A COMPUTER SIMULATION OF THE SCANNING PROCESS USING A SYSTEM RESPONSE TO LINE SOURCE DISTRIBUTION FUNCTION

Kenneth A. Krackow and Ralph J. Gorten

Veterans Administration Hospital and Duke University Medical Center, Durham, North Carolina

A computer simulation of the scanning process has been constructed to assist in the development and evaluation of computer techniques for radionuclide scan analysis. This simulation of radioisotope scans by computer is not without precedent (*1*). However, the use of simulation techniques to help develop and evaluate computer programs for scan analysis is a new and useful application of this idea. The model described herein is presented for the purpose of showing a simple technique which rapidly and inexpensively provides computer-compatible data analogous to real scan data collected for digital computer display and analysis.

Simulation of the scanning process requires the derivation of a distribution function to express the collimator focusing characteristics for a given scanning system. The function described here represents a convenient method for modeling the response of a collimator to a *solid* radioactive source.

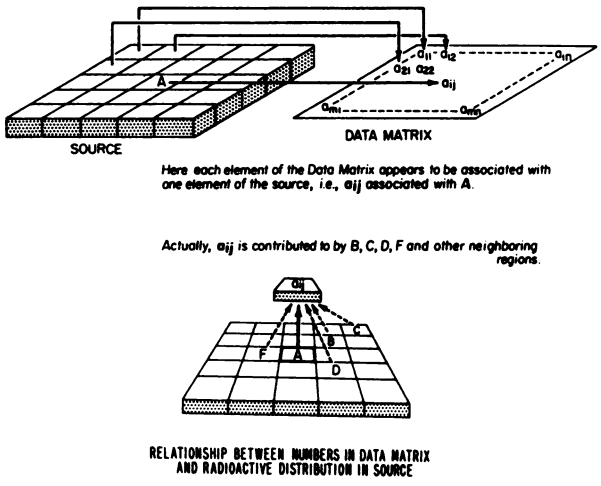

FIG. 1. Top: Diagramatic representation of apparent 1-to-1 correspondence between size of numbers in data matrix and tracer concentration of source elements. Size of these elements depends only upon line spacing, scan speed and duration of counting period. Bottom: Description of fact that each number of the data matrix contains information from nearby tissue elements and not just from that tissue element which has relationship denoted in upper portion of diagram.

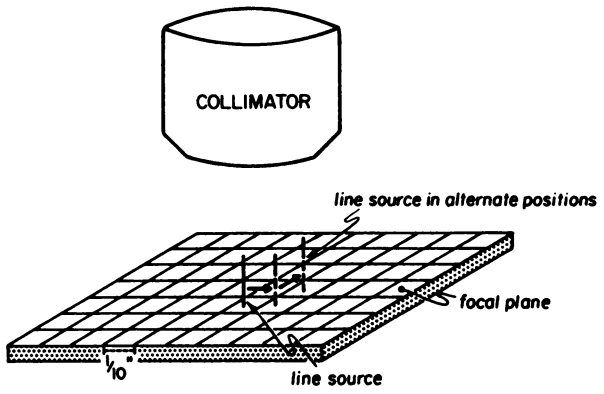

FIG. 2. Relationship of collimator to line source is shown. Note location of line source at intersections of parallel lines.

DISTRIBUTION FUNCTION

Data from a rectilinear organ scan are generally handled by a computer as a two-dimensional array of numbers (*2,3*). These numbers represent counts recorded over specific regions of the source being scanned. Each data value in the matrix is associated with a certain volume of organ tissue. This volume depends on length of counting period, scan speed and line spacing (Fig. 1, top). In addition, collimator focusing imperfections cause each number in the data matrix to contain information originating from adjacent elements of tissue (Fig. 1, bottom). It is the task of the distribution function to describe, according to individual collimator characteristics, the percent contribution to counts observed directly over one segment of tissue which was likely to have come from other nearby tissue elements.

