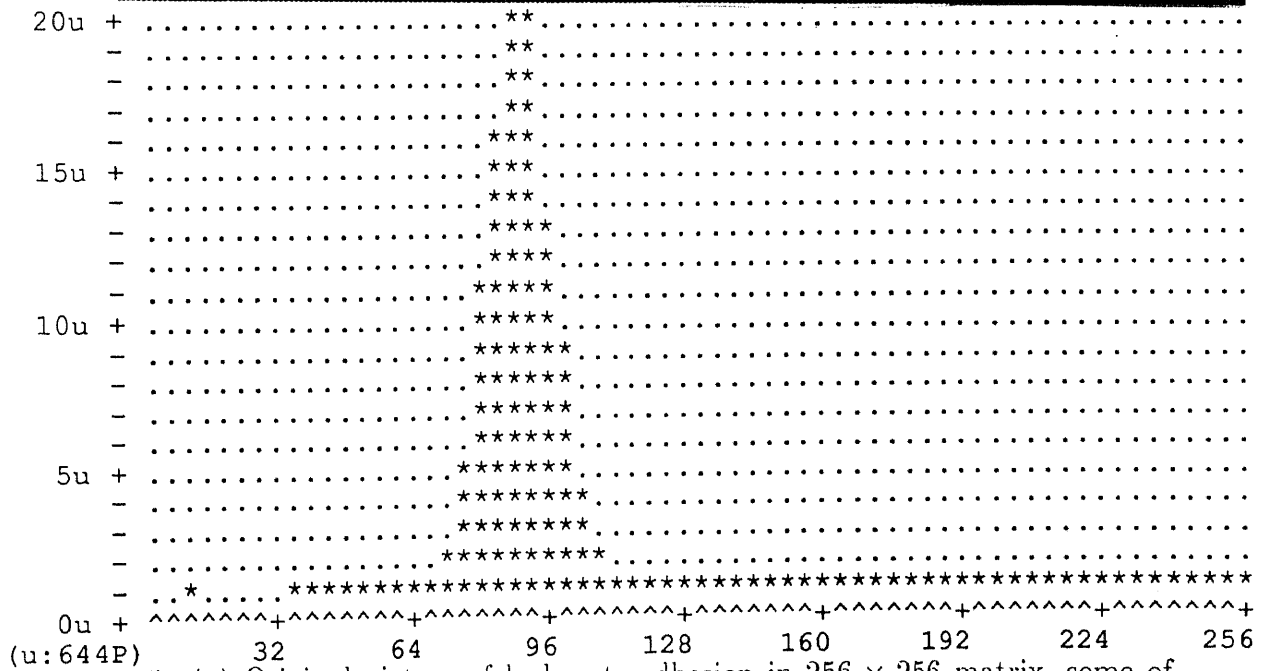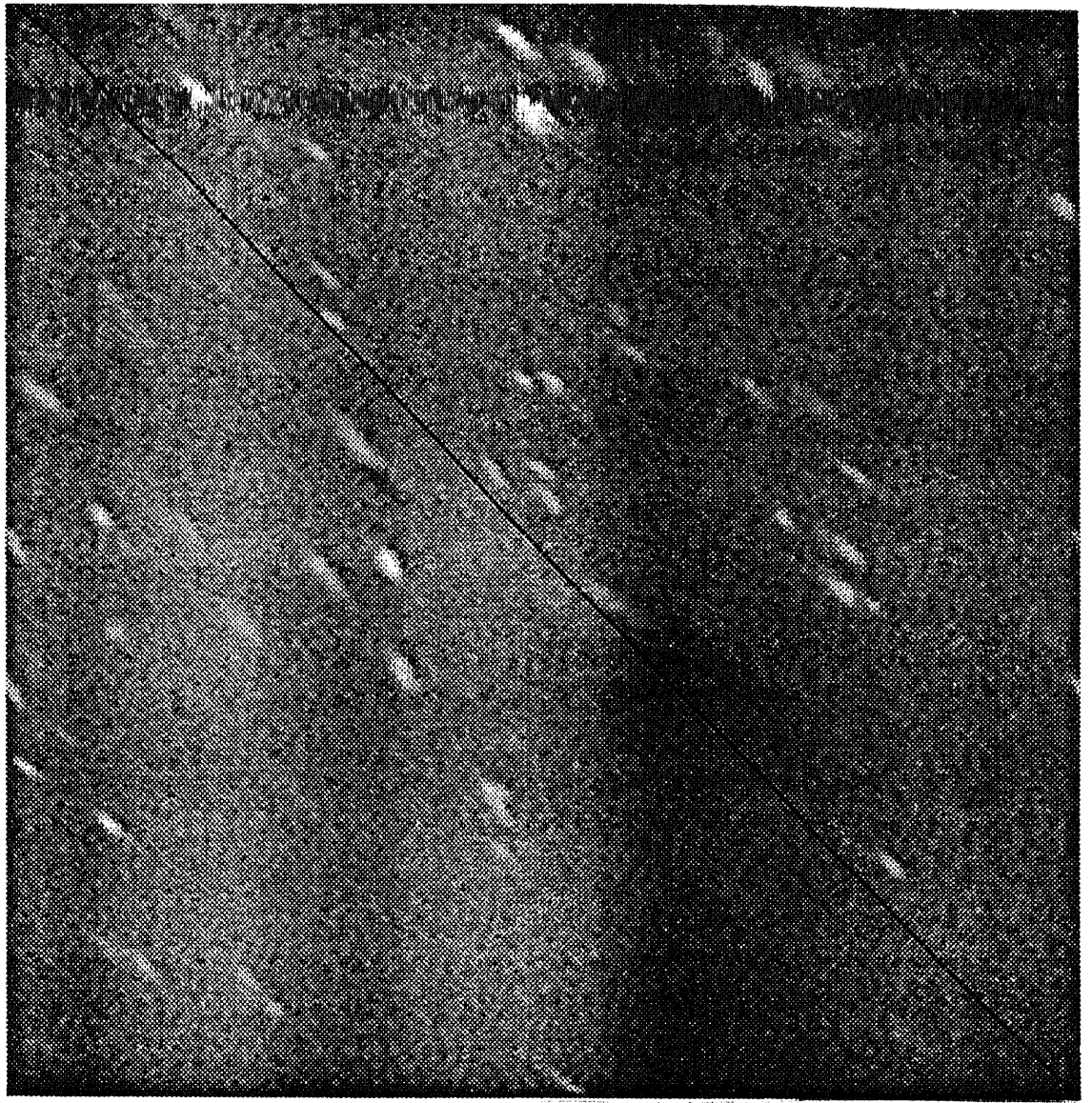
Figure 3: (a) Original picture of leukocyte adhesion in 256 × 256 matrix, some of leukocytes are barely visible result from microscope misfocus and relative motion. (b) The distribution of this histogram is concentrated in one region, from 70 to 110 in gray scale.

