PROCESSING RADIOISOTOPE SCANS

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In an earlier paper (*1*) we discussed theoretically some aspects of the problem of processing data of radioisotope scans (except where specifically noted the term "scan" is used to mean the output of any radioactivity mapping device and the term "scanning" to mean the process by which that output is produced). We will now present some practical procedures to implement the conclusions of that paper and will illustrate by examples the effect of these procedures. In the earlier paper we pointed out that processing had to perform two tasks: (1) it must correct for the geometric degradation due to imaging (or previous processing) on the basis of the known characteristics of the imaging device and processing procedures used; (2) it must smooth to produce the continuous activity distribution responsible for the set of discrete events recorded (dots) on the basis of statistics and *a priori* knowledge about the activity distribution. We pointed out that in both operations the processing parameters should depend on the local dot density at the point of interest and its surroundings. We suggested that the whole process could be visualized and approximated as a shifting of dots followed by smoothing. The purpose of the dot shifting is to replace the coordinates of the received events by the coordinates of the most probable origins of those events which are likely to reflect more closely the activity distribution and thus provide a better base for the subsequent smoothing.

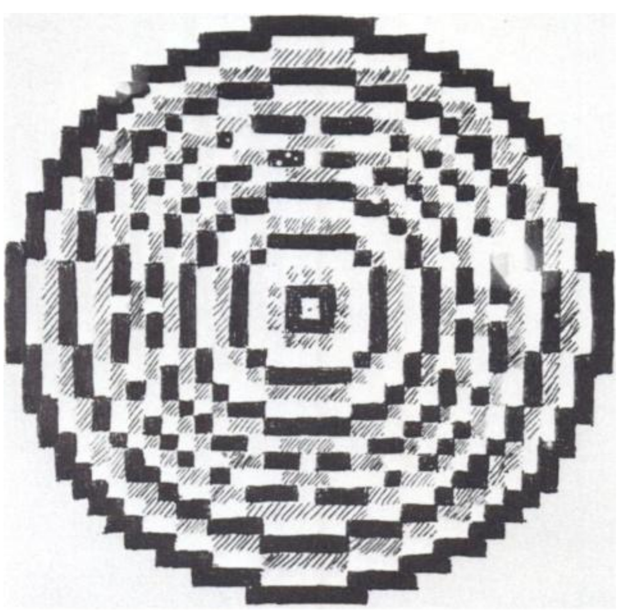

FIG. 1. Categorization of grid elements into concentric rings.

Nothing was said, however, about the method by which an initial dot-density estimate needed to implement both shifting and smoothing should be obtained. It should be realized that in such procedures the method of determining the density may have an important effect on the results given by the procedure. It is reasonable to expect that the density estimation should be done in a way consistent with the assumptions on which the density-dependent procedure is based.

SMOOTHING METHODS

Only one specific procedure for variable smoothing was suggested which we will now call "variable smearing." In this procedure each dot was replaced by a circular spot with constant light flux and Gaussian intensity distribution, but with an area varying inversely with the local dot density. We will now consider another smoothing procedure as well; realizing that the local dot-density evaluation is itself a smoothing procedure, we can use its outcome directly as a smoothed output. Conventionally the intensity (dot density) at a point is computed by centering a fixed sampling area at the point and counting the number of dots in the area. This

Received Feb. 29, 1968; revision accepted July 19, 1968.

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method, which we call "fixed spatial averaging," with its fixed sampling area does not follow the conclusion of Ref. *1* that the greater the density of the surrounding population of dots the smaller the area needed to adequately estimate that density. To correct this situation and thereby to eliminate the superfluous blurring resulting from a fixed sampling area, we must devise a procedure which we will call "variable spatial averaging" in which the sampling area decreases as the local dot density increases.