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For reprints contact: Ralph J. Gorten, Div. of Nuclear Medicine, Duke University Medical Center, Durham, N.C. 27706.

In order to describe the collimator response to a solid radioactive source, a line source was oriented parallel to the axis of the collimator. For this study ^{203}Hg was sealed inside a 20-gage needle 0.8 in. long. The length of the source may be varied and should be chosen to correspond to the thickness of the organ, the scan of which is to be simulated. The source was located with its center in the plane of focus and at points of intersection of two sets of parallel lines spaced 0.1 in. apart (Fig. 2). With the collimator stationary the source was placed at these intersections and counts were recorded at each point. The area of data collection was essentially circular and its radius was chosen to be just large enough so that observations taken at its perimeter were not significantly higher than room background activity. When a collimator with symmetrical response characteristics is being used, it is possible to minimize the amount of data collection by taking advantage of these properties of symmetry.

The observed counts were then processed by a computer program. By interpolation, intermediate values were calculated to correspond to counts spaced at intervals of 0.05 in. These values were further subdivided, and the resultant matrix was normalized so that a percentage value was associated with elements of tissue measured in hundredths of an inch. By using line spacing and scan speed factors appropriate to the type of scan being simulated it was possible to calculate the size of a tissue element which would ideally correspond to a number in a data matrix (Fig. 1, top). Having calculated these dimensions, the computer summed appropriate elements of the normalized matrix, thereby producing a response function suited to the line spacing and scan speed parameters of the desired simulation.

This type of distribution function differs from work of other investigators (*4,5*), and the following advantages need to be considered. First, a line source oriented parallel to the axis of the collimator and integrated over the plane of focus results in description of responses from a *solid* source, whereas a point source used similarly would describe the response to a plane. The distribution function obtained from a source 0.8 in. long may not differ greatly from that of a point source. However, in the simulation of scans from larger organs, i.e., using longer line sources, there will be significant advantages in the choice of line sources. Certainly a point source could be placed in a series of planes parallel to the focal one. However, this would increase considerably the amount of time and effort required to gather the necessary count data as well as increase computer time and storage requirements. Second, scattering phenomena may be modeled by constructing the function in a selected medium. Third, only one experimental determination of data is necessary for a given collimator and radioactive source since the computer program allows for variations of scan speed, line spacing and counting period.

SIMULATION OF SCANNING PROCESS

The distribution function, determined in this manner from the collimator response of an instrument system, has been employed in the computer simulation of the scanning process. The computer model is designed to receive as input a two-dimensional array of numbers that represents relative concentrations of radioactive tracer in some source organ (Fig. 3). This input matrix of numbers is arbitrary; it is constructed by the investigator according to his specifications and as such may be regarded as a "digital phantom." The distribution of these phantom numbers can be made by the investigator to contain variations consistent with anatomic structures and pathologic lesions. These numbers do not contain the random variation present in digital scan data; that is, the distribution in the phantom is smooth as is the actual distribution of radioactive tracer in a source organ (compare Figs. 3 and 4 to Fig. 5).

The computer next proceeds to scan this digital phantom. Starting at one corner of the matrix, it considers one data position (i,j) at a time and calculates the contributions from nearby locations by use of the distribution function. Using these contributions an estimate denoted a_{ij} is made of the activity most likely to be detected while scanning the position (i,j) of the matrix.