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 20u +.................................*......*...*...*.................*
     -.................................*......*...*..*..................
     -..............................*..*..*..*..*..*..*.................
     -..........................*..*..*..*..*..*..*..*.................
     -....................*..*..*..*..*..*..*..*..*...................
     -.................*..*..*..*..*..*..*..*..*..*..*...............
 15u +..............*..*..*..*..*..*..*..*..*..*...*..*.............
     -.............*..*..*..*..*..*..*..*..*..*..*..*.............
     -............*..*..*..*..*..*..*..*..*..*..*..*.*...........
     -...........*..*..*..*..*..*..*..*..*..*..*..*..*..........
     -..........*..*..*..*..*..*..*..*..*..*..*..*..*..........
 10u +....*....*..*..*..*..*..*..*..*..*..*.*..*.............
     -......*..*.*..*..*..*..*..*..*..*..*..*..*..*..........
     -.....*....**.*..*.*..*..*.*..*..*..*..*..*..*.........
     -....**.*.**.*.*..*.*.*..*.*.*..*.*..*.*.**.**..*.**
     -...*******.*.*..*.*.*.*.*..*.*.*..*.*.**.***.****
  5u +..*******.*.*..*.*.*.*.*.*.*.*.*.*.*.**.*******
     -..*******.*.*..*.*.*.*.*.*.*.*.*.*.*.**.*******
     -..*******.*.*..*.*.*.*.*.*.*.*.*.*.*.**.*******
     -..*******.*.*..*.*.*.*.*.*.*.*.*.*.*.**.*******
     -..*******.*.*..*.*.*.*.*.*.*.*.*.*.*.**.*******
  0u +^^^^^^^+^^^^^^^+^^^^^^^+^^^^^^^+^^^^^^^+^^^^^^^+^^^^^^^+^^^^^^^+
(u:175P)    32      64      96     128     160     192     224     256
```
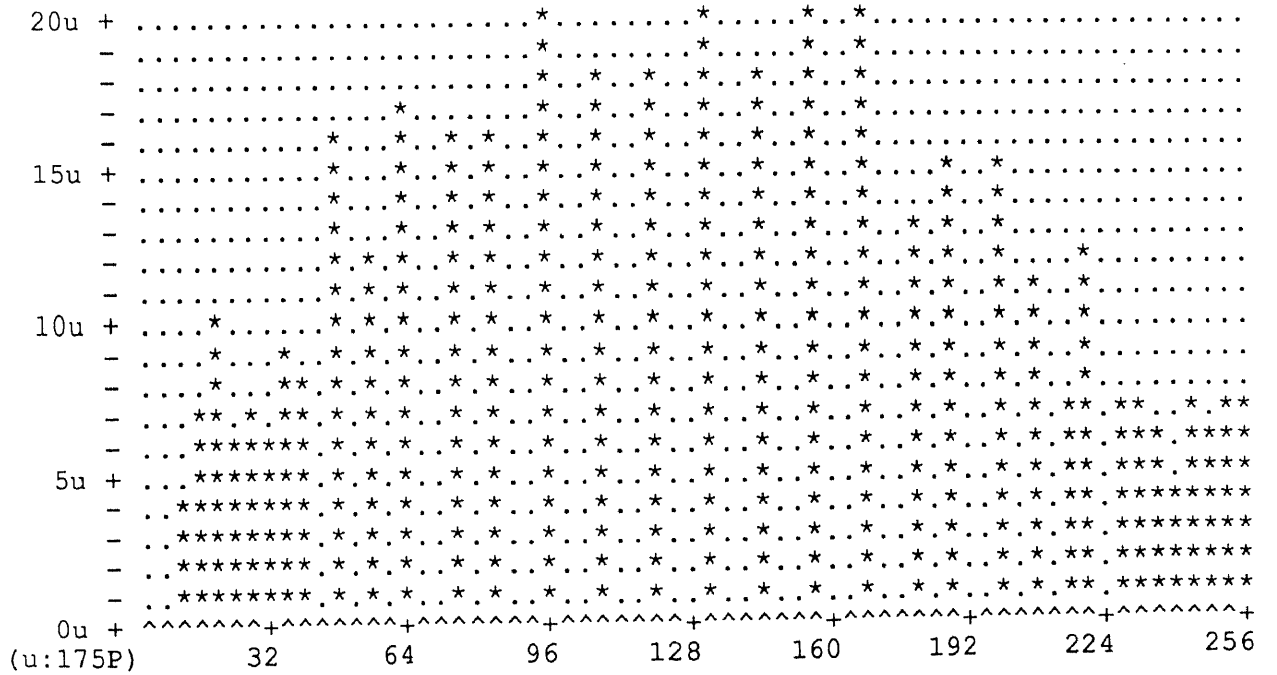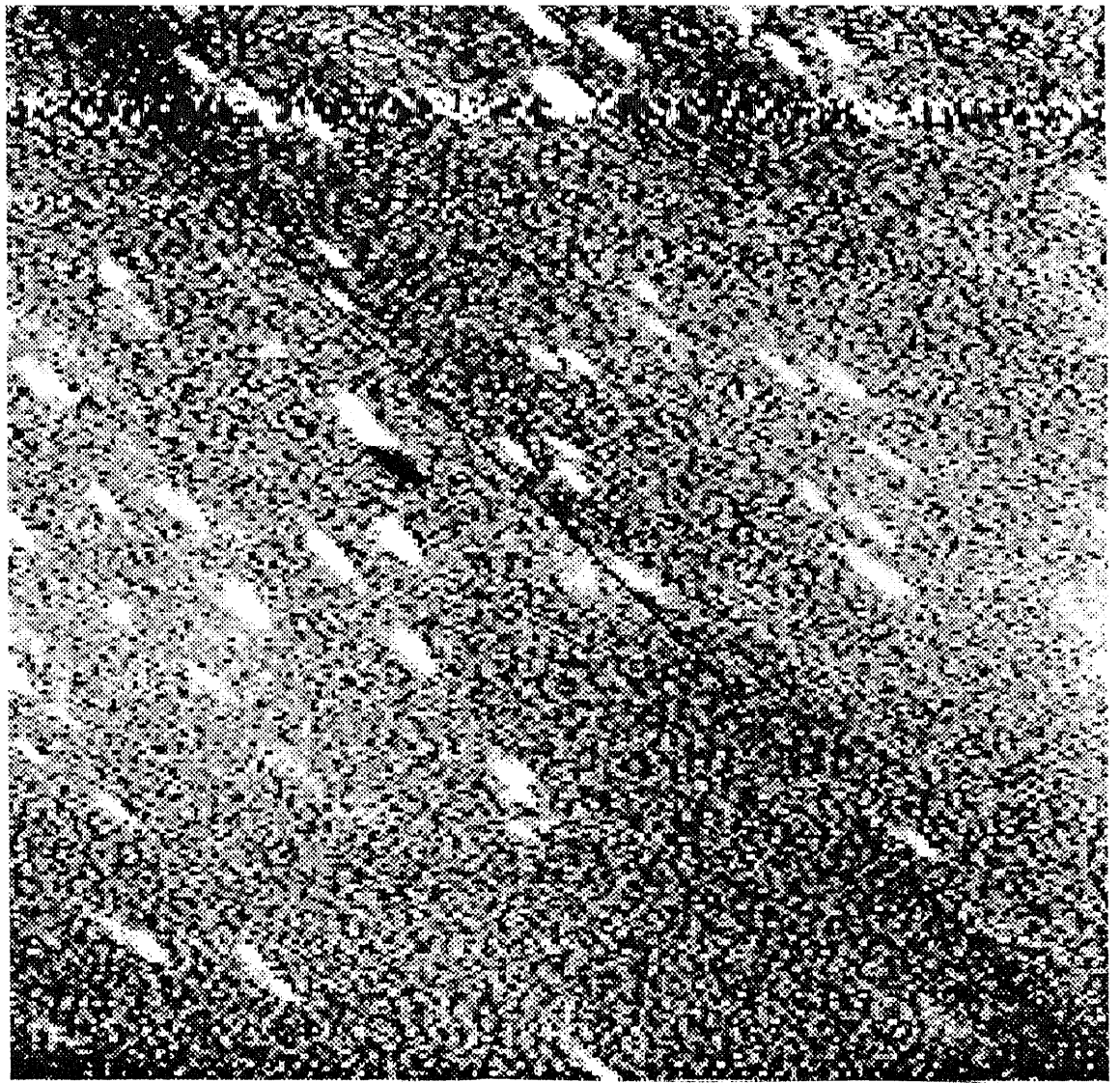
Figure 4: (a) After histogram equalization, the hidden information beneath epith-
lium are enhanced, simultaneously the noise has been graded up. (b) The equalized
histogram is achieved by spreading effect of histogram-equalization techniques.

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3.3 Thresholding

The main application of thresholding is the extraction of objects. Simple gray level thresholding is effective in extracting objects when the objects have a characteristic range or set of gray level.[4]

From the image of fluorescent labeled PMN's, the approach to threshold selection is to try a range of thresholds , and choose the one for which the threshold picture has some desired property. After histogram equalization, we can "lock on" some barely visible leukocytes to measure their gray levels and average them, then choose a threshold value adjacent below to this mean value. In image digital image program, subroutine THRH allows the user to assign any gray level range to a specified gray level. For the formula for thresholding

$$f_z(j,i) = \begin{cases} N & \text{if f(j,i) is element of z} \\ unchanged & \text{otherwise} \end{cases} \tag{10}$$

As fig.5 shows, we assign background gray level equal to 0, and objects(leukocytes) and noise lay on the range [105,255]. After the first of segmentation, now the procedure is noise cleaning.

3.4 Noise Filtering

Two major types of image noise dominate the image of leukocyte adhesion. The first type is an electro-optical component associated with the image formation and

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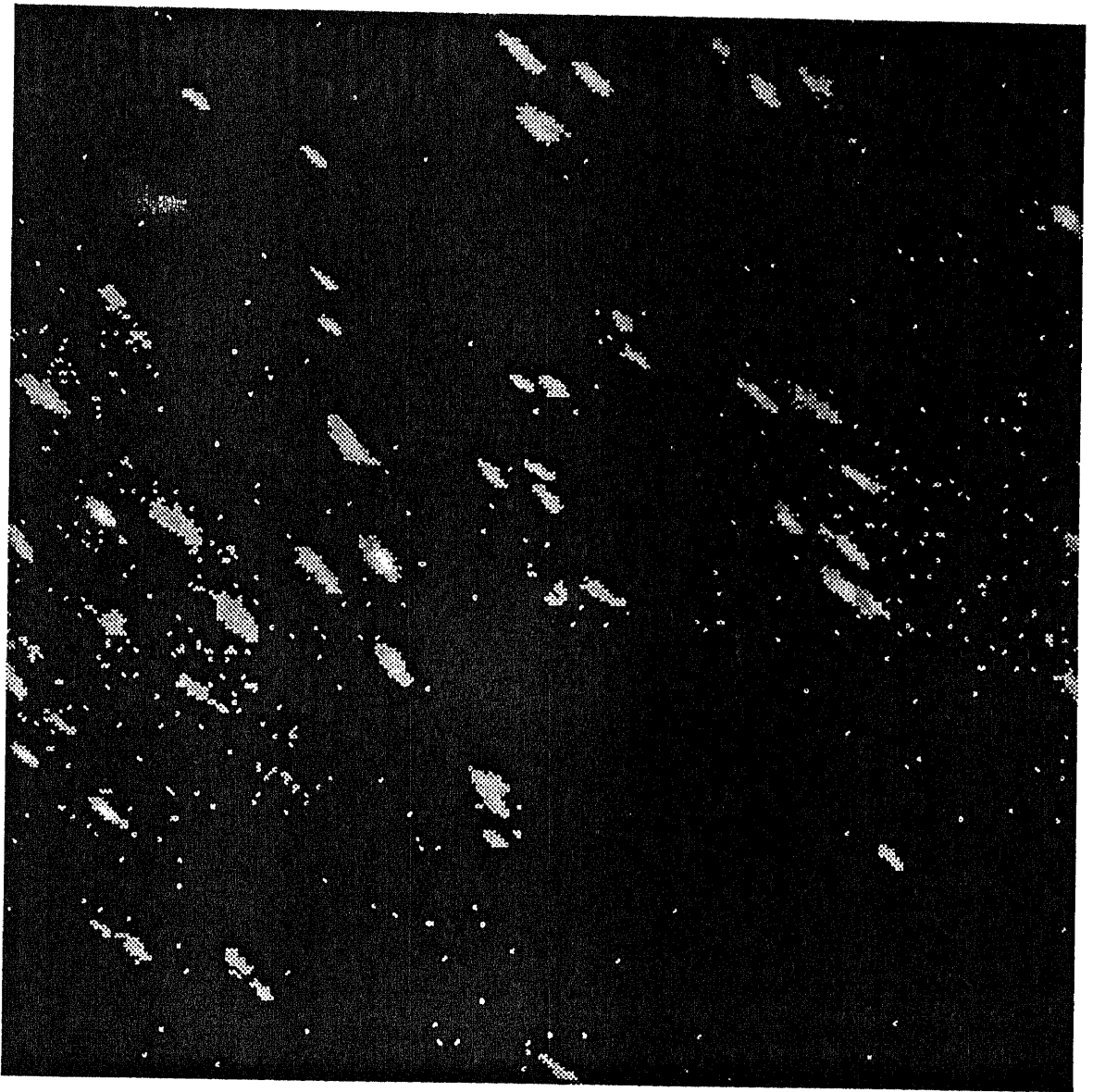
Figure 5: Using the thresholds techniques to define the gray level of background to 0, and leave the leukocytes and noise to old values, such process called semi-thresholding. And the picture show the "salt and pepper" noise caused by electro-optical component in experimental system.

quantization process within the TV camera, videotape recorder and digitizer. The sensed image intensities cannot be recorded without sensor noise. The characteristics of sensor noise are complex function of the sensed intensities. In addition, the characteristics are usually nonlinear so that one cannot assume superposition of signal and noise either in the recorded image or in the reconstruction of the recorded image.

The second type of noise is optical noise due to the experimental system. There are two components of this noise. The first is due to the optical properties of the object observed (the rugged surface of rat heart). The second component is due to the factors associated with lens design and manufacturing, light source, focusing and optical filters. Noise has a distribution over the gray level range 0 to 255.[13]

After optimal thresholding, as shown in fig.5, the techniques for removing "salt-and-pepper" noise in the two value case now can be implemented. In this study, we use two method to remove noise.

3.4.1 Modified interpolation

Before discussing this method we have to define the neighborhood (connectedness) for an object in one certain image. A point P=(j,i) of a digital picture Σ has four horizontal and vertical neighbors, namely the points

$$(j-1,i), \quad (j,i-1), \quad (j,i-1), \quad (j+1,i)$$

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We call these points the 4-neighbors of P, and say that they are 4-adjacent to P. In addition, P has four diagonal neighbors , namely

$$(j-1, i-1), \quad (j-1, i+1), \quad (j+1, i-1), \quad (j+1, i+1)$$

These, together with the 4-neighbors are called 8-neighbors of P(8-adjacent to P). Note that if P is on the border of Σ, some of its neighbors may not exist. In the image pattern of leukocyte adhesion, we define the object is 8-adjacent connectedness. A path π of length n from P to Q in Σ is a sequence of points $P = P_0, P_1, ..., P_n = Q$ such that P_i is a neighbor of P_{i-1}, $1 \leq i \leq n$. Thus we can speak of π being 8-path. Let an object be a subset of Σ, and let P,Q be points of object. We say that P is 8-connected to Q in the object if there exists an 8-path from P to Q consisting entirely of points of object. For any P in the object, the set of points that are connected to P in the object is called a connected component of the object.[16] From fig.6 two leukocytes lay down on the x-y plane shown in the form of 8-connected component. The concept concerns the geometric relation of noise and object. When the noise consists of isolated points or group of connected points smaller than the size of leukocyte, we can attempt to detect noise points by comparing each point's gray level z with the level z_i of its neighbors, if z is substantially larger(or smaller) than all, or nearly all, of all z_i, we can classify it as a noise point, and remove it by interpolation, ie. replace z by the background gray level.

As fig.5 shown in "salt and pepper" noise and the given picture is "two valued", zero and nonzero gray levels. Here we detect the noise point by counting the number

f(j−1,i−1) f(j,i−1) f(j+1,i−1)
f(J−1,i) f(j,i) f(j+1,i)
f(j−1,i+1) f(j,i+1) f(j+1,i+1)
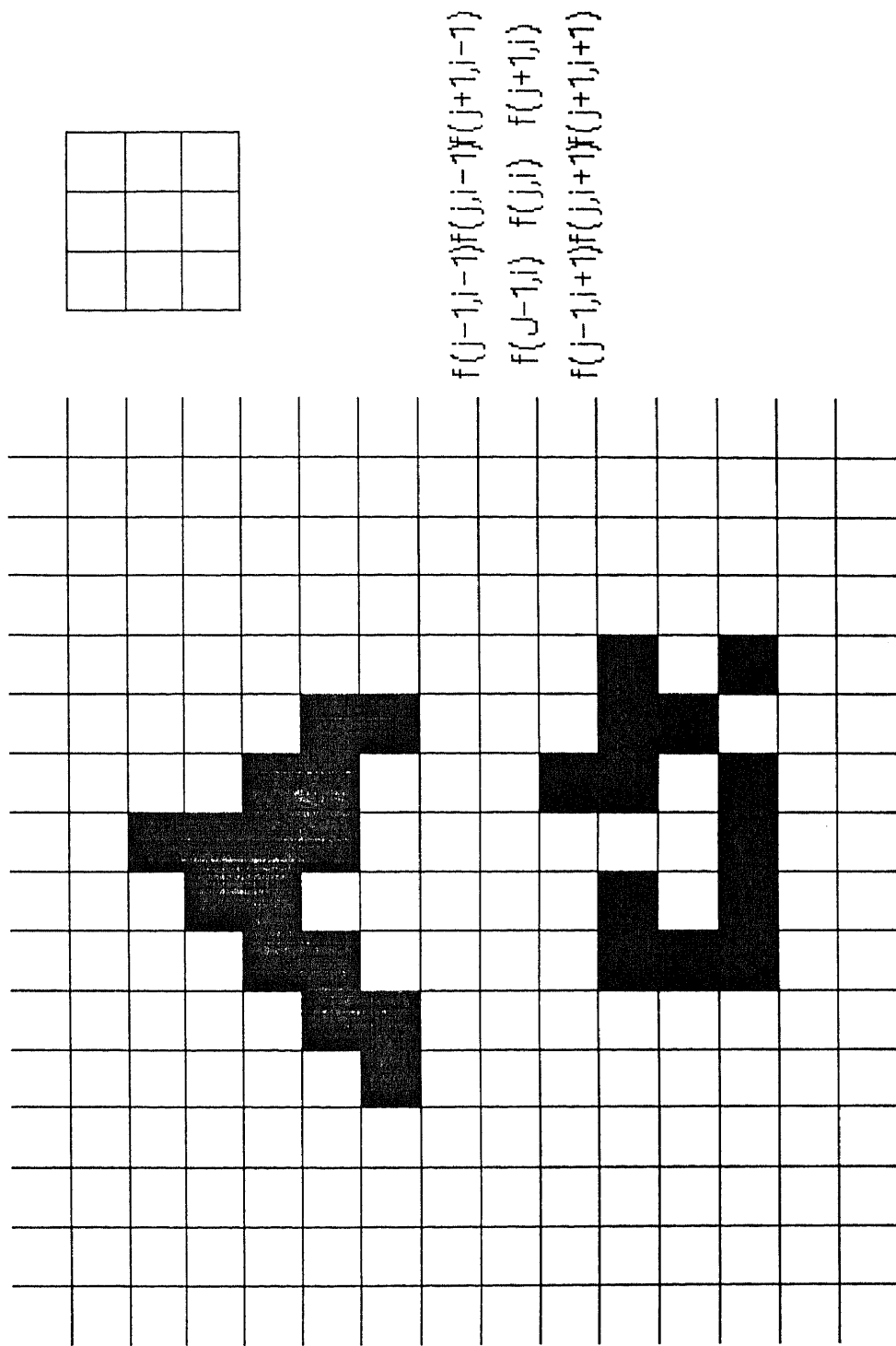
Figure 6: The concept of neighborhood(connectedness)

of their neighbors from which they differ . A white point that has too many ("nearly all") black neighbors can be changed from white to background gray level .

The method makes a forced-choice decision as whether or not the given point is a noise point. If we decide that the point or a group of points is smaller than the size of a leukocyte; in choosing the new gray level for these points, we pay no attention to its old level. On the other hand, if we decide that a group of connected points greater than leukocyte in shape, then we do not change the gray level at all. Using this method to develop the subroutine SMOTH, we can assign the nonzero gray level points to a certain value, further to give the number of neighbors connect to the processing point will delete these points if its'(processing point) neighbors number is smaller than the assign number, for example we assign the gray level to 127 and neighbor number to 4 that the result tell us from fig. 7 means every leukocyte in scene is homogeneous in gray level and "object" smaller than 5-connected component is excluded.

In some cases, if we apply SMOTH subroutine to process sizes of noise or undesired objects, greater than 3×3 matrix, these ones will remain. So we need a second method to give us more flexibility to process the image.
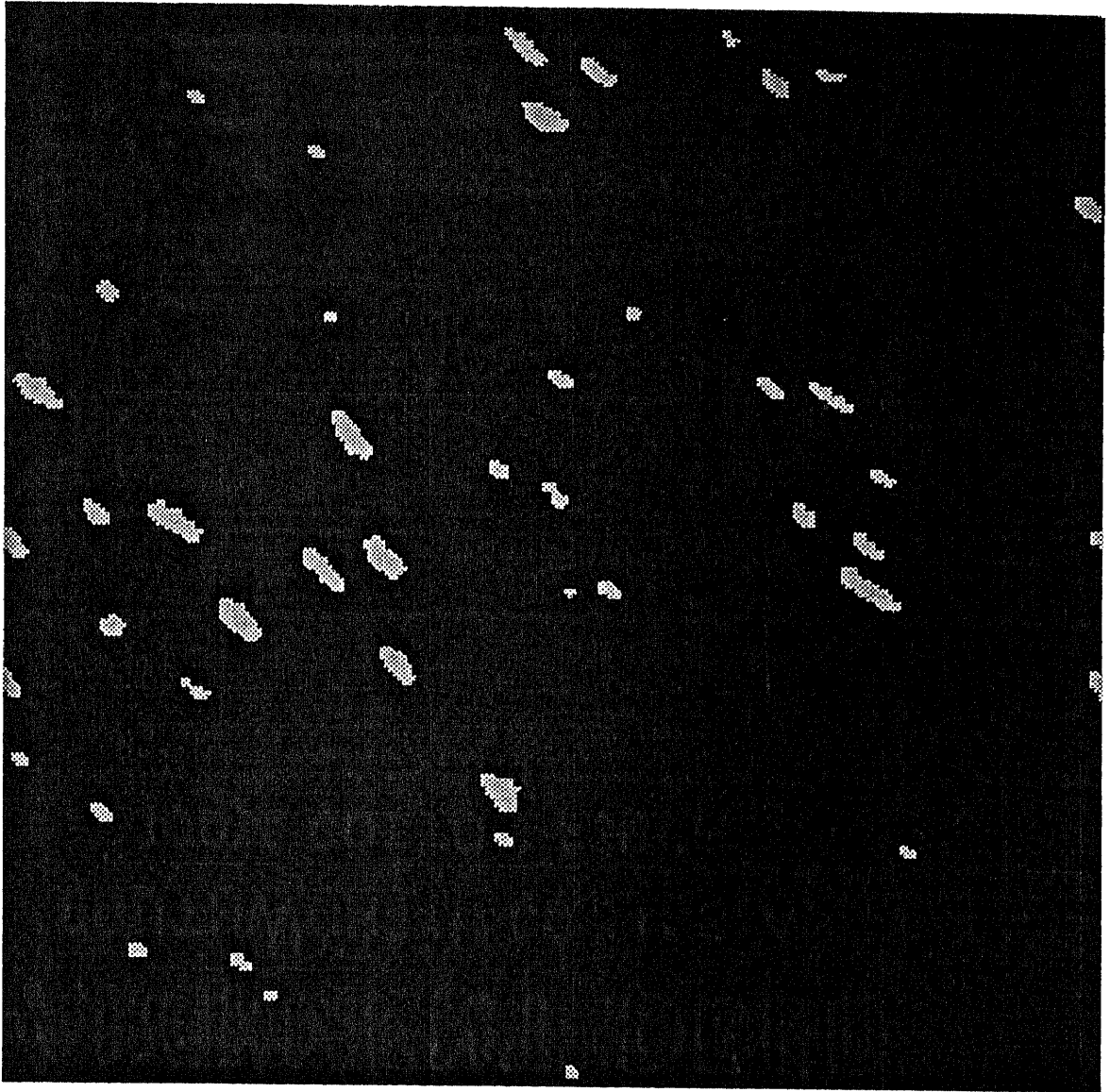
Figure 7: Noise is deleted by modified interpolation, the gray level of leukocytes is assigned to 127, the connected points smaller than 5 are excluded.

3.4.2 Morphological filtering

Digital image processing and analysis in the USA has been developed since the 1960s motivated mainly by problems in remote sensing and scene analysis; its main mathematical tools included classic linear filters, Fourier analysis, and statistical or syntactic pattern recognition. Parallel to, but independent from these ideas, mathematical morphology has evolved in Europe since the 1960s as a set-theoretic method for image analysis, motivated mainly by problems in quantitative microscopy. Its mathematical tools are related to integral geometry and stereology. The theoretical foundations of mathematical morphology which stem from Minkowski set operation, also called morphological filters, are more suitable for shape analysis than are linear filters.[10][11]

Image morphology can be used to reveal the structure of objects by transformation which correspond to shape filtering. An image can be represented by a set of pixels. The morphological operators can be thought to work with two images. The image being processed is referred to as active image and the other image being a kernel is referred to as the structuring element. Each structuring element has a designed shape which can be thought of as a probe or filter of the active image. We can modify the active image by probing it with various structuring elements.

Erosion and dilation are two basic concepts through set operations in morphological filtering.

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A. Erosion

Erosion combines two sets using vector subtraction of set elements. If A and B are sets in Euclidean space which elements a and b respectively. $a = (a_1, \cdot, a_n)$ and $b = (b_1, \cdot, b_n)$ being N-tuples of elements coordinates , then the erosion of A by b is the set of all elements x for which x+b $\in$ A for every b $\in$ B. Erosion $A \ominus_b B$ can be interpreted as the locus of all center c such that the translation B_c is entirely contained within the set A. One should be aware that erosion is different from Minkowski subtraction which is the intersection of translations of A by the elements b $\in$ B. Whereas, dilation is identical to Minkowski addition. Some erosion equivalent terms are "shrink" and reduce". The binary erosion of A by B is denoted by $A \ominus_b B$ and is defined as

$$A \ominus_b B = \{x \in E^N \mid x + b \in A \ for \ every \ b \in B\} \tag{11}$$

Equivalently, we may write

$$A \ominus_b B = \bigcup_{b \in B} (A)_{-b} \tag{12}$$

Fig.8 shows the effect of erosion from fig.7. The structuring element is 3×3 matrix is big enough to delete the noise, but shrink some valuable information.

B. Dilation

Dilation is the morphological dual to erosion, and combines two sets using vector addition of set elements, thus the dilation of A by B is the set of all possible vector

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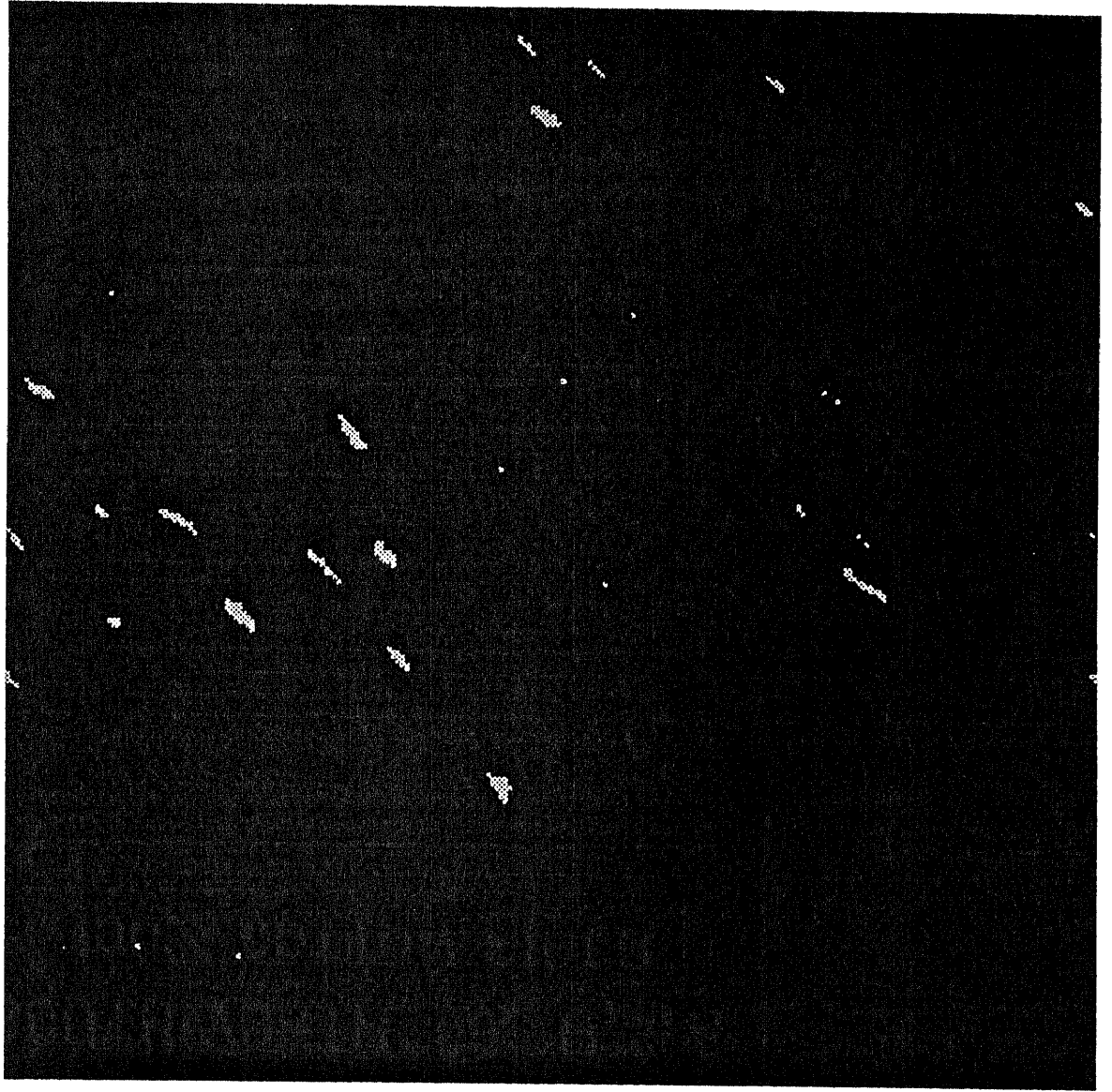
Figure 8: Effect of erosion from the result of fig. 7, show the outlayer of leukocytes are shrink by a 3 × 3 matrix .

sum of pair of elements, one coming from A and the other from B. In dilation, the roles of the sets A and B are symmetric. Dilation has a local interpretation. That is, if we think of each point a of A as a seed that grows the flower B_a (by placing the origin of B at a), and the union of all the flowers is the dilation of A by B. Dilation by disk structuring elements corresponds to isotropic expansion algorithm popular to binary image processing. Dilation by small square (3 × 3) is an 8-neighborhood operation easily implemented by adjacently connected array architectures and is the one known by the name "fill", "expand" or "grow". The binary dilation of A by B is denoted by A $\oplus$ $_b$B and is defined as

$$A \oplus_b B = \{c \in E^N \mid c = a + b \ \ for \ \ some \ a \in A \ and \ b \in B\}. \tag{13}$$

Equivalently, we may write

$$A \oplus_b B = \bigcup_{b \in B} (A)_b = \bigcup_{a \in A} (B)_a. \tag{14}$$

From fig.9 the size of leukocyte is expanded using the dilation technique.

Simply speaking in our analysis, suppose that we change all white points to black if they have any white neighbors, and then change all black points to white if they have any white neighbor. The first step shrinks all white region while the second step reexpands them; When the structuring element is set to 3 × 3 matrix, a white object that is two point wide or less will disappear completely at the first step, so that the second step cannot restore it. Thus this process deletes not only isolated points, but
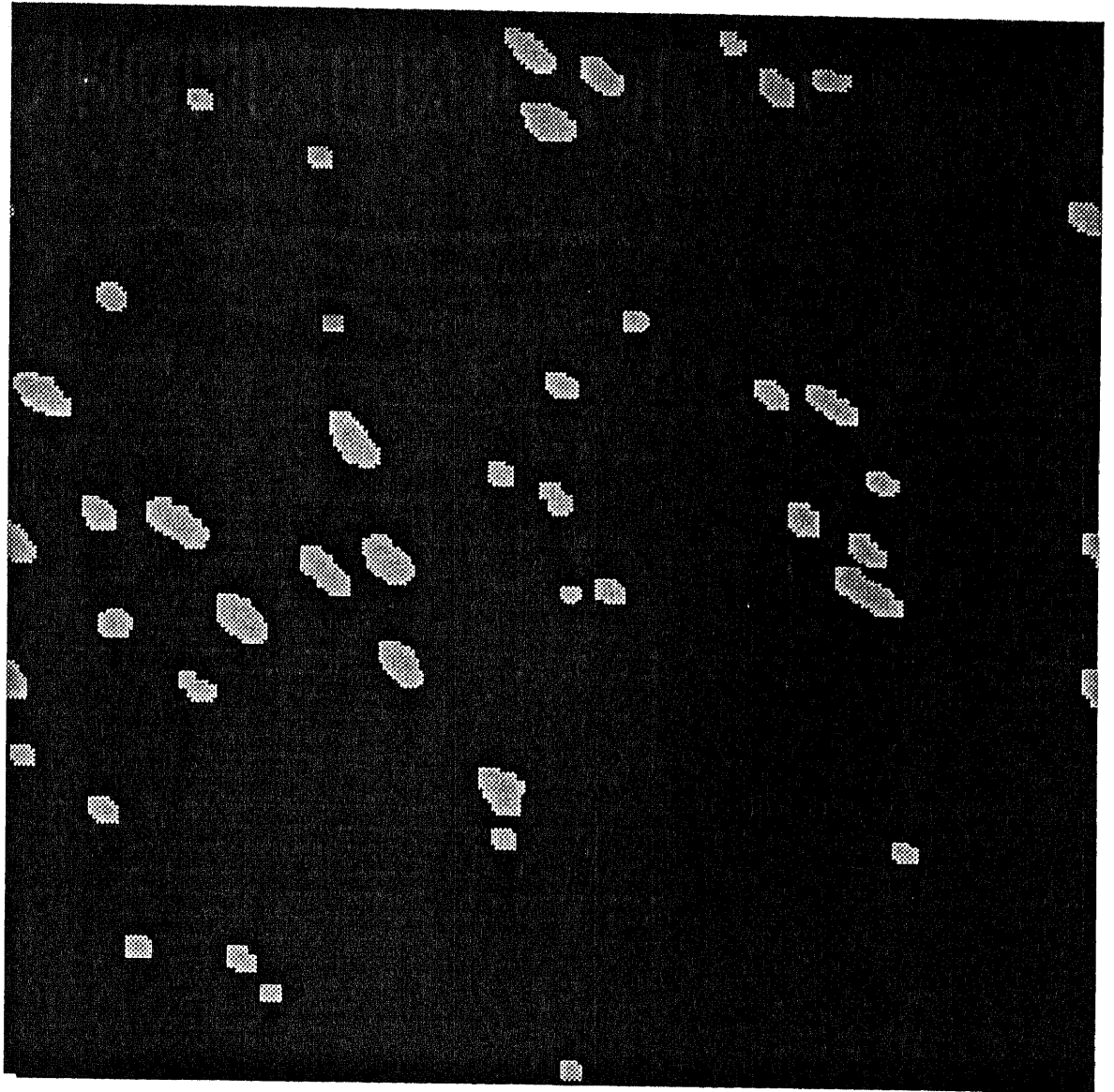
Figure 9: Effect of dilation from the result of fig. 7, show the outlayer of leukocytes are expanded by a 3 × 3 matrix.
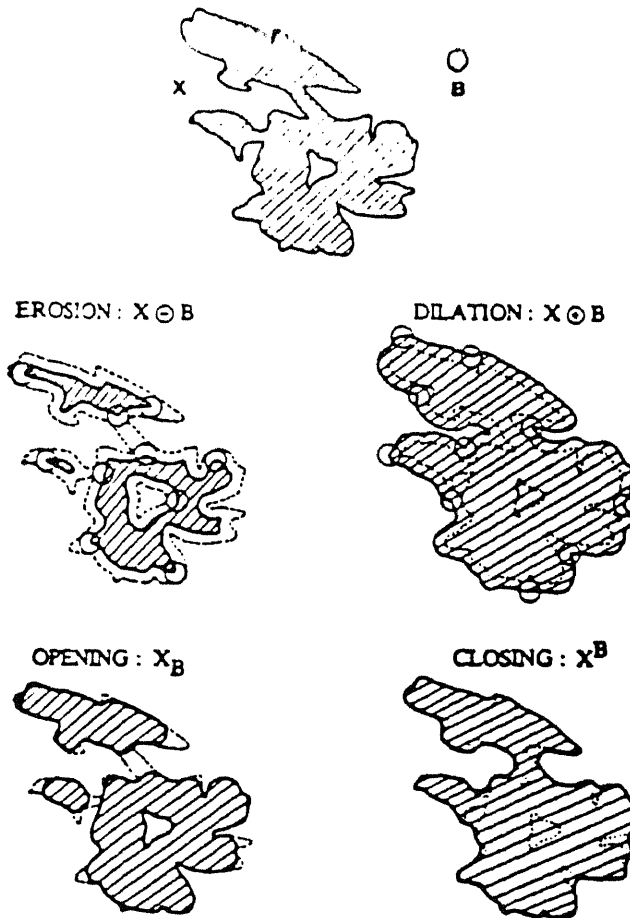
Figure 10: Erosion-dilation pairs show different effects on the morphologic sphere X probed by structuring element B. Left hand side tell X shrinked by B first, and dilated by B following, the structure of X is separated into 3 parts, this process we call it **opening**. Right hand side tell X dilated by B, and shrinked by B in order, the hole in X is filled by B, we call it **closing**.

also thin line, such process we call *opening*, will give us an effect of fig.11 shown. And

some morphological shape leukocytes will divide into many parts.

In practical applications, dilation and erosion pairs are used in sequence, either

dilation of an image followed by the erosion of the dilated result(opening), or erosion

followed by dilation(closing). From fig.10 shown us the basic application of morpho-

logical filtering with two processing, opening and closing. In either case, the result of

iteratively applied dilations and erosions is an elimination of specific image's detail
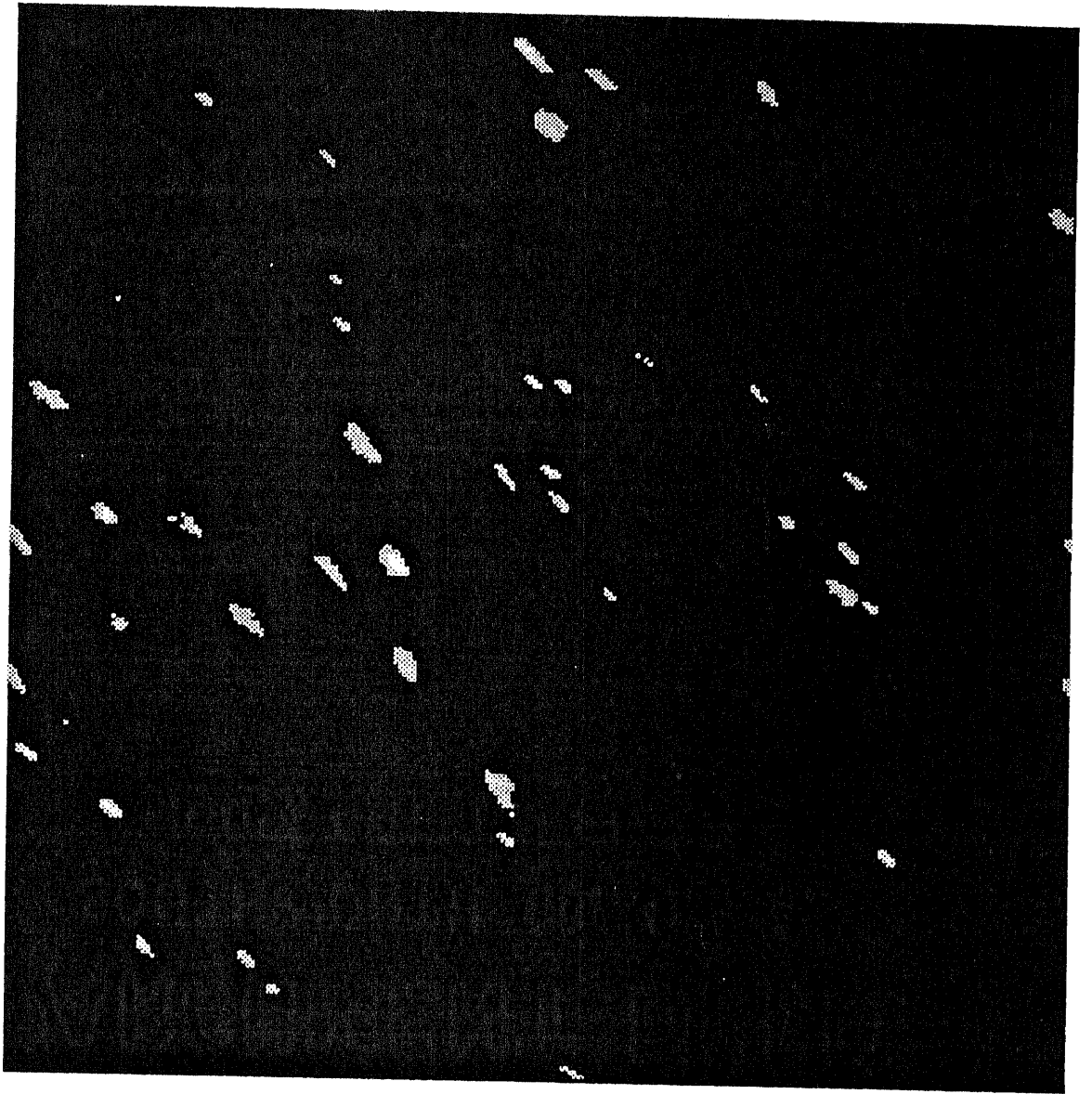
Figure 11: Use the technique of opening to process the result of fig. 5 can delete the noise in the scene, but will give us false information. Compare with the technique of modified interpolation, some leukocytes have critical size are "killed" by structuring element.
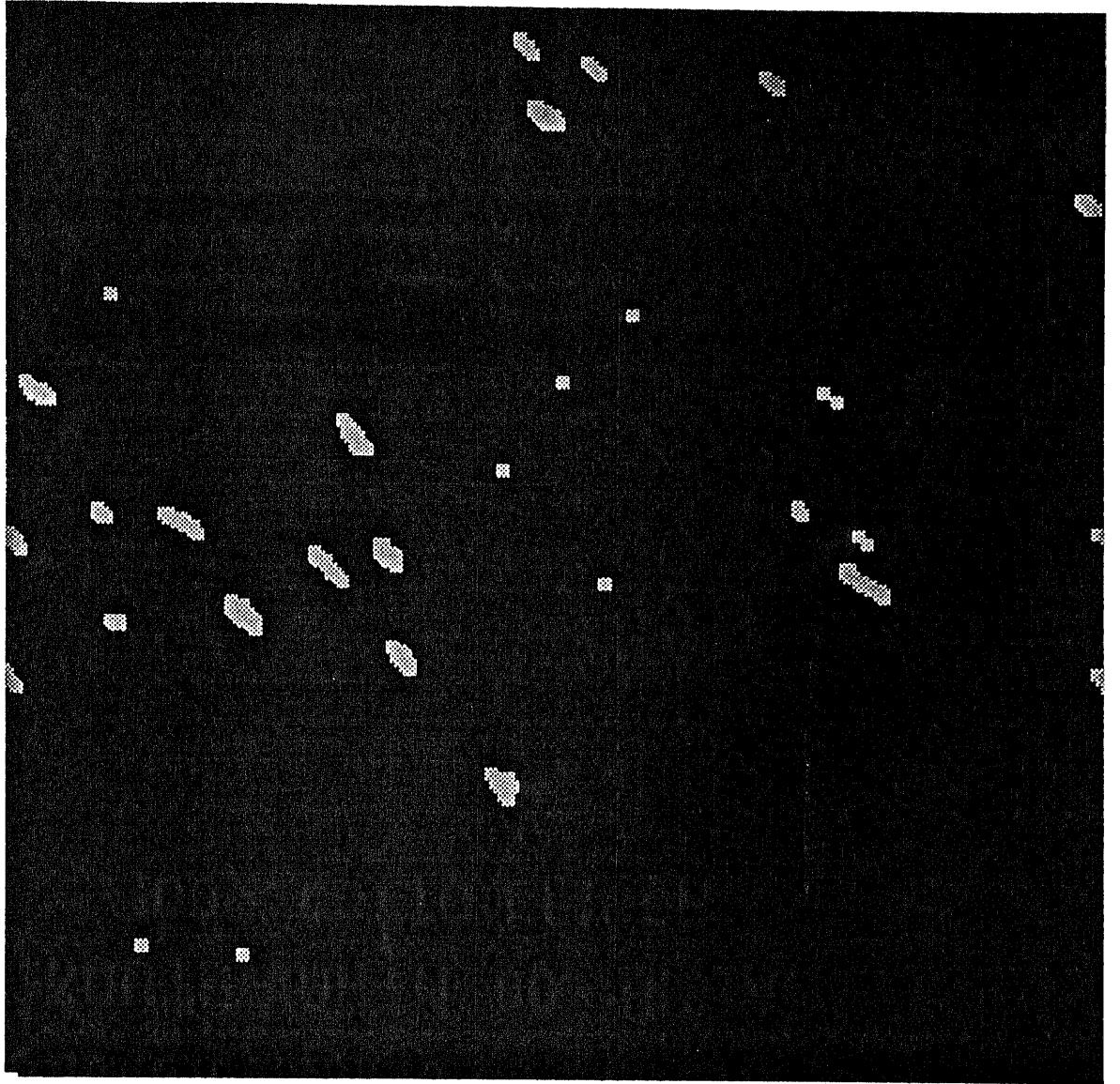
Figure 12: Use the technique of closing to process the result of fig. 5 show the merge effect of separate objects.

smaller than the structuring element without the global geometric distortion of un-suppressed features.[17] In this analysis, from fig.5 known the given picture is" two valued", noise that is smaller than the picture detail can be removed by a process of erosion and dilation. Fig. 12 is the effect of closing comparing with opening that it will merge the nearby spots.

3.5 Tracking Technique

For the purpose of counting the PMN's in a 256 × 256 window, the image shall turn to bilevel image without noise existing. The image processing techniques we discussed above are for preparing the next procedure.

The basic of this algorithm is from the sequential segmentation, the concept is concerned in processing a point, of the result at previously processed points that is neighborhood (connectedness) base on the same criteria. In these inherently se-quential methods, the processing that is performed at a point, and the criteria for accepting it as part of an object, can depend on information obtained from earlier processing of other points, and in particular on the nature and location of the points already accepted as parts of objects.

Using the sequential approach to detect possible object points, once some such points have been detected then more complex computations can be used to track the objects. The detection computations following the processed image can be relatively simple, may have to be performed at every point, since it need only detect every

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points of object.

The tracking criterion based on gray level and direction can depend in a comparison between the current point(j,i) and its candidate neighbors, so as to discriminate against candidates whose gray levels etc. do not resemble that of (j,i), if desired, in our analysis, we want to accept all candidate points that satisfy the tracking criterion. And we define that leukocyte is an connected(8-adjacent to point(j,i)) components.

The following is the algorithm for the counting technique in the processed image of leukocyte adhesion.

(1) Set up a count main routine to scan the predefined window from the address of (1,1), the raster direction is right and down, accept the first point meeting the detection criterion, and assign this point to be the initial point of a object that is to be tracked.

(2) For each object (leukocyte) currently being tracked, apply the appropriate tracking criterion to the points in its acceptance; adjoin the resulting accepted point to the object, This criterion depends on the gray level of the points, if no new points are accepted into the object, tracking of object has terminated.

(3) Erase the points of object, return to main count routine to add 1, and starting at adjacent pixel of preceding initial point of object to detect the following object.

(4) Repeat procedure (2) and (3).

(5) When the bottom row is reached, the count process is complete, and the description yields the number of PMN in a predefined window.

Fig. 13 displays the counting mechanism in term of the concept of connectedness (8- path) of objects to trace the same criteria using recursive program. This algorithm is effective in counting the numbers in fig.7 and the others processed binary images.

TRACK

TO FIND THE NEIGHBORS OF(J,I)

IF (J,I−1).NE. 0 CALL TRACK

IF (J−1,I−1).NE. 0 CALL TRACK

IF (J−1,I).NE. 0 CALL TRACK

IF(J−1,I+1).NE. 0 CALL TRACK

IF (J,I+1).NE. 0 CALL TRACK

IF (J+1,I+1).NE.0 CALL TRACK

IF (J+1,I).NE. 0 CALL TRACK

IF (J+1,I−1).NE. 0 CALL TRACK

AND ERASE THE POINTS
WHICH HAVE BEEN TRACKED
TILL THE LAST POINT
AND ALL ITS'NEIGHBORS
ALL EQUAL TO 0
EARSE ITSELF

AND RETURN TO COUNT

BACK TO THE ADDRESS OF(J,I)

SEARCH ANOTHER PIXEL NOT
EQUAL TO 0

COUNT

SCAN THE WINDOW FROM THE

ADDRESS OF (1,1)

WHEN (J,I).NE.0 THEN CALL

TRACK

HOW MANY RETURN THAT

TRACK SEND IT BACK

EQUAL TO THE NUMBER OF

LEUKOCYTE

Figure 13: The counting mechanism of leukocyte adhesion

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4 Discussion and Conclusion

4.1 Discussion

In our analysis, if it were to be required to define enhancement, it would be particularly difficult because one man's enhancement may be another man's noise. As a rule, enhancement broadly refers to manipulation of imagery to present to the viewer. Nevertheless, since the target object is the leukocyte, then the situation is obvious to process.

As known, broad categories of enhancement techniques might be listed as follows: (a) intensity mappings or point process; (b) edge sharpening or spatial processes; (c) artifact generation. The method of histogram equalization is classified to points processes, and it has many motivating factors. From a practical viewpoint, motivation for the use of this method arise from the simplicity of the operation as well as potential for real time implementation, additional one is that of attempting the removal of monotonic nonlinearities experienced in our image. Turn to statistical motivated point processes, the image histogram becomes particularly significant. The question often arises as to what enhancement techniques can be utilized when the gray levels are not well distributed by quantizing process. This method is most useful when there exists a finely quantized image from which there are an abundant but narrowly distributed number of quantization levels that can be stretched over a broader but

fewer number of gray shades. The subtle adjacent-in-gray scale changes which occur most often in the original image are stretched to become more obvious at the expense of losing gray levels that occur less frequently.

There are three general argument in favor of histogram equalization. They are (a) maximum zero order entropy. (b) monotonic nonlinearity compensator. (c) preprocessing normalizer.[1] Maximum zero order entropy means that an equalized image presents to the viewer every gray level in an equally likely mode. This is a maximum entropy mode, but may or may not be a desirable operation as fig.4(a) shows. The motivation provided by monotonic nonlinearity compensator is derived from the fact that, for a large number of bits of quantization, the equalized image will be the same as the equalized object, provided the object was passed through strictly monotonic processes. The third motivation of a preprocessing normalizer that each numeric value occurs equally as often as every other value and, as such, guarantees the same amount of image energy as in any other histogram equalized image. This is a particularly useful property for comparing images as inputs to further data extraction algorithms. as next step in thresholding. It is not necessary to simply stick with histogram equalization as the only statistically motivated point process of interest. Naturally an output image could be generated with any distribution desired. The histogram of an image combined with collateral data may suggest other point process mapping, such as histogram modification.[9]

Definitely, spatial processes applied in the Fourier domain, using ramp or other

monotonically increasing functions in the spatial frequency plane is another possible assessment in this analysis.

Obviously, modified interpolation or mathematical morphological filtering, are not suitable for global processes. The greatest advantage of these two noise filtering is that applied together, as in this study, they can be used for any size object, whether it is greater than 3×3 matrix, or smaller than 3×3 matrix. The possible methods to delete the noise have also been introduce by many studies. [13] [14] Image enhancement, smoothing and noise filtering by use of local statics or global information have been developed for many years, and it applied to many complicated computation for individual case (picture). Within the experimental data, 40 frames per rat heart, every picture has its unique characteristic of gray level distribution, and there are many diverse differences between frames. It is difficult to find any optimal global parameter to fit all the 40 frames per rat heart. Differences may be caused by the unstable experimental environment, such as vibration of focal plane, focus sharpness judged by the human eye, temperature influence to vidicon camera to affect system gain during longtime experiment, etc. From inspecting the experimental data, use of any local statics or global statics information to delete noise or smoothing will not give us any significant results.

One of the difficulties we encounter is from the experimental system. In the RTE system, the HP machine only offer FORTRAN 77 to develop software. In our analysis, we need to use recursion to do the tracking techniques, (see appendix: subroutine

COUNT) as we know many commonly used programming languages such as FOR-TRAN, COBOL do not allow recursive programs. The solution to our experimental problem can be derived and stated quite simply using recursive techniques, and can be programmed in FORTRAN or COBOL by simulating the recursive solution using more elementary operation.[18][2]

In general, a nonrecursive version of a program will execute more efficiently in term of time and space than will a recursive version. Sometimes a recursive solution is the most natural and logical way of solving a problem. The conflict between machine efficiency and programmer efficiency is another interesting topic arise from this software developing.

4.2 Conclusion

Image processing algorithms are presented in this work in order to provide biomedical investigators with tools to get results devoid human uncertainty. Further research in this area is to evaluate the accuracy of the number of fluorescent labeled PMN's experimental data between pre and after processing images. It is also possible to extend the image processing techniques to gray-level morphology method to enhance and extract the object directly.

Appendix

A   : Digital image program I2