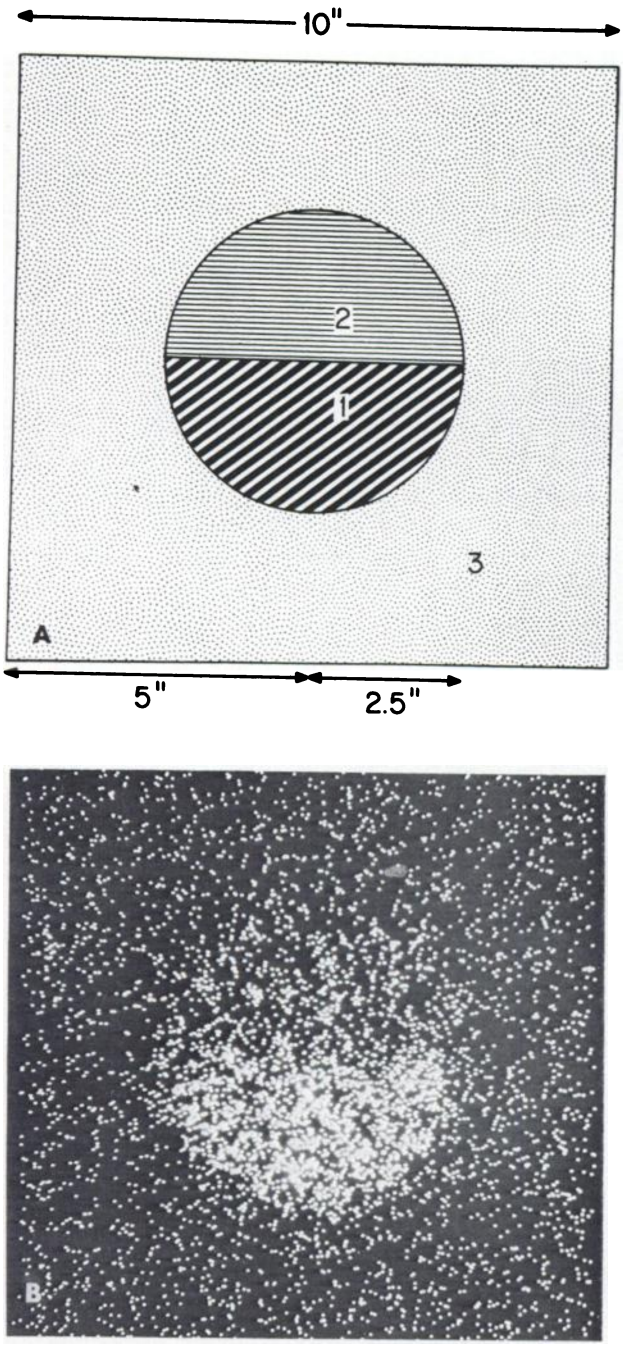

FIG. 2. A shows activity pattern used for simulated scan. B shows 5,000 dots simulated scan used for all processing examples.

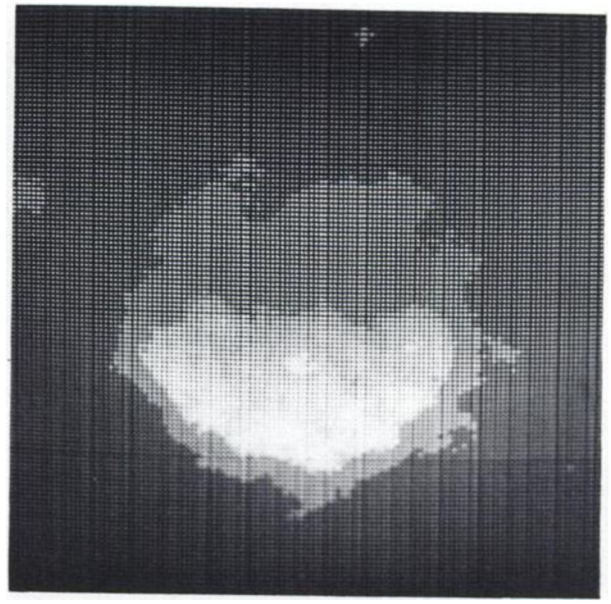

FIG. 3. Variable spatial averaging to 40 dots.