DIGITAL HEART PHANTOM WITH UNIFORM DISTRIBUTION OF 'TRACER'

1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	10	1	1	1	1	1	1	1
1	1	1	1	1	1	10	12	12	10	10	1	1	1	1	1
1	1	1	1	10	12	12	14	14	12	12	10	1	1	1	1
1	1	1	1	10	14	14	17	17	14	14	12	10	1	1	1
1	1	1	10	12	17	19	21	21	21	19	17	12	10	1	1
1	1	10	12	14	19	21	23	26	23	21	19	14	10	1	1
1	10	12	14	17	21	23	26	28	26	23	21	17	14	10	1
1	5	12	17	19	23	26	28	30	28	26	21	19	14	10	1
1	12	14	17	21	26	26	30	35	30	26	21	19	14	12	1
1	10	12	17	21	26	28	30	33	30	26	21	19	14	12	1
1	5	12	17	21	23	28	30	33	30	26	21	19	14	10	1
1	5	12	14	19	21	26	30	30	28	23	19	14	10	5	1
1	1	10	12	17	21	23	28	28	26	23	19	14	10	1	1
1	1	10	14	17	19	23	28	28	26	23	19	14	10	1	1
1	1	10	12	14	19	23	26	26	23	21	17	12	10	1	1
1	1	10	10	12	19	21	23	23	21	19	14	10	1	1	1
1	1	1	10	12	17	19	21	19	19	17	12	10	1	1	1
1	1	1	10	10	14	17	17	17	17	12	10	1	1	1	1
1	1	1	1	7	12	14	14	14	14	10	10	1	1	1	1
1	1	1	1	1	7	12	14	12	12	10	1	1	1	1	1
1	1	1	1	1	7	10	12	12	10	7	1	1	1	1	1
1	1	1	1	1	1	7	10	10	7	1	1	1	1	1	1
1	1	1	1	1	1	1	7	7	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

FIG. 3. Digital phantom representing excised pig heart containing ^{203}Hg-chlormerodrin tracer. This phantom is intended to represent normal pig heart without myocardial infarction.

DIGITAL HEART PHANTOM WITH INCREASED 'TRACER CONCENTRATION' IN UPPER RIGHT QUADRANT OF SOURCE

1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	10	1	1	1	1	1	1	1
1	1	1	1	1	1	10	12	12	10	10	1	1	1	1	1
1	1	1	1	10	12	12	18	38	27	28	13	11	1	1	1
1	1	1	1	10	18	18	17	40	43	48	31	28	1	1	1
1	1	1	10	12	17	19	21	48	62	69	60	39	10	1	1
1	1	10	12	18	19	21	23	52	60	61	55	43	10	1	1
1	10	12	18	17	21	23	26	55	52	52	52	48	18	10	1
1	5	12	17	19	23	26	28	30	28	26	21	19	18	10	1
1	12	18	17	21	26	26	30	35	30	26	21	19	18	12	1
1	10	12	17	21	26	28	30	33	30	26	21	19	18	12	1
1	5	12	17	21	23	28	30	33	30	26	21	19	18	10	1
1	5	12	18	19	21	26	30	30	28	23	19	18	10	5	1
1	1	10	12	17	21	23	28	28	26	23	19	18	10	1	1
1	1	10	18	17	19	23	28	28	26	23	19	18	10	1	1
1	1	10	12	18	19	23	26	26	23	21	17	12	10	1	1
1	1	10	10	12	19	21	23	23	21	19	18	10	1	1	1
1	1	1	10	12	17	19	21	19	19	17	12	10	1	1	1
1	1	1	10	10	18	17	17	17	17	12	10	1	1	1	1
1	1	1	1	7	12	18	18	18	18	10	10	1	1	1	1
1	1	1	1	1	7	12	18	12	12	10	1	1	1	1	1
1	1	1	1	1	7	10	12	12	10	7	1	1	1	1	1
1	1	1	1	1	1	7	10	10	7	1	1	1	1	1	1
1	1	1	1	1	1	1	7	7	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

FIG. 4. Digital phantom representing pig heart containing ^{203}Hg-chlormerodrin tracer. This phantom displays higher count density in upper right quadrant of organ view when compared to Fig. 3 and is intended to represent myocardial infarction due to coronary arterial ligation.