```
FTN66
$CDS ON
$EMA /A/ ! revision: Jan.15,1991 by LIN, YEE-RUH
$FILES 1,1
        PROGRAM I2
C       ------- ------
C
C
C       April,1983                      Wolfgang Braun
C                                       UMDNJ DEPT.PHYSIOLOGY
C       August,1985                     Alan J. Stein
C                                       UMDNJ DEPT.PHYSIOLOGY
C       September,1987                  Arthur B. Ritter
C                                       UMDNJ DEPT.PHYSIOLOGY
C       Jan,1991                        Lin Yee-Ruh
C                                       NJIT DEPT.BIOMED. ENG
C       PROGRAM I2
C ....is a program to interact with the Quantex Digital Image
C       MEMORY. It is a dialog oriented program, designed to ex-
C       plain the functions and ask for necessary inputs and out
C       puts. Emphasis is made on achieving a multiuse modular
C       and self-documenting design. IMAG91 is a merge of the ol
C       IMAG2 and SLAVE programs with the PTOP and FMP calls
C       eliminated and the changes in exec read and write calls
C       the Quantex modified to run on the HP A-900.
C
C
C       Program description:
C       The mainroutine initializes the program to a defined
state.
C       It computes all necessary logical unit numbers on the HP
IB
C       Bus with the given address in the function call. It will
C       check if the power on the digitizer is turned on!
C       While the dimension for the workspace is dynamic (i.e.
C       the dimensions are dependent on loser input) it will ask
for
C       the x-y boundaries.
C       Note: In this program setup the maximum space defined in
C       COMMON /A/ is 256*256!
C       After this initialization process the program starts its
C       guiding menu to lead you through the program.
C       Before stopping the program the ending sequence will clo
C       all opened files.
C
C       The parameters are as follows:
C         IARRY  : workspace accessive for the user
C         IPXL   : reserved project space for picture processing
C         LX,LY  : actual line length,number of lines of the imag
C                  residing in the workspace.
C         LSX,LSY: starting address of the residing image
C         LU,LQTX: Logic unit number of the
terminal,Quantex,HP2240A
C          ,I2240
C         IFLAG, : represents the state of a Writefile
```