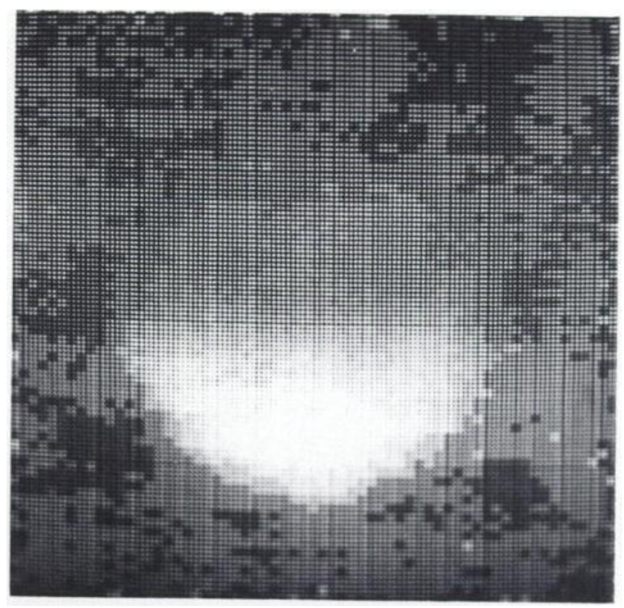

FIG. 4. Best fixed spatial averaging.

The criterion which we will use to set the variation of the sampling area is that the expected relative error in intensity should be constant over the scan. This leads to a method in which the sampling area is increased until the number of dots enclosed reaches a fixed value, N. Then if r is the radius of the sampling area centered at the point at which the density is being computed, the density estimate is $(N - 1)/\pi r^2$. ($N - 1$ appears rather than N because we require an unbiased estimator.)

The density distribution arrived at by variable spatial averaging may be considered as a final estimate of density or as a basis for other density dependent procedures such as dot shifting and variable smearing.

SPECIFICATIONS FOR IMPLEMENTED METHODS

The dot distribution was obtained by dividing the scan into a 128×128 grid and counting the number of dots in each grid element. All distributions calculated from the dots are also in the form of a 128×128 grid.

Variable spatial averaging. The number of dots to be counted to was chosen by a combination of theory and experiment to give the best compromise between statistical accuracy and geometric blurring. The theoretical selection was based on a model described elsewhere (*2*). As mentioned above, the object of this routine is to compute for each grid element the dot density in the smallest circle centered at the element which encloses a given number of dots. To accomplish this the grid elements are categorized into rings, i.e., elements approximately equidistant from the center (Fig. 1), and a running sum is kept of the dots in these elements, starting with the smallest ring and including progressively larger rings until the running sum reaches a preset value. To avoid a directional bias in the averaging procedure the elements of a ring considered successively are not consecutive (i.e. clockwise or counterclockwise) but rather distributed about the full circle.

When the running sum reaches a certain threshold, N, the number of elements considered up to that point is called M and the density in dots per element is computed as $(N - 1)/M$.

Variable smearing. The spot radius is taken to be inversely proportional to the square root of the dot density in the grid element in question, as given by variable spatial averaging. The constant of proportionality is chosen to give the best compromise between smoothing and geometric blurring. The light flux from all the spots is added to give the final distribution.