SIMULATION OUTPUT FROM PHANTOM WITH ABNORMALLY INCREASED 'TRACER CONCENTRATION' IN UPPER RIGHT QUADRANT OF SOURCE

1	0	1	1	0	0	0	3	2	1	1	2	0	2	1	2	0	0
1	1	1	0	0	1	2	2	1	6	3	0	2	1	0	4	0	1
0	0	0	1	0	1	0	6	6	7	5	10	1	3	0	1	1	0
1	0	1	0	3	1	4	4	12	10	14	6	14	12	3	2	0	1
0	0	1	1	3	5	8	14	25	23	33	19	27	19	6	2	1	0
0	1	1	2	5	6	18	16	26	39	35	33	32	23	8	2	2	1
0	2	2	5	4	8	18	23	39	51	47	44	45	21	16	6	2	1
2	1	3	7	13	20	15	23	30	25	55	39	43	26	13	11	3	0
1	3	11	9	11	15	26	28	37	44	46	43	36	24	16	10	0	3
1	2	7	13	15	13	13	33	32	41	31	23	32	18	18	7	1	1
1	3	8	4	16	23	15	23	29	32	34	23	29	23	8	3	5	4
1	4	7	16	13	16	26	21	29	40	25	27	29	20	14	8	8	0
3	3	2	9	18	19	24	27	36	26	28	23	17	15	12	12	5	1
1	5	3	14	18	22	22	22	31	27	38	19	16	22	10	12	4	2
2	3	3	11	12	14	24	26	28	26	29	18	13	14	7	3	0	0
2	3	3	9	14	16	15	15	29	24	25	27	13	8	3	6	2	1
1	1	4	6	5	11	14	15	25	23	17	6	21	8	3	4	3	0
1	2	2	12	10	13	19	27	25	29	23	18	16	10	7	0	2	0
1	2	1	5	8	16	14	17	26	24	20	17	9	7	3	0	1	1
0	1	2	0	6	7	13	8	21	18	11	5	10	4	3	2	0	1
2	0	2	2	3	9	12	9	22	13	16	15	7	7	3	1	1	2
2	0	2	1	0	10	8	10	12	8	8	10	9	4	1	0	2	0
1	1	1	1	0	5	5	7	13	18	5	7	2	2	1	1	1	1
0	0	2	0	3	4	3	4	8	7	2	4	1	2	2	0	0	1
1	0	0	2	0	0	2	1	3	7	2	3	2	2	1	1	1	1
1	1	2	2	0	1	1	2	2	4	0	2	2	1	0	1	1	0
2	2	2	0	0	1	0	1	2	2	2	0	0	1	1	1	0	1

FIG. 5. Computer printout of matrix representing computer simulated scan of digital phantom with infarct as in Fig. 4.

The next task is to simulate the random nature of radioactive events which obey the Poisson distribution. For purposes of this application a normal distribution may be used to approximate the Poisson (*6*). By choosing a number from a population of normally distributed numbers with mean and variance equal to a_{ij} the computer simulates the statistical fluctuation of observations taken over the position (i,j) of the matrix. The IBM Scientific Subroutine GAUSS (*7*) has been found useful for this purpose.* The chosen random number is placed in a new matrix with its position corresponding to the location in the digital phantom over which the computer is centered (see Fig. 6 for summary).