```
C          IFLGR :          "         "         "    " " Readfile
C                          -1 : not yet logged on
C                           0 : close open files
C                           1 : no file open
C                           2 : NF option was used; no files will be
allowed
C                          > 10 : a file was created and is opened
C       Note: all these parameters are global and passed via
COMMON!
C          JEQT,IEQT,IMENU are local dummy parameters.
C
C       External subroutines:
CONTR,FILER,LOGIN,PROC,MATH,QWRIT,TFMGR
C       Calling procedure    : RU,IMAGXX
C
C
C       **************************
C       ** M A I N R O U T I N E **
C       **************************
C
C       This is the main routine of the program.
C       It initializes and guides the user through a mode menu.
C
C       INITIALIZATION
C
        COMPLEX SPECT
        COMMON /A/ IARRY(256,256),IPXL(256,256)
        COMMON LU,LQTX,ISC,JSC,LUBUS
        COMMON /INIT/LX,LY,LSX,LSY,NAPX,NAPY,MAXLY
        COMMON /FLAG/IFLAG,IFLGR
        COMMON /BUFR/ JBUF(128)
        COMMON /STACK/ ISTAK(56),IPTR
        COMMON /HISTO/ IHIST(0:255)
        LU = LOGLU(LU)
        LX = 0
        LY = 0
        IBELL = 3400B
        NAPX = 20
        NAPY = 75
        MAXLY = -1
        IRETR = 0
        IPTR  = 1
        ISWITCH = 0

C->The address of Quantex is set to 4! (Note in LBGET function

        LQTX = LBGET(LU,4,ISC,ISWITCH) ! ISWITCH = 0; RETURN
SELECT CODE

C OF QUALIFYING DEVICE. ISWITCH = 1; FIND QUALIFYING DEVICE
WHOSE
C SELECT CODE MATCHES ISC.

        ISWITCH = 1
```

```
            ENDIF
         ENDIF
         IF (IMENU.EQ.6.AND.IRETR.EQ.1) CALL PROC(IARRY,IRETR)
         IF (IMENU.EQ.7) GOTO 30
         GOTO 20

C->Ending sequence

30       WRITE (LU,32)
32       FORMAT(/" IMAGE:  Ending sequence begun . . .")
         IF (IFLAG.LT.10.AND.IFLGR.LT.10) GOTO 34
         IFLAG = 0
         CALL FILER(0,IARRY)
34       CALL LOGIN
         STOP 0001
         END


         FUNCTION LBGET(LU,IAD,KSC,ISWITCH)
C        -------- ----- -- ---

C->Loop to search for QUANTEX bus number

         DO 10,LLU=7,63
         LBGET = LLU
         CALL EXEC(100015B,LLU,I,J,K)   ! The no-abort option is
used here
         GOTO 10                        ! This line is executed on
error

C->Logical match and fooling the compiler

2        IF (IAND(J,37400B).EQ.17400B.AND.IAND(K,37B).EQ.IAD)THEN
            IF(ISWITCH.EQ.0)THEN
               KSC=IAND(J,77B)
               RETURN
            ELSE
            IF(KSC.EQ.IAND(J,77B))RETURN
            ENDIF
         ENDIF
10       CONTINUE
         LBGET = 0

C->Error message

         WRITE (LU,12) IAD
12       FORMAT(" LU address "I2," cannot be computed on this
bus!")
         RETURN
         END
C
C        *********************
C        ** SUBROUTINE TFMGR  **
C        *********************
C
```

```
C       Transfers a file into memory (or reads from Quantex mem.
C       It is the read supervisor. It asks for necessary info an
C       branches to the requested operation.
C
        SUBROUTINE TFMGR(IARRY)
C       ---------- ----- -----
        EMA IARRY
        COMMON LU
        COMMON /INIT/LX,LY,LSX,LSY
        DIMENSION IARRY(256,256)
10      WRITE (LU,12)
12      FORMAT(//" Would you like to "/
     1"        1. read from Quantex memory (what's on the
     screen),"/
     2"        2. read from an existing data file, or "/
     3"        3. return to main menu ?")
        READ (LU,*,ERR=10) IANS
        IF (IANS.EQ.1) GOTO 20
        IF (IANS.EQ.3) RETURN
        IF (IANS.NE.2) GOTO 10
        CALL FILER(1,IARRY)
        GOTO 40
20      WRITE (LU,22)
22      FORMAT(//" Type 0 to get a screen cursor; type 1000 to
     return"/
     1" to the previous menu.")
24      WRITE (LU,26)
26      FORMAT(//" Type your start address (column,row)?  _")
        READ (LU,*,ERR=24) LSX,LSY
        IF (LSX.EQ.1000.OR.LSY.EQ.1000) GOTO 10
        IF (LSX.EQ.0.OR.LSY.EQ.0) CALL CURSR(IARRY)
        IF (LSX.GT.512.OR.LSY.GT.512) GOTO 24
        IF (LSX.EQ.0.OR.LSY.EQ.0) GOTO 24
30      WRITE (LU,32)
32      FORMAT(//" How many columns and rows? _")
        READ (LU,*,ERR=30) LX,LY
        IF (LX.GT.256.OR.LY.GT.256) GOTO 30
        CALL QDIMR(IARRY)
40      RETURN
        END
C
C       ****************************
C       ** SUBROUTINE  Q D I M R    **
C       ****************************
C
C       Quantex Digital Image Memory Read...
C       prepares the array string to set up Quantex for sending
the
C       requested data from a defined location.
C
        SUBROUTINE QDIMR(IARRY)
C       ---------- ----- -----
        EMA IARRY
        COMMON LU,LQTX,ISC,JSC,LUBUS
```

```
      COMMON /INIT/LX,LY,LSX,LSY
      DIMENSION INTO(10),IARRY(256,256),IBUF(256),NPL(5)
      JCLMN = LSX
      JROW = LSY
      DO 10 I=1,LX
      ICLMN =JCLMN + I-1
      DO 10 J=1,LY
      IROW =JROW +J - 1
      CALL ADRCV(IROW,ICLMN,NPL)

C->NECESSARY ARRAY VARS

      INTO(1) = 00475B
      INTO(2) = 21002B
      INTO(3) = IOR(ISHFT(NPL(1),8),NPL(2))
      INTO(4) = IOR(ISHFT(NPL(3),8),NPL(4))
      INTO(5) = IOR(ISHFT(NPL(5),8),03B)
      CALL ADRCV(0,LX,NPL)
      INTO(6) = IOR(ISHFT(NPL(1),8),NPL(2))
      INTO(7) = IOR(ISHFT(NPL(3),8),NPL(4))
      INTO(8) = IOR(ISHFT(NPL(5),8),017B)
      IX = 1
C->Do not send EOI but require it from Q.

C     CALL EXEC(3,LQTX+2500B,34000B)

C->Send a IFC (interface clear) to get Q. attention
C
      CALL EXEC(3,LUBUS+5100B)
      CALL EXEC(2,LQTX+2100B,INTO,8)
      CALL EXEC(1,LQTX+100B,IBUF,IX)
 10   IARRY(J,I)=IBUF(1)
      CALL EXEC(3,LUBUS+5100B)
      CALL SEPAR(IARRY)
C->Separate the compressed workspace
      RETURN
      END
C
C     *********************************
C     **    SUBROUTINE QWRIT          **
C     *********************************
C
C ...is a control unit for most output functions.
C
      SUBROUTINE QWRIT(IARRY)
C     ---------- ----- -----
      EMA IARRY
      COMMON LU,LQTX,ISC,JSC,LUBUS
      COMMON /INIT/LX,LY,LSX,LSY
      DIMENSION IARRY(256,256)
      IBELL = 3400B
 10   WRITE (LU,12)
 12   FORMAT(///" You want to write into Quantex memory."/
     1 " To do so I need more information."//
```

```
       2 "    1. Read in an image first."/
       3 "    2. Utilize an available test pattern."/
       4 "    3. Use the data we already have in the program's
memory."/
       5 "    4. Go back into main menu."//
       6 " Please type the number of your request (1-4)?  _")
        READ (LU,*,ERR=10) IREQ
        IF (IREQ.EQ.1) GOTO 1111
        IF (IREQ.EQ.2) GOTO 2222
        IF (IREQ.EQ.3.AND.LX.GT.0) GOTO 3333
        IF (IREQ.EQ.3.AND.LX.EQ.0) WRITE (LU,14) IBELL
        IF (IREQ.EQ.4) RETURN
        GOTO 10
14      FORMAT(A1,"There isn't any data in the program's
memory!")

C->Branch to the appropriate request.

1111   CALL TFMGR(IARRY)
        IF (LX.GT.0) GOTO 3333
        GOTO 10

2222   WRITE (LU,30)
30      FORMAT(//"    Choose one of the following test
patterns:"//
       1"   1.Black dot in white area "/
       2"   2.Vertical line"/
       3"   3.Two dots"/
       4"   4.Dotted square"//
       5"    Your selection?  _")
        READ (LU,*,ERR=2222) INUM
        IF (INUM.EQ.1000) GOTO 10
        IF (INUM.LT.1.OR.INUM.GT.4) GOTO 2222
        CALL TPAT(IARRY,INUM)

C-> Now definitely have an image

3333   WRITE (LU,42)
42      FORMAT(//' Now we have something to write!'/
       1 ' Select one of the following possibilities:'//
       2 '    1. Write the image beginning at the predefined
location.'/
       3 '    2. Write the image into a defined window.'/
       4 '    3. Use the automatic placement routine.'/
       5 '    4. Store the image in a file.'/
       6 '    5. Use the cursor to find the best location for the
image.'/
       7 '    6. Go back to menu.               _'/)
        READ (LU,*,ERR=3333) ISELC
        IF (ISELC.LT.1.OR.ISELC.GT.6) GOTO 2222
        IF (ISELC.EQ.1) CALL WQTX(IARRY)
        IF (ISELC.EQ.2) CALL WINDW(IARRY)
        IF (ISELC.EQ.3) CALL AUTO(IARRY)
        IF (ISELC.EQ.4) CALL FILER(0,IARRY)
```

```
            IF (ISELC.EQ.5) CALL CURSR(IARRY)
            IF (ISELC.EQ.4.OR.ISELC.EQ.5) GOTO 3333
            RETURN
            END

            SUBROUTINE TPAT(IARRY,INUM)
C           ---------- ---- ----- ----
            EMA IARRY
            COMMON /INIT/LX,LY
            DIMENSION IARRY(256,256)
            LX = 64
            LY = 64
            DO 10 I=1,64
            DO 10 J=1,64
10          IARRY(I,J) = 200

C-> Choose which to do

            GOTO (100,200,300,400) INUM

100         DO 120 I=30,35
            DO 120 J=30,35
120         IARRY(I,J) = 0
            RETURN

200         DO 220 I=31,33
            DO 220 J=10,54
220         IARRY(J,I) = 0
            RETURN

300         DO 320 I=14,18
            DO 320 J=30,35
            IARRY(J,I) = 0
320         IARRY(J,I+32) = 0
            RETURN

400         DO 420 I = 17 , 47 , 6
            DO 420 J = 17 , 47 , 6
            IF (I.EQ.17.OR.I.EQ.47.OR.J.EQ.17.OR.J.EQ.47) THEN
                IARRY(I,J) = 0
                IARRY(I,J+1) = 0
                IARRY(I+1,J) = 0
                IARRY(I+1,J+1) = 0
            ENDIF
420         CONTINUE
            RETURN
            END
            SUBROUTINE AUTO(IARRY)
C           ---------- ---- -----
            EMA IARRY
            COMMON LU
            COMMON /INIT/ LX,LY,LSX,LSY,NAPX,NAPY,MAXLY
            COMMON /STACK/ ISTAK(56),IPTR
            DIMENSION IARRY(256,256)
```

```
C->Initilize

        ILFT = 20
        IRT = 450
        ITOP = 75
        IBTM = 475
        IFLAG = 0

C->If NAPX & NAPY (20,75) then just go to 400 (write to left
top)