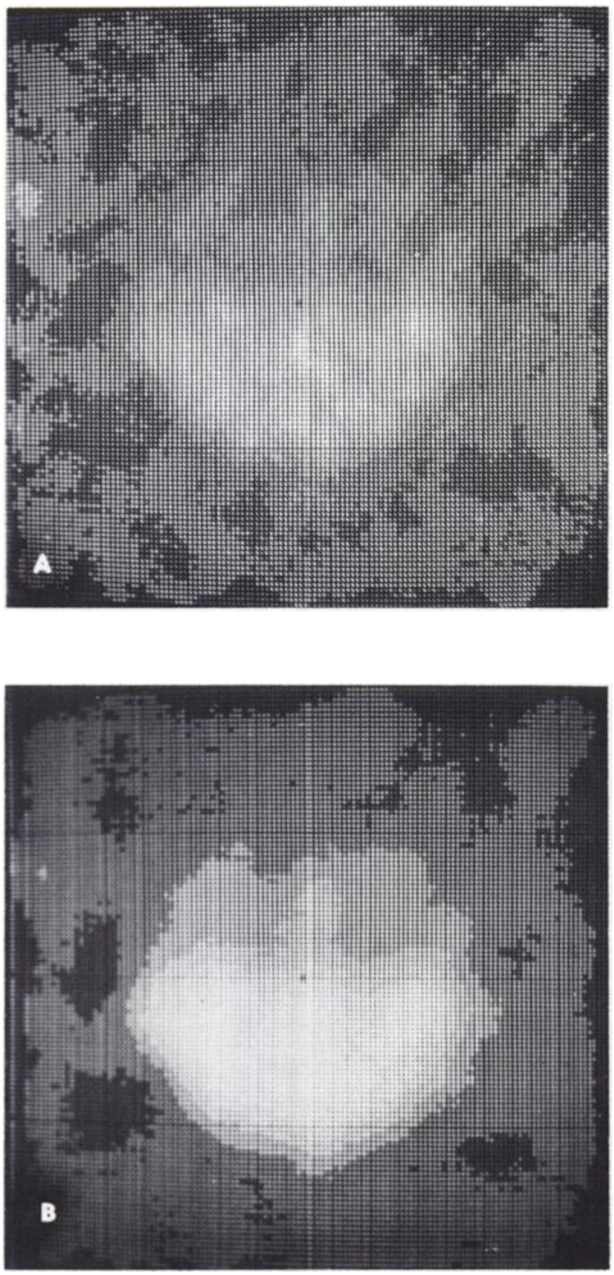

FIG. 5. A shows variable smearing with average spot radius equal to 4% of scan side. B shows variable smearing with average spot radius equal to 7% of scan side.

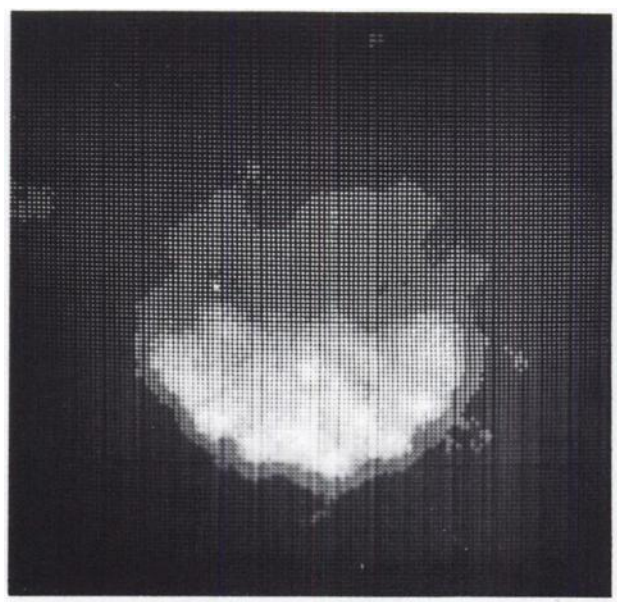

FIG. 6. Dot shifting followed by variable spatial averaging to 40 dots. Comparison with Fig. 3 shows that halo about bottom of circle is considerably reduced.