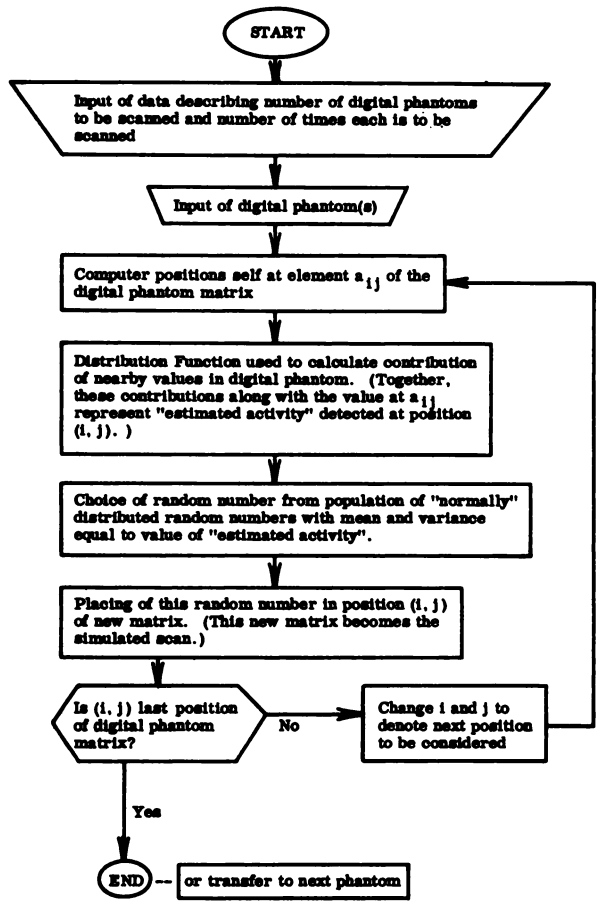

FIG. 6. Flow diagram for computer simulation of scanning process.

* This subroutine is relatively fast and requires a small number of computer memory locations. Subjectively speaking, its results have been quite satisfactory. Objective evaluation has also been made. The underlying uniform random number generator RANDU has been shown by the Triangle Universities Computation Center, Research Triangle Park, N.C. (Memorandum No. GI-38-2) to produce uniformly distributed pseudo-random numbers, as judged by a chi-square goodness of fit test, which are apparently without serial correlation according to the lag-product test with lags of one through 12 used. That the subroutine GAUSS generates pseudo-random numbers with an approximately normal distribution has been accepted by the authors on the basis of a chi-square goodness of fit test ($p < 0.05$) applied to a series of runs of 10,000 random numbers each. For the particular application at hand approximately normal distribution without serial correlation is the most important requirement for a proposed random number generator to satisfy. Neither extremely close agreement of the generator with the tails of the normal distribution [mean $\pm$ ($\geq$ 2.5 s.d.)] nor the accurate agreement of the frequency of particular values is essential in this application. Thus GAUSS has been found useful for our purposes.

The results from the random number generator are modified to the extent that upon selection of a negative number, this negative result is discarded and the computer selects a second random number. The computer will select a third random number if the second one is also negative. If a non-negative result is not obtained after this third try, the computer assigns the value zero to the appropriate position of the new matrix.

The entire process described above is repeated for each position of the digital phantom. The new matrix constructed is a computer simulation of a radionuclide scan. It is the computer's observation of the pattern of radioactivity in a digital phantom as seen through a collimator described by the distribution function and allowing for the characteristic statistical fluctuations of radioactive phenomena.

This simulation of scan data which the computer model supplies as output has a number of applications. In this laboratory the computer simulation technique has been used to build a library of "scans" with specific diagnostic characteristics. With the use of other computer programs, unclassified real scans are compared to the various categories in this library for purposes of computer analysis of the real scans (*8*).

With the use of simulated scans from known digital phantoms, it has been possible to evaluate objectively iterative techniques applied recently to computer focusing of scan data. In addition the simulations may be used to test computer methods of organ recognition and location within a scan data matrix. They may also be used to evaluate the effectiveness or over-effectiveness of various smoothing techniques used on digital scan data and to assess the accuracy, validity and sensitivity of computer programs designed to analyze radionuclide scans.

SUMMARY

A distribution function has been derived experimentally from a system response to a *vertical* line source. This function describes the collimator response to a *solid* source and allows for scattering phenomena if necessary. It is used together with a modified normal random number generator to simulate the scanning process. The simulation is effected by scanning a digital phantom. This digital phantom is a two-dimensional array of numbers whose relationships are arbitrary but which represent the source or organ being modeled by the phantom. This simulation model is useful in the testing, evaluation and improvement of an investigator's digital computer techniques for radionuclide scan analysis.

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