        IF (NAPX.EQ.20.AND.NAPY.EQ.75) GOTO 400

C->Menu

10      WRITE (LU,12)
12      FORMAT(//"     Auto Placement Menu"//
     1" 1. Place the image in the top left corner of the
screen."/
     2" 2. Overwrite the previous image."/
     3" 3. Write the image to the next free area on the
screen."/
     4" 4. Overwrite one of the other preceding images."/)
        READ (LU,*,ERR=10) IANS
        IF (IANS.LT.1.OR.IANS.GT.4) GOTO 10
        GOTO (100,200,400,300) IANS

C->    Clear stack

100     IPTR = 1
        NAPX = ILFT
        NAPY = ITOP
        GOTO 400

C-> Pop one, write to that location

200     CALL POP (NAPX,NAPY)
        GOTO 400

C-> Pop until correct one found, overwrite

300     WRITE(LU,302)
302     FORMAT(/"Which image, counting in the order in which the
were"/
     1"put up?    _")
        READ (LU,*) IANS
        KOUNT = (( IPTR - 1) / 2) - IANS + 1
        DO 310 I=1,KOUNT
310     CALL POP (NAPX,NAPY)


C->Check to see if new row needed
```

```fortran
400     NN = NAPX + LX
        IF (NN.GT.IRT) THEN
                        NAPX = ILFT
                        NAPY = NAPY + MAXLY + 5
        ENDIF

C->Check to see if bottom out of range

        NN = NAPY + LY
        IF (NN.GT.IBTM) THEN
                        ISLY = LY
                        LY = IBTM - NAPY
                        IFLAG = 1
        ENDIF

C->Store old values of LSX,LSY; write to screen

        ISLSX = LSX
        ISLSY = LSY
        LSX = NAPX
        LSY = NAPY
        CALL WQTX(IARRY)

C->Restore old values

        NAPX = LSX
        NAPY = LSY
        LSX = ISLSX
        LSY = ISLSY
        IF (IFLAG.EQ.1) LY = ISLY
        CALL PUSH (NAPX,NAPY)

C->Compute new NAPX

        NAPX = NAPX + LX + 5

C->Check for new MAXLY

        IF (LY.GT.MAXLY) MAXLY = LY
        RETURN
        END

        SUBROUTINE PUSH(IVAL,JVAL)
C       ---------- ---- ---- ----
        COMMON /STACK/ ISTAK(56),IPTR
        ISTAK(IPTR) = IVAL
        IPTR = IPTR + 1
        ISTAK(IPTR) = JVAL
        IPTR = IPTR + 1
        RETURN
        END

        SUBROUTINE POP(IVAL,JVAL)
C       ---------- --- ---- ----
```

```
      COMMON /STACK/ ISTAK(56),IPTR
      IPTR = IPTR - 1
      JVAL = ISTAK(IPTR)
      IPTR = IPTR - 1
      IVAL = ISTAK(IPTR)
      RETURN
      END
C
C     *******************************
C     **  SUBROUTINE  W Q T X      **
C     *******************************
C
C     Write to Quantex memory
C ...initializes the Quantex for write procedures.
C
C     It sets up the outputstring in Quantex "NIBBLE" format
C     then it puts out the dimensioned IARRY.
C
      SUBROUTINE WQTX(IARRY)
C     ----------- ---- -----

      EMA IARRY
      COMMON LU,LQTX,ISC,JSC,LUBUS
      COMMON /INIT/LX,LY,LSX,LSY
      DIMENSION NPL(5),INTO(5),ITEMP(128),IARRY(256,256)
C
C->Convert the workspace into a compressed output field
C  and set up the address string.

      CALL COMB(IARRY)
      ICLMN = LSX
      JROW = LSY
      NLX=INT((LX+1)/2.)
      DO 10 J=1,LY
      IROW = JROW + J - 1
      CALL ADRCV(IROW,ICLMN,NPL)
      INTO(1) = 00461B
      INTO(2) = 21002B
      INTO(3) = IOR (( ISHFT (NPL(1),8)) , NPL(2))
      INTO(4) = IOR (( ISHFT (NPL(3),8)) , NPL(4))
      INTO(5) = IOR (( ISHFT (NPL(5),8)) , 0017B)
C
      DO 5 J1=1,LX,2
      JJ=INT((J1+1)/2.)
      ITEMP(JJ)=IARRY(J,J1)
    5 CONTINUE
C
C->EXEC will cause a Interface Clear -) the only way
C  to get Quantex attention!
C
      CALL EXEC(3,LUBUS+5100B)
      CALL EXEC(2,LQTX+2100B,INTO,5)
   10 CALL EXEC(2,LQTX+2100B,ITEMP,NLX)
C 10  WRITE (LQTX) (INTO(I),I=1,5),(IARRY(J,J1),J1=1,LX,2)
```

```
                CALL SEPAR(IARRY)
                RETURN
                END
C
C         ***************************
C         ** SUBROUTINE   W I N D W **
C         ***************************
C
C         Description:
C         window replaces the dormant workspace to any defined
C         position in the memory(==screen).
C
                SUBROUTINE WINDW(IARRY)
C         ---------- ----- -----

                EMA IARRY
                COMMON LU
                COMMON /INIT/LX,LY,LSX,LSY
                DIMENSION IARRY(256,256)

C->Store the original window

                ISLX = LX
                ISLY = LY
                ISLSX = LSX
                ISLSY = LSY


C->Dialog, and do the window

10              WRITE (LU,12)
12              FORMAT(" Type your new start address (column,row)? _")
                READ (LU,*,ERR=10) LSX,LSY
                IF (LSX.EQ.1000) RETURN
                IF (LSX.GT.512.OR.LSY.GT.512) GOTO 10
20              WRITE (LU,22)
22              FORMAT(" Type length of field (x,y)? _")
                READ (LU,*,ERR=20) LX,LY
                IF (LX.GT.256.OR.LY.GT.256) GOTO 20
                CALL WQTX(IARRY)
                WRITE (LU,24)
24              FORMAT(" Would you like to save this image? _")
                READ (LU,26) IANSW
26              FORMAT(A1)
                IF (IANSW.EQ.1HY) CALL FILER(0,IARRY)

C->Restore the original window

                LX = ISLX
                LY = ISLY
                LSX = ISLSX
                LSY = ISLSY
                RETURN
                END
C         ***************************
```

```
C          ** SUBROUTINE   C U R S R    **
C          *****************************
C
C          Description:
C           Cursor display on the monitor. A dot on the monitor, at
C           the defined position, will appear. After typing G (go)
C           the cursor is removed and the original data is written
C           back.
C
           SUBROUTINE CURSR(IARRY)
C          ---------- ----- -----
           EMA IARRY
           COMMON LU
           COMMON /INIT/LX,LY,LSX,LSY
           DIMENSION IRST(3,3),IARRY(256,256)
           ISLSX = LSX
           ISLSY = LSY
           LX = 10
           LY = 10
           ISLX = LX
           ISLY = LY

C->Save the IARRY contents of the cursor position

C          DO 2 I=1,LY
C          DO 2 J=1,LX
C 2        ISAVE(I,J) = IARRY(I,J)
C
10         WRITE (LU,12)
12         FORMAT(/" Type the cursor address (column,row)? _")

C->Read the cursor position and store the memory contents in
IRST.

           READ (LU,*,ERR=10) LSX,LSY
           IF (LSX.EQ.1000) RETURN
           CALL QDIMR(IARRY)
           ICC = 0
           IF (IARRY(1,1).LT.128) ICC = 255
           LX=3
           LY=3
           DO 20 I=1,LX
           DO 20 J=1,LY
           IRST(J,I) = IARRY(J,I)
20         IARRY(J,I) = ICC

C->Write the cursor to monitor

           CALL WQTX(IARRY)
           WRITE (LU,30)
30         FORMAT(" Hit any key and <return> to continue! _")
32         READ (LU,34) IANSW
34         FORMAT(A1)
           IF (ITLOG(IANSW).EQ.0) GOTO 32
```

```
C->Restore the monitor greycolours & orig. IARRY values

          DO 40 I=1,LX
          DO 40 J=1,LY
40        IARRY(J,I) = IRST(J,I)
          CALL WQTX(IARRY)
C
C         DO 50,I=1,LY
C         DO 50,J=1,LX
C 50      IARRY(I,J) = ISAVE(I,J)

C->Restore the original window

          LX = ISLX
          LY = ISLY
          LSX = ISLSX
          LSY = ISLSY
          RETURN
          END
          SUBROUTINE SCALR(IARRY,IPXL)
C         ---------- ----- ----- ----

          EMA IARRY,IPXL
          COMMON LU
          COMMON /INIT/LX,LY,LSX,LSY
          DIMENSION IARRY(256,256),IPXL(3,256)
          ISLSX = LSX
          ISLSY = LSY
          ISLX = LX
          ISLY = LY
          IANS = 1HX
1         LX = 170
          LY = 1
          J1 = 0
          ICC = 300

C->Let's open our textbooks to page 1, class . . .

10        WRITE (LU,12)
12        FORMAT(/"Input row number:    _")
          READ (LU,*,ERR=10) LSY
          IF (LSY.EQ.1000) RETURN
          IF (LSY.LT.1.OR.LSY.GT.512) GOTO 10
14        IF (IANS.NE.1HX) GOTO 19
          WRITE (LU,16)
16        FORMAT(/"White or black line (W/B) :    _")
          READ (LU,18) IANS
18        FORMAT(A1)
19        IF (IANS.EQ.1HW) ICC = 170
          IF (IANS.EQ.1HB) ICC = 30
          IF (ICC.GT.255) THEN
               IANS = 1HX
               GOTO 14
```

```
            ENDIF

C->Here we go Quantex, here we go!!  (knock wood)

            DO 22 I=1,3
            LSX = 2 + 170 * (I - 1)
            CALL QDIMR(IARRY)
            DO 20 J=1,170
            J1 = J + 170 * (I - 1)
            IPXL(I,J) = IARRY(1,J)
            IARRY(1,J) = ICC
            RJ1 = FLOAT(J1)
            IF (J1 / 5.EQ.RJ1 / 5.0) IARRY(1,J) = 100 - IDIM(50,ICC)
            IF (J1 / 50.EQ.RJ1 / 50.0) IARRY(1,J) = 250 * IDIM(31,IC
20          CONTINUE
            CALL WQTX(IARRY)
22          CONTINUE
            WRITE (LU,30)
30          FORMAT(/"Right row (Y/N) :     _")
            READ (LU,18) JANS
            IF (JANS.EQ.1HY) GOTO 50

C->Wheah yu thin yu goin wit dat!

40          DO 44 I=1,3
            LSX = 2 + 170 * (I - 1)
            DO 42 J=1,170
            IARRY(1,J) = IPXL(I,J)
42          CONTINUE
            CALL WQTX(IARRY)
44          CONTINUE
            IF (JANS.EQ.1HY) GOTO 70
            GOTO 1

C->He likes it - hey Mikey!

50          WRITE (LU,52)
52          FORMAT(/"Please locate the scalar nearest to your"/
        1"starting point; count the number of markers and input
(Note:"/
        2"the lightest/darkest markers occur at 10,20,30,etc.")
            READ (LU,*,ERR=50) IPT
            ICOL = 5 * IPT + 1
54          WRITE (LU,56)
56          FORMAT(/"Please type in whether your starting point is"/
        1" 1. Far Left"/
        2" 2. Near Left"/
        3" 3. Center"/
        4" 4. Near Right"/
        5" 5. Far Right"/
        6"Enter the corresponding number :     _")
            READ (LU,*,ERR=54) IEXCT
            ICOL = ICOL + IEXCT - 3
```

```
C->You tell 'em---No,you(!) tell 'em!

        WRITE (LU,60) ICOL,LSY
60      FORMAT(/"The address of your starting pixel is
("I3,","I3,")."/
        1"Take the starting point of your window accordingly!")
        GOTO 40

C->I'us dard as a dooornail, but he ressuurreecctteed me!

70      LSX = ISLSX
        LSY = ISLSY
        LX = ISLX
        LY = ISLY
        RETURN
        END
C
C
C       ***********************
C       ** SUBROUTINE GRAB      **
C       ***********************
C
C
        SUBROUTINE GRAB
C       ---------- ----

        COMMON LU,LQTX,ISC,JSC,LUBUS
        COMMON /INIT/ LX,LY,LSX,LSY,NAPX,NAPY,MAXLY
        DIMENSION INTO(2)

C->Reset NAPX & NAPY for new screen

        NAPX = 50
        NAPY = 75
        MAXLY = -1

C->Necessary array vars for quantex

        INTO(1) = 00442B
        INTO(2) = 07777B
        CALL EXEC(3,LUBUS+5100B)
        CALL EXEC(2,LQTX+2100B,INTO,-3)
        CALL EXEC(3,LUBUS+5100B)
        RETURN
        END

C       ****************************
C       ** SUBROUTINE  L O G I N  **
C       ****************************
C
        SUBROUTINE LOGIN
C       ---------- -----

C
```

```
C->This subroutine,'LOGIN', just prints a header and a closing
C  statement on logging off.
C
       COMMON LU
       COMMON /FLAG/IFLAG,IFLGR
       IF (IFLAG.EQ.-1) GOTO 30

C->Logging off

       WRITE (LU,2)
2      FORMAT(" IMAGE:  Logging off now . . . bye!"//)
       RETURN

C->Logging on

30     WRITE (LU,32)
32     FORMAT(//////" IMAGE:  A data acquisition and processing
program"/
      1" servicing the Quantex digital image memory in
communication "/
      2" with the Hewlett-Packard 1000 computer system."///)
       CALL EXEC(12,0,2,0,-1)  !  wait 1 sec, then continue
       IFLAG = 1
       IFLGR = 1
       RETURN
       END
C
C      *****************************
C      ** SUBROUTINE  A D R C V    **
C      *****************************
C
       SUBROUTINE ADRCV(IRW,ICLMN,NPL)
C      ----------  -----  ---  -----  ---
C
C
C      Address Conversion takes a given row and column, and cal
C      calculates the Quantex memory address or pixelcount.
C      As output a array in nibble QUANTEX format is provided.
C
C      Remark: the Quantex memory has a 18 Bit address. Since w
C        are working on a 16 Bit integer base we prevent overfl
C        by dividing the row into blocks of 128 lines.
C       If the row number is )512 the program will print a erro
C       message and terminate the program!
C       Input  : IRW,ICLMN
C       Output : NPL(1-5)
C
       COMMON LU
       COMMON /FLAG/IFLAG,IFLGR
       DIMENSION NPL(5)
       IROW = IRW
       DO 10,I=1,4
       J = I-1
       IF (IROW.LE.128) I = 4
       IROW = IROW - 128
```

```
10      CONTINUE
        NPL(5) = J + 000140B
        IROW = IROW + 128
        IF (IROW.LE.128) GOTO 20
        WRITE (LU,12)
12      FORMAT("Row too big!!!")
        IFLAG = 0
        CALL LOGIN

C->Calculate the 16 Bit address and combine the 4 Bit data wit
C   4 Bit Quantex control data (2-6).

20      IF (IROW.EQ.0) IROW = 1
        IADR = ((IROW-1) * 512) + ICLMN
        ISHRG = IADR
        DO 30 I=1,4
        J = I + 1
        NPL(I) = IAND (ISHRG,017B)
        JJ = ISHFT(J,4)
        NPL(I) = IOR (NPL(I),JJ)
        ISHRG = IADR
        ISHRG = ISHFT (ISHRG,-4)
        IADR = ISHRG
30      CONTINUE
        RETURN
        END
C
C       ************************
C       ** SUBROUTINE COMBINE  **
C       ************************
C
C       combines 2 adjacent integers in a 16 bit word (2n-1
spaced)
C
C        Input  : IARRY containing 0 to 255 integers
C        Output : IARRY  with compressed  contents.
C
        SUBROUTINE COMB(IARRY)
C       ---------- ---- -----
        EMA IARRY
        COMMON /INIT/LX,LY,LSX,LSY
        DIMENSION IARRY(256,256)
        DO 111 I=1,LY
        DO 111 J=1,LX
        J1 = J+1
111     IARRY(I,J) = IOR (ISHFT (IARRY(I,J),8) , IARRY(I,J1))
        RETURN
        END
C
C       ************************
C       ** SUBROUTINE SEPARATE  **
C       ************************
C
C       Separates the two compressed pixelintegers (16 bit)
```

```
C
C         Input  : IARRY containing a 2*8bit information in the
C                     (2n-1) field location.
C         Output : IARRY containing 0 to 255 integers.
C
C

          SUBROUTINE SEPAR(IARRY)
C         ---------- ----- -----
          EMA IARRY
          COMMON /INIT/LX,LY,LSX,LSY
          DIMENSION IARRY(256,256)
          DO 111 I=1,LY
          DO 111 J=1,LX,2
          ISAVE = IARRY(I,J)
          J1 = J+1
          IARRY(I,J) = ISHFT (IARRY(I,J) , -8)
          IARRY(I,J1) = IAND (ISAVE,0377B)
111       CONTINUE
          RETURN
          END
C         ****************************
C         ** SUBROUTINE  F I L E R    **
C         ****************************
C
C
C         Description:
C         does all filehandling in a dialog mode. It keeps track o
C         opened files with FLAG and IFLGR, and allows only one op
C         file at a time.
C
C            A data compression is done to save memory(see COMB).
C         call proc. : CALL FILER(IRQST,IARRY)    &   COMMON's
C
          SUBROUTINE FILER(IRQST,IARRY)
C         ---------- ----- ----- -----
C
          EMA IARRY
          COMMON LU
          COMMON /INIT/LX,LY,LSX,LSY
          COMMON /FLAG/IFLAG,IFLGR
          COMMON /BUFR/JBUF(128)
          DIMENSION INBUF(64),IARRY(256,256),JTIME(15),LBUF(128)
          DIMENSION IHEAD(16),ITIME(5)
          DATA IHEAD/16*1H /
          CALL LGBUF(JBUF,128)

C->control to read or write sections

          IF (IRQST.EQ.1) GOTO 500

C->write section

          IF (IFLGR.GT.10) CLOSE
  (88,IOSTAT=IERR,ERR=999,STATUS='KE')
```

```
        IF (IFLAG.GT.10) GOTO 100   ! file is already open,ready
be written
        IF (IFLAG.EQ.0) GOTO 200    ! file needs to be closed

C->dialog with loser

        IFLAG = IFLAG + 10
        WRITE (LU,2)
2       FORMAT(//////"IMAGE:  Program Filer"//)
        WRITE (LU,4)
4       FORMAT(/"Please input file namr:  _")
        READ (LU,6) (INBUF(I),I=1,64)
6       FORMAT(64A2)

C->open file

        OPEN(88,IOSTAT=IERR,ERR=999,FILE=INBUF,STATUS='UN')
        WRITE (LU,8)
8       FORMAT(/"IMAGE:  file opened successfully"/)

C->puts header on file

        WRITE (88,10,IOSTAT=IERR,ERR=999)
10      FORMAT(1X,10HIMAGE FILE)
        CALL FTIME(JTIME)
        WRITE (88,12,IOSTAT=IERR,ERR=999) (JTIME(I),I=1,15)
12      FORMAT(15A2)

C->get system time; store msecs with size of image

        CALL EXEC(11,ITIME)
100     ENCODE(32,102,IHEAD) ITIME(2),LX,LY,LSX,LSY
102     FORMAT(5I4)
        WRITE (88,104,IOSTAT=IERR,ERR=999) (IHEAD(I),I=1,16)
104     FORMAT(16A2)
        WRITE (LU,106)
106     FORMAT(/"IMAGE:  parameters written to file"/)

C->compress data; write to file one line at a time

        CALL COMB(IARRY)
        IFLAG = 11
        NEWLX = (LX + 1) / 2
        DO 110 I=1,LY
        DO 108 J=1,LX,2
108     LBUF((J + 1) / 2) = IARRY(I,J)
110     WRITE (88,112,IOSTAT=IERR,ERR=999 (LBUF(K),K=1,NEWLX)
112     FORMAT(128A2)
        WRITE (LU,114)
114     FORMAT(/"IMAGE:  data written to file  "/)

C->separate data

        CALL SEPAR(IARRY)
```

```
C->close file

200     CLOSE(88,IOSTAT=IERR,ERR=999,STATUS='KE')
        WRITE (LU,202)
202     FORMAT(/"IMAGE:   file closed successfully"/)
        IF (IFLAG.GT.10) IFLAG = IFLAG-10
        IF (IFLGR.GT.10) IFLGR = IFLGR-10
        RETURN

C->READ SECTION
C  ----  -------

500     IF (IFLAG.GT.10) CLOSE(88,IOSTAT=IERR,ERR=999,STATUS='KE
        IF (IFLGR.GT.10) GOTO 600 !   file is open already
        IF (IFLAG.EQ.0) GOTO 200  !   close up & get out

C->open file

        IFLGR = IFLGR+10
        WRITE (LU,2)
        WRITE (LU,4)
        READ (LU,6) (INBUF(I),I=1,64)
        OPEN (88,IOSTAT=IERR,ERR=999,FILE=INBUF,STATUS='OL')

C->read header

        WRITE (LU,8)
600     READ (88,602,IOSTAT=IERR,ERR=999) (IHEAD(I),I=1,16)
602     FORMAT(16A2)
        WRITE (LU,602) (IHEAD(I),I=1,16)
        READ (88,602) (IHEAD(I),I=1,16)
        WRITE (LU,602) (IHEAD(I),I=1,16)

C->assign file data to LX,LY,etc.