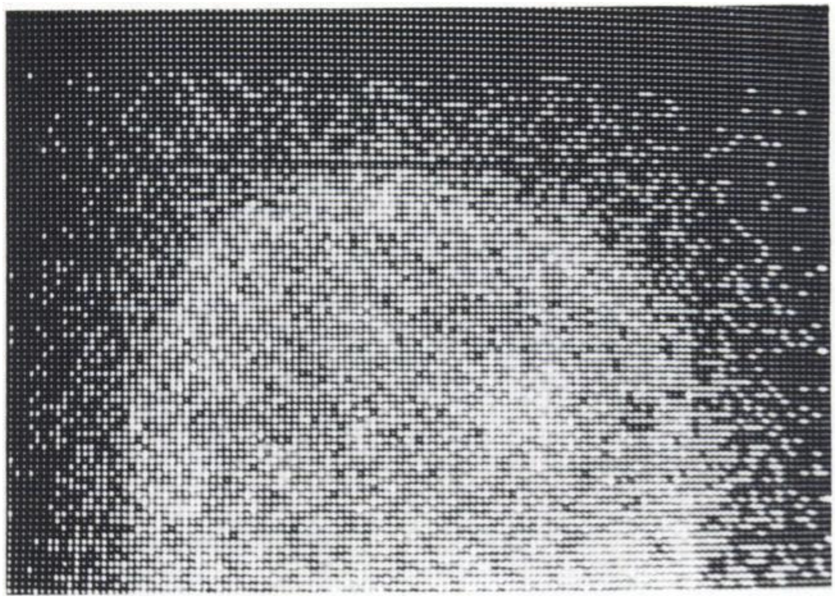

FIG. 7. Actual brain scan, unprocessed.

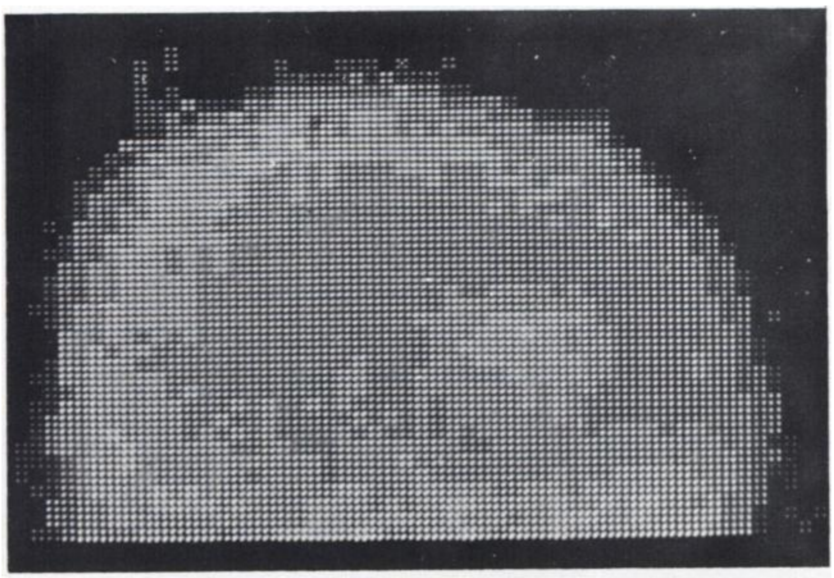

FIG. 8. Same brain scan as Fig. 7; best fixed spatial averaging.

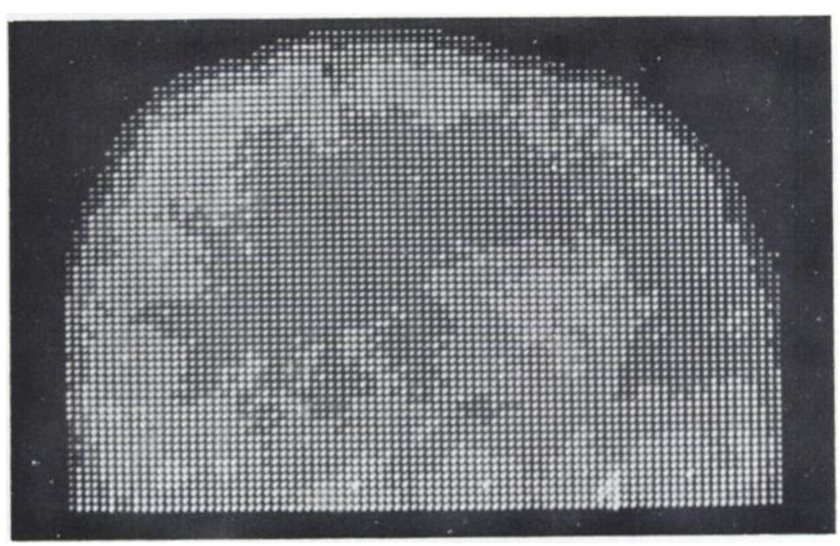

FIG. 9. Same brain scan as Fig. 7; variable spatial averaging.