        READ (88,604,IOSTAT=IERR,ERR=999)(IHEAD(I),I=1,10)
604     FORMAT(10A2)
        DECODE (32,606,IHEAD) ITIME(2),LX,LY,LSX,LSY
606     FORMAT(5I4)

C->read file data

        NEWLX = (LX + 1) / 2
        DO 610 I=1,LY
        READ (88,112,IOSTAT=IERR,ERR=999) (LBUF(J),J=1,NEWLX)
        DO 608 J=1,LX,2
608     IARRY(I,J) = JBUF((J + 1) / 2)
610     CONTINUE

C->separate workspace

        CALL SEPAR(IARRY)
        WRITE (LU,612)
```

```
612    FORMAT(/"IMAGE:  file read successfully"/)
       GOTO 200

C->if error occurs, call FIERR routine

999    CALL FIERR(IERR)
       RETURN
       END
       SUBROUTINE FIERR(IERR)
C      ---------- ----- ----
       COMMON LU

       IF (IERR.EQ.462.OR.IERR.EQ.506) THEN
           WRITE (LU,10)
       ELSE IF (IERR.EQ.459.OR.IERR.EQ.508) THEN
           WRITE (LU,11)
       ELSE IF (IERR.EQ.502) THEN
           WRITE (LU,12)
       ELSE IF (IERR.EQ.507) THEN
           WRITE (LU,13)
       ELSE IF (IERR.EQ.514) THEN
           WRITE (LU,14)
       ELSE IF (IERR.EQ.515) THEN
           WRITE (LU,15)
       ELSE IF (IERR.EQ.532) THEN
           WRITE (LU,16)
       ELSE IF (IERR.EQ.533) THEN
           WRITE (LU,17)
       ELSE IF (IERR.EQ.546) THEN
           WRITE (LU,18)
       ELSE
           WRITE (LU,19) IERR
       ENDIF

10     FORMAT(/"IMAGE: File not found")
11     FORMAT(/"IMAGE: File already open")
12     FORMAT(/"IMAGE: Duplicate file name")
13     FORMAT(/"IMAGE: Wrong security code")
14     FORMAT(/"IMAGE: Directory full")
15     FORMAT(/"IMAGE: Illegal file name")
16     FORMAT(/"IMAGE: Cartridge not found - probably not
mounted")
17     FORMAT(/"IMAGE: No room on cartridge")
18     FORMAT(/"IMAGE: File has too many extents")
19     FORMAT(/"IMAGE: File handling error "I3," occured.")

       WRITE (LU,100)
100    FORMAT(/"Would you like to continue with the program,"/
      1"or stop here?    _")
102    READ (LU,104) IANS
104    FORMAT(A1)
       IF (IANS.EQ.1HC) RETURN
       IF (IANS.NE.1HS) THEN
           WRITE (LU,106)
```

```
106      FORMAT(/"Please answer with a C or S    _")
         GOTO 102
      ENDIF

      IFLAG = 0
      CALL LOGIN
      STOP 0005
      END

      SUBROUTINE PROC(IARRY,IRETR)
C     ---------- ---- ----- -----

      COMPLEX SPECT
      EMA IARRY,IPXL,SPECT
      COMMON LU
      COMMON /INIT/LX,LY
      DIMENSION
ITAG(20),IARRY(256,256),IPXL(256,256),SPECT(256,256)
      DIMENSION IOFF(36)
      IBELL = 3400B
      ITAG(4) = LX
      ITAG(5) = LY
      ITAG(10) = 0
      IF (LX.EQ.0.OR.LY.EQ.0) WRITE (LU,10)
10    FORMAT(//" Warning !!!! there is no workspace defined.")
20    WRITE (LU,22)
22    FORMAT(///" Here are the goodies for picture processing!
     1" The following routines work on your given workfield"/
     2" Note: Some of the routines will change the picture"/
     3"          information. If you want to keep your original"/
     4"          it is recommended to go back to menu and store"/
     5"          the workfield first!")
24    WRITE (LU,26)
26    FORMAT(" Choose one of the following: "/
     1"      1. Neighborhood Enhancement-Background spot
elimination. "/
     2"      2. Expand/Compress the graycolor range of the image.
     3"      3. Histogram equalization."/
     4"      4. Smoothing by average filtering."/
     5"      5. Enhancment for more edge contrast. "/
     6"      6. Enhancing with laplacian."/
     7"      7. Kirsch Edge Detection Algorithm."/
     8"      8. Butterworth high-pass filter."/
     9"      9. Homomorphic filtering."/
CC   &"     10. Power Spectrum equalization."/
CC   1"     11. Weiner filtering."/
     2"     12. Signal Averaging."/
     3"     13. Subtraction of two windows."/
     4"     14. Threshold filtering."/
     5"     15. Display the histogram."/
     6"     16. Percentage of image in grayscale range."/
     7"     17. Pause."/
     8"     18  Smooth the noise."/
     9"     19. Count the number of leukocyte adhesion."/
```

```
      1"  20. Erosion."/
      2"  21. Dialation."/
      3"  22. Back to main menu.")

         WRITE (LU,28) IBELL         ! Ring bell
28       FORMAT(A1)
         READ (LU,*,ERR=24) ITAG(1)
         IF(ITAG(1).EQ.22) GOTO 999
         IF (ITAG(1).GT.20.OR.ITAG(1).LT.1) GOTO 20
         IF (IRETR.EQ.2.AND.ITAG(1).LT.14) GOTO 24
         IF(ITAG(1).GE.2) GOTO 40
30       WRITE (LU,32)
32       FORMAT(/"Please enter lower & upper threshold boundaries
     _")
         READ (LU,*,ERR=30) ILTB,IUTB
         IF (ILTB.EQ.1000) GOTO 24
         IF (ILTB.LT.0.OR.IUTB.GT.255.OR.ILTB.GT.IUTB) GOTO 30
         ITAG(2) = ILTB
         ITAG(3) = IUTB
         CALL NGHBR(IARRY,IPXL,ILTB,IUTB)
         GOTO 24


40       IF(ITAG(1).NE.2) GOTO 50
C->Get old maximum value; store in ITAG(2)

         WRITE (LU,42)
42       FORMAT(/"Please enter the desired maximum graycolor  _")
         READ (LU,*,ERR=40) MAXGCL
         IF (MAXGCL.EQ.1000) GOTO 24
         IF (MAXGCL.LE.0.OR.MAXGCL.GT.255) GOTO 40
         ITAG(2) = MAXGCL
         CALL EXPND(IARRY,MAXGCL)
         GOTO 24


50       IF(ITAG(1).EQ.3) CALL HSTEQ(IARRY)
         IF(ITAG(1).EQ.4) CALL FILTR(IARRY,IPXL)
         IF(ITAG(1).EQ.5) CALL LAPL(IARRY,IPXL)
         IF(ITAG(1).EQ.6) CALL HOLPL(IARRY,IPXL)
         IF(ITAG(1).EQ.7) CALL KIRSH(IARRY,IPXL)
         IF(ITAG(1).GE.12) GOTO 70
         IF(ITAG(1).LE.7) GOTO 24
C->Here user decides which transform to use

60       WRITE (LU,62)
62       FORMAT(/"Which transform would you like to use:"//
     1"        1- Fourier Transform"/
     2"        2- Walsh Transform"/
     3"        3- I don't know what the fuck you're talking
     about."//)
         READ (LU,*,ERR=60) ITAG(3)
         ITAG(2) = ITAG(1)   ! This lets SHELL know which routine
     use.
         IF (ITAG(3).GE.1.AND.ITAG(3).LE.2) GOTO 68
         WRITE (LU,64)
```

```
64      FORMAT(/"Unfortunately, the filter you've chosen uses a
pro-"/
        1"cedure known as a Fast Fourier Transform.  This process
is"/
        2"wonderfully efficient when using an image whose size is
        3"a power of two (e.g., 64x64 or 128x128), but horrible
for"/
        4"other sizes.  If your image is not a power of two in
size,"/
        5"please don't try this filter.  This program wil die a
slow,"/
        6"painful death and your picture will be lost forever.")
        CALL EXEC (12,0,2,0,-5)      !  Give user a few seconds t
        GOTO 24                      !  digest the bad news
C->Store old values of LX and LY

68      LX1 = LX
        LY1 = LY
        IF(ITAG(1).GE.8.AND.ITAG(1).LE.11) CALL
SHELL(IARRY,SPECT,ITAG)
        GOTO 24


C->Here we take care of all the interactive routines

70      IF (ITAG(1).EQ.12)  CALL SAVRG(IARRY)
        IF (ITAG(1).EQ.13)  CALL SDIFF(IARRY)
        IF (ITAG(1).EQ.14)  CALL THRH(IARRY)
        IF (ITAG(1).EQ.15)  CALL HIST(IARRY)
        IF (ITAG(1).EQ.16)  CALL PCT(IARRY)
        IF (ITAG(1).EQ.17)  CALL EXEC(7)
        IF (ITAG(1).EQ.18)  CALL SMOTH(IARRY)
        IF (ITAG(1).EQ.19)  CALL COUNT(IARRY)
        IF (ITAG(1).EQ.20)  CALL ERSON(IARRY,IPXL)
        IF (ITAG(1).EQ.21)  CALL DATON(IARRY,IPXL)
        GOTO 24

C->Pause routine

80      PAUSE 1
        GOTO 24

999     RETURN
        END
        SUBROUTINE SAVRG(IARRY)
C       ---------- ----- -----

        EMA IARRY,IPXL
        COMMON LU
        COMMON /INIT/LX,LY,LSX,LSY
        COMMON /FLAG/ IFLAG
        DIMENSION IARRY(256,256),IPXL(256,256)
        IMAX = 0
        IMIN = 255
```

```
C->Feh!

10      WRITE (LU,12)
12      FORMAT(/"All windows must be of same size and saved in "
        1"data files for signal averaging - like to continue (Y/N
_")
        READ (LU,14) IANS
14      FORMAT(A1)
        IF (IANS.EQ.1HN) RETURN

C->Get count here

20      WRITE (LU,22)
22      FORMAT(/"How many windows will be averaged?  _")
        READ (LU,*,ERR=20) KOUNT
        IF (KOUNT.LT.2) GOTO 20

C->CALL THE PLUMBER,DEAR! (Seriously, call FILER to get LX & L

        CALL FILER(1,IARRY)

        DO 5 I = 1,LX
        DO 5 J = 1,LY
        IPXL(J,I) = IARRY(J,I)
5       CONTINUE
C
C NOW GET THE OTHER ARRAY
C
        DO 40 I = 2, KOUNT
        WRITE (LU,32) I
32      FORMAT (/"Please repeat for file # "I2)
        IFLAG = 1
        CALL FILER(1,IARRY)
        DO 25 J = 1 , LY
        DO 15 I2= 1 , LX
        IPXL(I2,J) = IPXL(I2,J) + IARRY(I2,J)
15      CONTINUE
25      CONTINUE
40      CONTINUE
C
C  NOW WE DIVIDE BY KOUNT
C
        DO 30 I=1,LX
        DO 30 J=1,LY
        IARRY(J,I) = IPXL(J,I) / KOUNT
        IF (IARRY(J,I).GT.IMAX) IMAX = IARRY(J,I)
        IF (IARRY(J,I).LT.IMIN) IMIN = IARRY(J,I)
30      CONTINUE
C->Wanna store this shit?

60      WRITE (LU,62)
62      FORMAT(/"Would you like to store this image in a file no
_")
        READ (LU,14) IANS
```

```
              IF (IANS.EQ.1HN) RETURN
              IFLAG = 1
              CALL FILER(0,IARRY)
              RETURN
              END
              SUBROUTINE SDIFF(IARRY)
C             ---------- ----- -----
              EMA IARRY,IPXL
              COMMON LU
              COMMON /INIT/LX,LY,LSX,LSY
              COMMON /FLAG/ IFLAG
              DIMENSION IARRY(256,256),IPXL(256,256)
              IMAX = 0
              IMIN = 255

C->Make sure loser has prepared to use this routine

10            WRITE (LU,12)
12            FORMAT(/"IMAGE:   This image sutraction routine requires
that"/
              1"both images involved must be the same size, and stored"
              2"in data files."//
              3"Is it ok to continue at this point?    _")
              READ (LU,14) IANS
14            FORMAT(A1)
              IF (IANS.EQ.1HN) RETURN

C->Here we get the first file

20            WRITE (LU,22)
22            FORMAT(/"This program will now ask you for the two
filenames - "/
              1"Please keep in mind that you may put either one in
first,"/
              2"since the program will take the absolute value of the"/
              3"difference."///)
              IFLAG = 1
              CALL FILER(1,IARRY)

C STORE THE FIRST ARRAY
              DO 8 I=1,LX
              DO 8 J=1,LY
              IPXL(J,I)=IARRY(J,I)
8             CONTINUE

C->Now we do the second file

              IFLAG = 1
              CALL FILER(1,IARRY)
50            WRITE (LU,52)
52            FORMAT(/"Crunch, crunch, crunch...")
C
              DO 30 I=1,LX
              DO 30 J=1,LY
```

```
              IARRY(J,I)=IABS(IARRY(J,I)-IPXL(J,I))
              IF (IARRY(J,I).GT.IMAX)  IMAX = IARRY(J,I)
              IF (IARRY(J,I).LT.IMIN)  IMIN = IARRY(J,I)
30            CONTINUE

C->Files?

70            WRITE (LU,72)
72            FORMAT(/"Would you like to store this image in a file no
     _")
              READ (LU,14) IANS
              IF (IANS.EQ.1HN) RETURN
              IFLAG = 1
              CALL FILER(0,IARRY)
              RETURN
              END
              SUBROUTINE SAERR(IERR,ITAG)
C             ---------- ----- ---- ----

              LU = LOGLU(LU)
              IFUNC = ITAG(8)
              WRITE (LU,10) IERR,IFUNC
10            FORMAT(/"IMAGE:  Signal Averaging error "I6," occured."/
     1"The function was "I2," .  This can be deciphered by"/
     2"looking at the slave program"/
     3"Would you like to continue with the program, or stop"/
     4"here?  _")
11            READ (LU,12) IANS
12            FORMAT(A1)
              IF (IANS.EQ.1HC) RETURN
              IF (IANS.EQ.1HS) STOP 0007
              WRITE (LU,14)
14            FORMAT(/"Please answer the question with C or S    _")
              GOTO 11
              END
              SUBROUTINE THRH(IARRY)
C             ---------- ---- -----

              EMA IARRY
              COMMON LU
              COMMON /INIT/LX,LY
              DIMENSION
     IARRY(256,256),ISTGC(10),ISUTL(10),ISLTL(10),ISCNT(10)
              DATA IQM,IEM/1H?,1H!/
              DO 111,LN=1,10
10            WRITE (LU,12)
12            FORMAT(/" *** Program THRESHOLD *** "//
     1" ? : prints an explanation of the thresholding
     procedure;"/
     2" ! : will display your executed operations;"/
     3" G : will go back to the signal processing menu;"/
     4" <return> continues the program.")
              WRITE (LU,14)
14            FORMAT("*_")
```

```
        READ (LU,201) ISERV
        IF (ISERV.EQ.IQM) CALL EXPL(LU)
        IF (ISERV.EQ.IEM) THEN
            CALL DISPL(LN,ISTGC,ISUTL,ISLTL,ISCNT,LU)
            GOTO 10
        ENDIF
        IF (ISERV.EQ.1HG) RETURN

C->Initialization

        ICNT = 0
        ILTL = 0
        IUTL = 255


C->Loser input

20      WRITE (LU,22)
22      FORMAT(/" Type your Upper Threshold Limit (UTL):   _"/)
        READ (LU,*,ERR=20) IUTL
24      WRITE (LU,26)
26      FORMAT(/" Type your Lower Threshold Limit (LTL):   _"/)
        READ (LU,*,ERR=24) ILTL
28      WRITE (LU,30)
30      FORMAT(/" To which graycolour value should your given"/
     1" range be assigned?   _"/)
        READ (LU,*,ERR=28) ITGCV


C->LOSER INPUT CHECK

        FLAG = 0
        IF (IUTL.LT.0.OR.IUTL.GT.255) FLAG = 1
        IF (ILTL.LT.0.OR.ILTL.GT.255) FLAG = 1
        IF (ITGCV.LT.0.OR.ITGCV.GT.255) FLAG = 1
        IF (FLAG.NE.1) GOTO 333
        WRITE (LU,106)
106     FORMAT(//" Input out of range!! "//)
        LN = LN-1
        GOTO 10
333     IF (IUTL.EQ.0) IUTL = 255
        ISTGC(LN) = ITGCV
        ISUTL(LN) = IUTL
        ISLTL(LN) = ILTL