Mathematically the process computes a 128 × 128 matrix $\underline{B}$ from the formula

$$B_{ij} = \sum_{k=-n}^{n} \sum_{l=-n}^{n} A_{i+k,\,j+l} P_{kl}^{(ij)},$$

where the matrix $\underline{A}$ gives the number of dots in each grid element, and $\underline{P}$ is the spot matrix centered at i,j. $\underline{P}$ is such that the sum of its elements and the shape of the spot it represents remain constant while its width is inversely proportional to $C_{ij}^{1/2}$ where C_{ij} is the dot density computed by variable spatial averaging with center i,j.

Dot shifting. This method shifts the dots in each grid element to the center of gravity of the dot-density distribution weighted by the given spread function centered at the grid element in question. Mathematically this means computing for each grid element (at position $\underline{x}$ = i,j) a new origin $\underline{x}'$ as follows:

$$x' = x + \frac{\sum_{k=-n}^{n} \sum_{l=-n}^{n} (k, l)\, F_{kl}\, C_{i+k,\,j+l}}{\sum_{k=-n}^{n} \sum_{l=-n}^{n} F_{kl}\, C_{i+k,\,j+l}},$$

where $\underline{F}$ is a matrix representation of the spread function and $\underline{C}$ is the dot density matrix given by variable spatial averaging. The new dot distribution is formed by placing the dot count formerly in grid element i,j in the grid element in which $\underline{x}'$ falls and doing this operation for all the grid elements.

RESULTS

The details of the computer system used to implement the various processing routines as well as to read in real scans can be found in the appendix.

Figure 2A gives an activity pattern for which a scan was simulated using a computer (*3*). Figure 2B gives the simulated scan with 5,000 dots, contrast 5:2:1 and resolution distance 5% of the scan side. Figure 3 gives the result of variable spatial averaging to 40 dots. Compare this result to Fig. 4 which gives the result of the best fixed spatial averaging. In the latter the boundaries are very blurred and overextended.

Both the variable smearing and dot shifting examples below are based on the dot-density distribution shown in Fig. 3.

Figures 5A and 5B give the results of variable smearing with average spot radius of 4% and 7% of the scan side, respectively. Comparison with Fig. 3 shows that Fig. 5A with the smaller spot is more mottled and Fig. 5B with the larger spot is more blurred. As might have been expected, statistical errors in the result of variable spatial averaging are exaggerated by variable smearing based on that result.

Figure 6 gives the result of dot shifting followed by 40 dot variable spatial averaging. Comparison with Fig. 3 shows that the halo about the bottom of the circle is considerably reduced.

CONCLUSIONS

Variable spatial averaging gives quite superior results to fixed spatial averaging. It is also superior to variable smearing. Dot shifting can measurably improve the sharpness of a scan. Initial results of processing a few dozen real scans bear out these conclusions. Figures 7, 8, and 9 showing an unprocessed scan, its best fixed spatial averaging and its variable spatial averaging, respectively, are representative of the effect observed.

REFERENCES

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2. Vetter, H. G. and Pizer, S. M.: A model for perception of quantum limited images and its application to radioisotope scanning. *Proc. 7th Intern. Conf. Med. Biol. Eng.* Stockholm, 1967, p. 113.

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APPENDIX

Description of Computer System

The hardware consists of a DEC PDP-7 computer with 8K 18-bit words, 2 Dectape units with 147,456 words per reel, teleprinter, paper-tape reader and punch, DEC 30-D scope. Also part of the system are a Fairchild 737A scope with a fast raster display interface and an interface to read ¼-in. 7-track magnetic tape. Both of the latter interfaces were especially designed at Massachusetts General Hospital.

The scans are recorded on-line by the scanner onto home-style magnetic tape. The PDP-7 reads this tape through the special tape-reading interface, assigns the events to cells in a square array and writes the resulting cell counts onto Dectape. The processing system reads the scans from Dectape, applies the particular processes desired and displays the results on the special fast raster scope.