C->Thresholding

        DO 222 LM=1,LY
        DO 222 N1=1,LX
        IF (IARRY(N1,LM).LT.ILTL.OR.IARRY(N1,LM).GT.IUTL) GOTO 2
        IARRY(N1,LM) = ITGCV
        ICNT = ICNT+1
222     CONTINUE
        ISCNT(LN) = ICNT
111     CONTINUE
201     FORMAT(A1)
```

```
       RETURN
       END

       SUBROUTINE EXPL(LU)
C      ---------- ---- --
       WRITE (LU,101)
101    FORMAT(" THRH EXPLANATION !"/
      1" Program THRH works with the following algorithm "/
      2"          fz(x,y)= / 1 if f(x,y) is ELEMENT of z"/
      3"                     0 otherwise"/
      4" This formula provides 3 different ways of operation:"/
      5"      1. If a upperthreshold limit is set "/
      6"         and the lower thrh. limit is default "/
      7"         then all greycolour values between 0"/
      8"         and utl. are changed to your given"/
      9"         greycolour value."/
      &"      2. If the ltl is set and default on the"/
      1"         utl.; greycolour values between ltl."/
      2"         and 255 are changed."/
      3"      3. If ltl. and utl. are set all values"/
      4"         in between are changed."/
      5"   combination of 1.,2. and 3. is called semi-"/
      6"   thresholding. 1. is used to extract objects"/
      7"   from background or noise. 2. removes sharp"/
      8"   contrasts. 3. enhances greycolour ranges(if"/
      9"   known exactly), which can be used for edge"/
      &"   detection."//)
       RETURN
       END


       SUBROUTINE DISPL(L,ISTGC,ISULT,ISLTL,ISCNT,LU)
C      ---------- ----- - ----- ----- ----- ----- --
C   ...displays the range and assigned graycolour value
C   of the THRH process including the number of changed
C   pixels.
       DIMENSION ISLTL(10),ISULT(10),ISTGC(10),ISCNT(10)

       DO 111,I=1,(L-1)
       WRITE (LU,101) I,ISLTL(I),ISULT(I),ISTGC(I),ISCNT(I)
101    FORMAT(I2". RANGE:"I3,"-"I3," CHANGED TO:"I3," # OF
CP:"I8)
111    CONTINUE
       WRITE (LU,102)
102    FORMAT(//)
       RETURN
       END

       SUBROUTINE HIST(IARRY)
C      ---------- ---- -----

C->Initialization

       EMA IARRY
       COMMON LU
```

```
      COMMON /INIT/LX,LY
      COMMON /HISTO/ IHIST(0:255)
      DIMENSION IARRY(256,256),IFT(130),ISAVE(17)
      DATA ICHAR/1H+/

C->Reset the IHIST array

      DO 555,I = 0,255
555   IHIST(I) = 0
      MAX = 0
      IOFFS = 0

C->Default group for histogram display.

      LM = 15
      SUM = 0
C->Sort greyc. values
1     DO 111,LN=1,LY
      DO 111,L=1,LX
      INDX = IARRY(LN,L)
      SUM = SUM + IARRY(LN,L)
111   IHIST(INDX) = IHIST(INDX)+1

C->Reset the first 17 ISAVE vars

      DO 666,I=1,17
666   ISAVE(I) = 0

C->Print header

2     WRITE (LU,101)
101   FORMAT(//"   #     N      I              frequency"/
     1"-- 0 --------I--------------------",
     2"----------------------------------")

C->Grouping and scaling

      DO 222,J=1,17
      DO 333,I=1,LM
      JJ = (IOFFS+((J-1)*LM)+I)
      ISAVE(J) = ISAVE(J)+IHIST(JJ)
333   CONTINUE
222   IF (ISAVE(J).GT.MAX) MAX = ISAVE(J)

C->Normalize the histogram frequency

      DIV = 50./FLOAT(MAX)

C->Output

      DO 444,I=1,17
      II = IOFFS+(LM*I)
      LN = INT(DIV*ISAVE(I))
```

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```
C->No 0A1 format possible -) LN must be >0

        IF (LN.LT.1) LN = 1
        ENCODE (130,102,IFT) LN
        WRITE (LU,IFT) II,ISAVE(I),(ICHAR,ICONT=1,LN)
102     FORMAT('(I4,I8," I",'I3,'A1)')
444     CONTINUE

C->The option (zooooom)
        WRITE(LU,1007) SUM
1007    FORMAT(/"  IOD for the selected window   ",I12)
        WRITE (LU,105)
105     FORMAT(/" Would you like to see a more detailed histogra
_")
        READ (LU,201) IANS
201     FORMAT(A1)
        IF (IANS.EQ.1HN) RETURN
        WRITE (LU,107)
107     FORMAT(/" Type your new range (low,high): _")
        READ (LU,*) NR1,NR2

C->Calculate (and correct) the new group size

        LM = INT (IABS ( (NR2 -NR1) / 17) + 0.5)
        IF ((17 * LM).LT.(MAX0 (NR1 , NR2))) LM = LM + 1

C->Reset the old ISAVE array

        DO 777,I=1,17
777     ISAVE(I) = 0
        IOFFS = NR1
        IF (NR2.LT.NR1) IOFFS = NR2
        GOTO 2
        END
        SUBROUTINE PCT(IARRY)
C       ---------- --- -----
        EMA IARRY
        COMMON LU
        COMMON /INIT/ LX,LY
        COMMON /HISTO/ IHIST(0:255)
        DIMENSION IARRY(256,256)

C-> Set IHIST array to zero

        DO 2 I=0,255
2       IHIST(I) = 0

C-> Sort graycolors (perform histogram operation)

10      DO 20 I=1,LY
        DO 20 J=1,LX
        IDUM = IARRY(J,I)
20      IHIST(IDUM) = IHIST(IDUM) + 1
```

```
C-> Loser input

30      WRITE (LU,32)
32      FORMAT(/" Please input graycolor range, low to high  _")
        READ (LU,*,ERR=30) ILOW,IHIGH
        IF (ILOW.EQ.1000) RETURN
        IF (ILOW.LT.0.OR.IHIGH.GT.255.OR.ILOW.GT.IHIGH) GOTO 30

C-> Compute size, sum pixels in range, compute percentage

        ISIZE = LX * LY
        ISUM = 0
        DO 40 I=ILOW,IHIGH
40      ISUM = ISUM + IHIST(I)

        PERCT = ( FLOAT (ISUM) / FLOAT (ISIZE) ) * 100.0

C-> Give user result

        WRITE (LU,50) PERCT
50      FORMAT(/" This range of graycolors makes up "F5.2," percent"/
       1" of the image"/)
        RETURN
        END
C
        SUBROUTINE EXPND(IARRY)    !  EXPAND RANGE ROUTINE FOR
SLAVE
C       ---------- ------ -----    !  8/10/84  AJS
        EMA IARRY
        COMMON LX,LY,MAX
        DIMENSION IARRY(256,256)
        IOLD = -1

C->Search for old maximum

        DO 10 I=1,LY
        DO 10 J=1,LX
        IF (IARRY(J,I).GT.IOLD) IOLD = IARRY(J,I)
10      CONTINUE

C->Now we have old maximum and desired new maximum,
C  so we can compute a conversion factor.

        RMULT = FLOAT (MAX) / FLOAT (IOLD)

C->Do it!

        DO 20 I=1,LY
        DO 20 J=1,LX
        IARRY(J,I) = IARRY(J,I) * RMULT
20      CONTINUE

C->Done!
```

```fortran
      RETURN
      END
      SUBROUTINE HSTEQ(IARRY)
C     ---------- ----- -----
      EMA IARRY
      COMMON LU
      COMMON /INIT/ LX,LY
      DIMENSION IARRY(256,256),IR(256),S(256),IG(256)
      INTEGER K,M
      REAL XS,YS
C->Set IR and S to zero, get total number of points for divisi
5     WRITE(LU,15)
15    FORMAT(//'Please input the size of picture'/
     1'How many columns and rows?_')
      READ (LU,*,ERR=5) XS,YS
      IF (XS.GT.256.0.OR.YS.GT.256.0)  GOTO 5

      DO  10 K=0,255
      IR(K) = 0.0
      S(K) = 0.0
10    CONTINUE
      A=DBLE(XS*YS)

C->Get histogram (Note K+1 because R(1) <-> gray level 0)

      DO 20 I=1,LY
      DO 20 J=1,LX
      K = IARRY(J,I)
      IR(K) = IR(K) + 1.0
20    CONTINUE
      DO 70 K=0 ,255
      PRINT *,'NUM',IR(K),A
70    CONTINUE

C->Get S's (just a summation, or density function)
      S(0) = DBLE(IR(0) /A)
      DO 30 K=1,255
      S(K)=DBLE(IR(K)/A)+DBLE(S(K-1))
30    CONTINUE
      DO 1 K=0,255
      A=DBLE(XS*YS)
      PRINT*,'S(',K,')=',S(K),'IR(',K,')=',IR(K),A
1     CONTINUE
C->Now multiply by 256 & truncate to get 256 distinct levels

      DO 40 M=0,255
      IG(M)=INT (S(M)*256.0)-1
40    CONTINUE
      DO 60 M=0 ,255
      A=DBLE(XS*YS)
      PRINT *,'S(',M,')=',S(M),'IG(',M,')=',IG(M),A
60    CONTINUE
```

```
C->Map new values into IARRY

        DO 50 I=1,LY
        DO 50 J=1,LX
        M=IARRY(J,I)
        IF(IARRY(J,I).EQ.M) IARRY(J,I) =INT (IG(M))
50      CONTINUE
        RETURN
        END
C       **************************
C       ** SUBROUTINE  F I L T R  **
C       **************************
C
C------------------------------------------------------------------
---
C  ...applies a digital filter (F) to a time domain array.
C     (smoothing by averaging)
C     method: takes the average of the 8 surrounding (adjacent
C             pixels and assigns it to the center.
C------------------------------------------------------------------
---
C     Ext.: none
C     call: CALL FILTR(IARRY,IPXL)    &    COMMON's
C------------------------------------------------------------------
---
C     Inp. to outp chngs: IARRY
C
        SUBROUTINE FILTR(IARRY,IPXL)
C       ---------- ----- ----- ----
        EMA IARRY,IPXL
        COMMON LU
        COMMON /INIT/ LX,LY
        DIMENSION F(3,3) , IARRY(256,256) , IPXL(256,256)
        DATA F/.125,.125,.125,.125,0.,.125,.125,.125,.125/
        LYS = LY - 1
        LXS = LX - 1
        DO 111 I=2,LYS
        DO 111 J=2,LXS
        P=0.
        DO 222 K=1,3
        DO 222 L=1,3
        P = P + F(K,L) * IARRY(J + K - 2 , I + L - 2)
222     CONTINUE
        NP = INT (P + .5)
        IF (NP.LT.0) NP = 0
        IF (NP.GT.255) NP = 255
        IPXL(J,I) = NP
111     CONTINUE
        DO 333 I=2,LYS
        DO 333 J=2,LXS
        IARRY(J,I) = IPXL(J,I)
333     CONTINUE
```

```
      RETURN
      END
C     ******************************
C     ** SUBROUTINE  L A P L       **
C     ******************************
C
C----------------------------------------------------------------
---
C  ...applies the LAPLACIAN method to enhance the picture.
C     (2nd. order gradient)
C   I am using a laplacian divider of (1/5) to get a
C   continuously weighted result rather than a black/
C   white contrast.
C     method:  0  1  0
C              1 -4  1
C              0  1  0
C the result of the multiplication matrix is divided by 5.
C----------------------------------------------------------------
---
C     ext. subs: none
C     call proc: CALL LAPL(IARRY,IPXL)    &    COMMON's
C----------------------------------------------------------------
---
C     Inp. to outp chngs: IARRY
C
      SUBROUTINE LAPL(IARRY,IPXL)
C     ---------- ---- ----- ----
      EMA IARRY,IPXL
      COMMON LU
      COMMON /INIT/ LX,LY
      DIMENSION F(3,3) , IARRY(256,256) , IPXL(256,256)
      DATA F/0.,1.,0.,1.,-4.,1.,0.,1.,0./
      LYS = LY - 1
      LXS = LX - 1
      DO 111 I=2,LYS
      DO 111 J=2,LXS
      P = 0.
      DO 222 K=1,3
      DO 222 L=1,3
      P = P + F(K,L) * IARRY(I + K - 2 ,J + L - 2)
222   CONTINUE

C   Use divider!

      NP = INT (.5 + (P / 5.))
      IPXL(J,I) = NP
111   CONTINUE
      DO 333 I=2,LYS
      DO 333 J=2,LXS
      IARRY(J,I) = IARRY(J,I) - IPXL(J,I)
      IF (IARRY(J,I).LT.0) IARRY(J,I) = 0
      IF (IARRY(I,J).GT.255) IARRY(I,J) = 255
333   CONTINUE
      RETURN
```

```
      END
C
C      *******************************
C      ** SUBROUTINE  H O L P L      **
C      *******************************
C
C----------------------------------------------------------------
---
C  ...applies the LAPLACIAN method to enhance the picture.
C      (N-th. order gradient)
C  k1=1st neighbour field
C  k2=2nd neighbour field
C   method:
C      *******-K2
C      * ,K1 *
C      * *** *
C      * *X* *
C      * *** *
C      *     *
C      *******
C----------------------------------------------------------------
------
C      ext. subs.: none
C      call proc.: CALL HOLPL(IARRY,IPXL)   & COMMON's
C----------------------------------------------------------------
---
C      Inp. to outp. chngs: IARRY
C
       SUBROUTINE HOLPL(IARRY,IPXL)
C      ---------- ----- ----- ----
       EMA IARRY,IPXL
       COMMON LU
       COMMON /INIT/  LX,LY
       DIMENSION IARRY(256,256) , IPXL(256,256)
C initialisation
       K1 = 3
       K2 = 7
C calculation of the laplacian
C inner boundary
       DO 111 K = 4 , LY - 3
       DO 111 L = 4 , LY - 3
       P=0.
       DO 222 I = 1 , K1
       DO 222 J = 1 , K1
       IF (J.EQ.1.OR.J.EQ.K1) GOTO 10
       IF (I.EQ.1.OR.I.EQ.K1) GOTO 10
       GOTO 222
10     P = P + IARRY (I + K - 2 , J + L - 2)
222    CONTINUE
       SK1 = P
C  outer boundary
       P=0.
       DO 333 I=1,K2
       DO 333 J=1,K2
```

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```
        IF (J.EQ.1.OR.J.EQ.K2) GOTO 20
        IF (I.EQ.1.OR.I.EQ.K2) GOTO 20
        GOTO 333
20      P = P + IARRY(I + K - 4 , J + L - 4)
333     CONTINUE
        SK2 = P
        IPXL(K,L) =INT ((SK1/(K1*K1)) - ((SK2-SK1) / ((K2*K2) -
(K1*K1))))
111     CONTINUE
C  normalisation to 0-255
        DO 444 I=1,LY
        DO 444 J=1,LX
        IARRY(J,I) = IARRY(J,I) - IPXL(J,I)
        IF (IARRY(J,I).LT.0) IARRY(J,I) = 0
        IF (IARRY(J,I).GT.255) IARRY(J,I) = 255
444     CONTINUE
        RETURN
        END
C       ****************************
C       **  SUBROUTINE  K I R S H  **
C       ****************************
C
C--------------------------------------------------------------
---
C  ...applies the KIRSCH operator method for edge detection.
C  (the K-op. method is a 1st order x-y difference equation)
C       method: subtracts the sum of the left 3 pixels
C           from the right 3 pixels,then subtrcts the sum
C           from the upper 3 pxls from the lower 3 pxls.
C           finally it takes the maximum of this two subtractions.
C--------------------------------------------------------------
---
C       ext.sub's: none
C       call proc: CALL KIRSH(IARRY,IPXL)    &  COMMON's
C--------------------------------------------------------------
---
C       Inp. to outp. chngs: IARRY
C
        SUBROUTINE KIRSH(IARRY,IPXL)
C       ---------- ----- ----- ----
C initialisation
        EMA IARRY,IPXL
        COMMON LU
        COMMON /INIT/ LX,LY
        DIMENSION IARRY(256,256) , IPXL(256,256)
        LYS = LY - 1
        LXS = LX - 1
C calculation of the k-op.
        DO 111 I = 2 , LYS
        DO 111 J = 2 , LXS
        IPXL(J,I) = 0
        ILFT = IARRY (J-1,I-1) + IARRY(J-1,I) + IARRY(J-1,I+1)
        IUP = IARRY(J-1,I-1) + IARRY(J,I-1) + IARRY(J+1,I-1)
        IDWN = IARRY(J-1,I+1) + IARRY(J,I+1) + IARRY(J+1,I+1)
```

```
                IRGT = IARRY(J+1,I-1) + IARRY(J+1,I) + IARRY(J+1,I+1)
                IPXL(J,I) = MAX0 (IABS (IRGT - ILFT) , IABS (IUP - IDWN)
      / 3
111             CONTINUE
                DO 333 I = 2 , LYS
                DO 333 J = 2 , LXS
                IARRY(J,I) = IPXL(J,I)
                IF (IARRY(J,I).LT.0) IARRY(J,I) = 0
                IF (IARRY(J,I).GT.255) IARRY(J,I) = 255
333             CONTINUE
                RETURN
                END
                SUBROUTINE NGHBR(IARRY,IPXL)
C               ---------- ----- ----- ----
                EMA IARRY,IPXL
                COMMON LU
                COMMON /INIT/ LX,LY
                DIMENSION IARRY(256,256) , IPXL(256,256)
C
C->TILT!
C
                DO 20 I=1,LX
                DO 20 J=1,LY
                IPXL(J,I) = IARRY(J,I)
20              CONTINUE
C
C->MAY THE FORCE BE WITH YOU!
C
                DO 111 I = 3 ,LY-2 , 2
                DO 111 J = 3 ,LX-2 , 2
                IF (IARRY(J,I).GT.IUTB.OR.IARRY(J,I).LT.LTB) GOTO 111
C
                DO 222 I1 = I-2 , I+2
                DO 222 J1 = J-2 , J+2
                I2 = IABS (I1-I)
                J2 = IABS (J1-J)
                IF (I2.LT.2.AND.J2.LT.2) GOTO 222
                IF (IABS (IARRY(J1,I1) - IARRY(J,I)).GT.3) GOTO 222
C
                I3 = INT (.5 * (I1 + I))
                J3 = INT (.5 * (J1 + J))
                IPXL(J3,I3) = INT (.5 * (IARRY(J,I) + IARRY(J1,I1)))
                IF ((I2+J2).NE.3) GOTO 222
                I3 = I3 + 1
                J3 = J3 + 1
                IPXL(J3,I3) = INT (.5 * (IARRY(J,I) + IARRY(J1,I1)))
222             CONTINUE
111             CONTINUE
C
C->SILLY RABBIT, TRIX ARE FOR KIDS!
C
                DO 30 I=1,LX
                DO 30 J=1,LY
                IARRY(J,I)=IPXL(J,I)
```

```
30      CONTINUE
        RETURN
        END
C       SUBROUTINE SVGCR(IARRY,IPXL,ITAG)
C       ---------- ----- ----- ----
C       EMA IARRY,IPXL
C       COMMON LX,LY,IMAX,IMIN
C       DIMENSION IARRY(256,256),IPXL(256,256),ITAG(20)


C       SUBROUTINE SDFCR(IARRY,IPXL,ITAG)
C       ---------- ----- ----- ----
C       EMA IARRY,IPXL
C       COMMON LX,LY,IMAX,IMIN
C       DIMENSION IARRY(256,256) ,IPXL(256,256),ITAG(20)
C->The first thing we have to do is store the first array

        SUBROUTINE SHELL (IARRY,SPECT,ITAG)
C       ---------- -----  ----- ----- ----
        COMPLEX SPECT
        EMA IARRY,SPECT
        COMMON /INIT/ LX,LY
        DIMENSION IARRY(256,256) , SPECT(256,256) , ITAG(20)

C->Transform to frequency domain
        CALL FWD2D (IARRY,SPECT,ITAG)

C->Choose filter

        IF (ITAG(1).EQ.8) CALL BHPF(SPECT,ITAG)
        IF (ITAG(1).EQ.9) CALL HMPHC (SPECT)
CC      IF (ITAG(1).EQ.10) CALL POWER (SPECT)
CC      IF (ITAG(1).EQ.11) CALL BLIND (SPECT)

C->Now transform back to time domain

        CALL INV2D (IARRY,SPECT,ITAG)
C->Go back to image processing menu

        RETURN
        END

        SUBROUTINE FWD2D(IARRY,SPECT,ITAG)
C       ---------- ----- ----- -----
        EMA IARRY,SPECT
        COMPLEX SPECT,TEMP
        COMMON/INIT/ LX,LY
        COMMON /BUFRS/ TEMP(256)
        DIMENSION IARRY(256,256) , SPECT(256,256),ITAG(20)

C->Store one row at a time into buffers TEMPA and TEMPB, do on
C  dimensional transform, store in temporary arrays

        DO 6 I=1,LY
```

```
      DO 2 J=1,LX
      DMY = FLOAT (IARRY(J,I)) + 0.01  ! The .01 is so log (0)
doesn't happen
      IF(ITAG(1).EQ.9) DMY = LOG (DMY)   ! Homomorphic needs lo
first !
2     TEMP(J) = CMPLX (DMY,0.0)
      IF (ITAG(3).EQ.1) CALL FFT(TEMP,LX)
      IF (ITAG(3).EQ.2) CALL FWT(TEMP,LX)
      DO 4 J=1,LX
4     SPECT(J,I) = TEMP(J) * FLOAT(LX)
6     CONTINUE

C->Do transform on each column of transformed data

      DO 12 J=1,LX
      DO 8 I=1,LY
8     TEMP(I) = SPECT(J,I)
      IF (ITAG(3).EQ.1) CALL FFT(TEMP,LY)
      IF (ITAG(3).EQ.2) CALL FWT(TEMP,LY)
      DO 10 I=1,LY
10    SPECT(J,I) = TEMP(I)
12    CONTINUE
      RETURN
      END
      SUBROUTINE INV2D (IARRY,SPECT,ITAG)
C     ---------- -----  ----- ----- -----
      EMA IARRY,SPECT
      COMPLEX SPECT,TEMP
      COMMON/INIT/ LX,LY
      COMMON /BUFRS/ TEMP(256)
      DIMENSION IARRY(256,256) , SPECT(256,256),ITAG(20)

C->Have to put each column into temporary buffers, take comple
C  conjugate of data to make forward FFT into inverse

      DO 6 J=1,LX
      DO 2 I=1,LY
2     TEMP(I) = CONJG (SPECT(J,I))
      IF (ITAG(3).EQ.1) CALL FFT(TEMP,LY)
      IF (ITAG(3).EQ.2) CALL FWT(TEMP,LY)
      DO 4 I=1,LY
4     SPECT(J,I) = TEMP(I)
6     CONTINUE

C->Now do inverse transform on each row; Since we only had a
real
C  function to start with, take the real part and mult. by LX.

      DO 12 I=1,LY
      DO 8 J=1,LX
8     TEMP(J) = SPECT(J,I)
      IF (ITAG(3).EQ.1) CALL FFT(TEMP,LX)
      IF (ITAG(3).EQ.2) CALL FWT(TEMP,LX)
      DO 10 J=1,LX
```

```fortran
        IARRY(J,I) = LX * REAL ((TEMP(J)))
        IF (ITAG(1).EQ.9) IARRY(J,I) = IFIX (EXP (FLOAT
(IARRY(J,I))))
10      CONTINUE
12      CONTINUE
        RETURN
        END
        SUBROUTINE BHPF(SPECT,ITAG)              ! Butterworth high-
pass filter
C       ---------- ---- ----- ----               ! with high-frequenc
emphasis
        EMA SPECT
        COMPLEX SPECT,TEMP
        COMMON LU
        COMMON/INIT/ LX,LY
        COMMON /BUFRS/ TEMP(256)
        DIMENSION SPECT(256,256) , ITAG(20)
        REAL * 8   C

C-> Set Do to 1/8 of distance
5       WRITE (LU,12)
12      FORMAT('Please input the length of x size:_')
        READ (LU,*,ERR=5) XS
        IF (XS.GT.256) GOTO 5
        DZERO = DBLE (XS) * SQRT (2.0) / 8.0

C-> Set n to 3

        N=3

C-> Compute D(u,v), then H

        DO 10 I=1,LX
        DO 10 J=1,LY
            C = DBLE (REAL (I ** 2)) + DBLE (REAL (J ** 2))
            D = DBLE (DSQRT (C))
            BLOB = (( (DZERO/D) ** (2*N)) * 0.414)
            H = ( (2+BLOB) / (1+BLOB) )
10          SPECT(J,I) = SPECT(J,I) * H
        RETURN
        END
        SUBROUTINE HMPHC(SPECT)
C       ---------- ----- -----
        EMA SPECT
        COMPLEX SPECT,TEMP
        COMMON /INIT/ LX,LY
        COMMON /BUFRS/TEMP(256)
        DIMENSION SPECT(256,256)
        REAL * 8   C
C
        DO 10 I=1,LX
        DO 10 J=1,LY
            C = DBLE (FLOAT (I ** 2)) + DBLE (FLOAT (J ** 2))
            D = SNGL (DSQRT (C))
```

```fortran
            H = (2.0 * EXP (-.1 * FLOAT(LX) / D))     ! This set
upper to 2
10          SPECT(J,I) = SPECT(J,I) * H
        RETURN
        END
        SUBROUTINE FFT(F,N)
C       ---------- --- - -
        COMPLEX F(256),U,W,T,CMPLX
        PI=3.141593
        DO 1 LN=1,9                              !  512 Largest image  !
        IDUM=2**LN
        IF (IDUM.EQ.N) GOTO 2
1       CONTINUE
        STOP 0007
2       NV2=N/2
        NM1=N-1
        J=1
        DO 5 I=1,NM1
            IF (I.GE.J) GOTO 3
            T=F(J)
            F(J)=F(I)
            F(I)=T
3           K=NV2
4           IF (K.GE.J) GOTO 5
            J=J-K
            K=K/2
            GOTO 4
5           J=J+K
        DO 7 L=1,LN
            LE=2**L
            LE1=LE/2
            U=(1.0,0.0)
            W=CMPLX(COS(PI/LE1),-SIN(PI/LE1))
            DO 7 J=1,LE1
                DO 6 I=J,N,LE
                IP=I+LE1
                T=F(IP)*U
                F(IP)=F(I)-T
6               F(I)=F(I)+T
7           U=U*W
        DO 8 I=1,N
8           F(I)=F(I)/FLOAT(N)
        RETURN
        END


        SUBROUTINE FWT(CF,N)
C       ---------- --- -- -
        COMPLEX CF(256)
        DIMENSION F(256)
        DO 10 LN=1,9
        IDUM=2**LN
        IF (IDUM.EQ.N) GOTO 20
10      CONTINUE
        STOP 0010
```

```
20      DO 30 I=1,128
30      F(I)=REAL(CF(I))
        NV2=N/2
        NM1=N-1
        J=1
        DO 3 I=1,NM1
            IF (I.GE.J) GOTO 1
            T=F(J)
            F(J)=F(I)
            F(I)=T
1           K=NV2
2           IF (K.GE.J) GOTO 3
            J=J-K
            K=K/2
            GOTO 2
3           J=J+K
        DO 5 L=1,LN
            LE=2**L
            LE1=LE/2
            DO 5 J=1,LE1
                DO 4 I=J,N,LE
                    IP=I+LE1
                    T=F(IP)
                    F(IP)=F(I)-T
4                   F(I)=F(I)+T
5               CONTINUE
        DO 6 I=1,N
6           CF(I)=CMPLX((F(I)/FLOAT(N)),0.0)
        RETURN
        END



        SUBROUTINE SMOTH(IARRY,IPXL)
C*******************************************************
C This subprogram is to define the size of leukocyte
C It is the powerful tool to eliminite noise which
C small than the defined size
C*******************************************************
        EMA IARRY
        COMMON LU
        COMMON /INIT/ LX,LY
        DIMENSION IARRY(256,256)
        INTEGER COUNT,OUTGREY,NEB
        OUTGREY=255
        NEB=0
C       This part is to make bigrey level
21      WRITE (LU, 22)
22      FORMAT(//'Please input the grey level you want:_')
        READ (LU,*,ERR=21) OUTGREY
C       To define the size of noise
30      WRITE(LU,32)
32      FORMAT(//'Please input the neberhor of pls:_')
        READ (LU,*,ERR=30) NEB
        IF (OUTGREY .GT. 255 .OR. OUTGREY .LT.0) GOTO 21
```

```fortran
            IF (NEB .GT. 8 .OR. NEB .LT.0) GOTO 30
C       This portion can cancel the spot which smaller than some
C       certain vaules
        DO 10 J=1,LX
        DO 10 I=1,LY
        IF (IARRY(J,I).NE.0)THEN
            COUNT=0
            IF (IARRY(J-1,I).NE.0) COUNT=COUNT+1
            IF (IARRY(J,I-1).NE.0) COUNT=COUNT+1
            IF (IARRY(J+1,I-1).NE.0) COUNT=COUNT+1
            IF (IARRY(J+1,I).NE.0) COUNT=COUNT+1
            IF (IARRY(J-1,I-1).NE.0) COUNT=COUNT+1
            IF (IARRY(J+1,I+1).NE.0) COUNT=COUNT+1
            IF (IARRY(J-1,I+1).NE.0) COUNT=COUNT+1
            IF (IARRY(J,I+1).NE.0) COUNT=COUNT+1
        IF (COUNT .LT. NEB) THEN
            IARRY(J,I)=0
        ELSE
C       Give spot a certain grey level vaule
            IARRY(J,I)=OUTGREY
            IF (IARRY(J-1,I).NE.0) IARRY(J-1,I)=OUTGREY
            IF (IARRY(J,I-1).NE.0) IARRY(J,I-1)=OUTGREY
            IF (IARRY(J+1,I-1).NE.0) IARRY(J+1,I-1)=OUTGREY
            IF (IARRY(J-1,I-1).NE.0) IARRY(J-1,I-1)=OUTGREY
            IF (IARRY(J,I+1).NE.0)  IARRY(J,I+1)=OUTGREY
            IF (IARRY(J+1,I+1).NE.0) IARRY(J+1,I+1)=OUTGREY
            IF(IARRY(J-1,I+1).NE.0) IARRY(J-1,I+1)=OUTGREY
            IF(IARRY(J+1,I).NE.0)  IARRY(J+1,I)=OUTGREY
        END IF
        END IF
10      CONTINUE
        RETURN
        END


        SUBROUTINE COUNT(IARRY)
C*********************************************************************
C The subroutine is to use the properity of connectivity
C to define an indivadual spot. Within the program existing
C a TRACK subprogram to caculate and search the connective
C pixel with the same grey level. After searching, the TRACK
C will erase the intact spot , and go back to COUNT to tell
C that it has already find one spot and earse it,then
C COUNT will add the number of spot
C*********************************************************************
        EMA IARRY
        COMMON/INIT/ LX,LY
        DIMENSION IARRY(256,256)
        INTEGER ICOUNT
        ICOUNT=0
        DO 10 I=1,LY
        DO 10 J=1,LX
        IF (IARRY(J,I) .NE.0) THEN
C       Now the route can trace the connective pixel to define
C       a complete spot
```

```fortran
            CALL TRACK(IARRY,J,I)
            ICOUNT=ICOUNT+1
         END IF
10       CONTINUE
         PRINT *,'THE NUMBER OF COUNTER: ',ICOUNT
         RETURN
         END


         SUBROUTINE TRACK(IARRY,J,I)
C*************************************************************
C The purpose of the subprogram is to find the adjectant pixel
C which exist a certain number of grey level,and determine the
C relation of connectivity to define an intact leukocyte
C*************************************************************
         EMA IARRY
         COMMON /INIT/ LX,LY
         DIMENSION IARRY(256,256)
         INTEGER PTR,STACK(10000),ADDR
C        Using a simulating method to do the recursive program
         PTR=1
10       IARRY(J,I)=0
         IF (IARRY(J-1,I).NE.0) THEN
         STACK(PTR)=J
         STACK(PTR+1)=I
         STACK(PTR+2)=1
         PTR=PTR+3
         J=J-1
         GOTO 10
         END IF
1        IF(IARRY(J-1,I+1).NE.0) THEN
         STACK(PTR)=J
         STACK(PTR+1)=I
         STACK(PTR+2)=2
         PTR=PTR+3
         J=J-1
         I=I+1
         GOTO 10
         END IF
2        IF (IARRY(J,I+1).NE.0) THEN
         STACK(PTR)=J
         STACK(PTR+1)=I
         STACK(PTR+2)=3
         PTR=PTR+3
         I=I+1
         GOTO 10
         END IF
3        IF( IARRY(J+1,I+1).NE.0) THEN
         STACK(PTR)=J
         STACK(PTR+1)=I
         STACK(PTR+2)=4
         PTR=PTR+3
         J=J+1
```

```
              I=I+1
              GOTO 10
              END IF
4             IF( IARRY(J+1,I).NE.0)   THEN
              STACK(PTR)=J
              STACK(PTR+1)=I
              STACK(PTR+2)=5
              PTR=PTR+3
              J=J+1
              GOTO 10
              END IF
5             IF (IARRY(J+1,I-1).NE.0) THEN
              STACK(PTR)=J
              STACK(PTR+1)=I
              STACK(PTR+2)=6
              PTR=PTR+3
              J=J+1
              I=I-1
              GOTO 10
              END IF
6              IF (IARRY(J,I-1).NE.0)THEN
              STACK(PTR)=J
              STACK(PTR+1)=I
              STACK(PTR+2)=7
              PTR=PTR+3
              I=I-1
              GOTO 10
              END IF
7             IF(IARRY(J-1,I-1).NE.0) THEN
              STACK(PTR)=J
              STACK(PTR+1)=I
              STACK(PTR+2)=8
              PTR=PTR+3
              J=J-1
              I=I-1
              GOTO 10
              END IF
8             IF (PTR.EQ.1) RETURN
              ADDR=STACK(PTR-1)
              I=STACK(PTR-2)
              J=STACK(PTR-3)
              PTR=PTR-3
              IF (ADDR.EQ.1)  GOTO 1
              IF (ADDR.EQ.2)  GOTO 2
              IF (ADDR.EQ.3)  GOTO 3
              IF (ADDR.EQ.4)  GOTO 4
              IF (ADDR.EQ.5)  GOTO 5
              IF (ADDR.EQ.6)  GOTO 6
              IF (ADDR.EQ.7)  GOTO 7
              GOTO 8
              END


              SUBROUTINE ERSON(IARRY,IPXL)
```

```
C*****************************************************************
C Use mathematical morphlogy to erase the noise,meanwhile it
C will erose the outer layer of leukocyte
C*****************************************************************
      EMA IARRY,IPXL
      COMMON LU
      COMMON /INIT/ LX,LY
      DIMENSION IARRY(256,256),IPXL(256,256),ST(10,10)
      INTEGER SX,SY,SX2,SY2
C     SAM is the gray level of struture element
      SAM=80
C     Now  set the size of strutrue element and assign its' gr
level
      SX=2
      SY=2
      SX2=(SX-1)/2
      SY2=(SY-1)/2
      DO 10 N=1,SY
      DO 10 M=1,SX
      ST(M,N)=SAM
10    CONTINUE

      DO 20 J=1+SX2,LX-(SX-SX2)+1
      DO 20 I=1+SY2,LY-(SY-SY2)+1
      DO 30 N=1,SY
      DO 30 M=1,SX
C     Now the formula of erosion

      VALUE=IARRY(J+M-SX2-1,I+N-SY2-1)-ST(M,N)
      SAM =MIN(SAM,VALUE)
      IF (SAM.LT.0) SAM=0
30    CONTINUE
      IPXL(J,I)=SAM
20    CONTINUE
      DO 50 J=1+SX2,LX-(SX-SX2)+1
      DO 50 I=1+SY2,LY-(SY-SY2)+1
      IARRY(J,I)=IPXL(J,I)
50    CONTINUE
      RETURN
      END



      SUBROUTINE DATON(IARRY,IPXL)
C*****************************************************************
C The Dialation will add an outer layer to the leukocyte
C it is the power tool to fill the hollow hole within the
C leukocyte
C*****************************************************************
      EMA IARRY,IPXL
      COMMON LU
      COMMON /INIT/ LX,LY
      DIMENSION IARRY(256,256),IPXL(256,256),ST(10,10)
      INTEGER SX,SY,SX2,SY2
C     Set the struture element gray level
```

```fortran
      LAG=0
C     The size of struture element
      SX=2
      SY=2
      SX=(SX-1)/2
      SY=(SY-1)/2
      DO 10 M=1,SX
      DO 10 N=1,SY
      ST(M,N)=LAG
10    CONTINUE

      DO 20 J=1+SX2,LX-(SX-SX2)+1
      DO 20 I=1+SY2,LY-(SY-SY2)+1
      LAG=0
      DO 30 M=1,SX
      DO 30 N=1,SY
C     The formula of dialtion
      VALUE=IARRY(J+M-SX2-1,I+N-SY2-1)+ST(M,N)
      IF (LAG.LT.VALUE) LAG=VALUE
      IF (LAG.GT.255) LAG=255
30    CONTINUE
      IPXL(J,I)=LAG
20    CONTINUE
      DO 50 J=1,LX
      DO 50 I=1,LY
      IARRY(J,I)=IPXL(J,I)
50    CONTINUE
      RETURN
      END
```

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