MISCELLANEA GEOGRAPHICA

WARSZAWA 1988

Wiktor Grygorenko

COMPUTER IDENTIFICATION OF CARTOGRAPHIC PICTURE STRUCTURE

Cartographic pictures, i.e. maps, are one of the means of transmitting information concerning the distribution and features of geographic objects and phenomena with the aid of visually perceived graphic symbols. This means that the form of information is as important as its content in the cartographic method of information transmission.

The term of the form of information includes:

— pictures of conventional signs of individual field objects which constitute the map content; and

— populations of graphic symbols distinguishable in the map content by features of external similarity — by the appearance of individual graphic elements or by the distribution method of these symbols.

Usually, populations of such symbols constitute specific cartographic image patterns in the form of certain conglomerations, as it occurs in the case of settlements, or in the form of patterns, as can be found in the case of images of growth of vegetation, cultivation areas, various soils etc. (Fig. 3).

This paper presents a discussion of theoretical assumptions and the implementation method of the process of computer recognition and synthesis of cartographic images in the form of conglomerations of homogeneous graphic signs in the direct nearness or against a background of other signs of the map content. The following circumstances (confirmed in practice) determine the conditions of computer recognition and synthesis of cartographic images:

1. Various forms of cartographic pictures obtained in the process of topological transformations, i.e. shifts and rotations with respect to the standard picture, or simplifications and enlargements of symbols in the process of conscious generalization (according to the criteria assigned in advance) do not falsify conveyed information.

2. The analogue (pictorial) form of a cartographic image can be easily transformed into a digital (numerical) form in the course of definite mechanical and electronical operations. Therefore, every symbol in the map

content and populations of homogeneous symbols forming various forms of images under consideration can be identified by means of analytical geometry.

3. The formalization of the process of image recognition in the numerical form can be confined to the storage of model numerical characteristics of images in the computer memory. These characteristics may be mathematically and logically transformed.

As regards a cartographic image it is usually coordinates x, y, that are model characteristics of every point symbol. If the image is complex and consists of many point symbols, then mutual distances between all symbols of the same image can be accepted as standard values.

Hence, objects recognized on the map are objects and field phenomena which are presented in the form of cartographic symbols connected with letter and numeral inscriptions. Every modification of the picture of a given object, e.g. the picture of the same settlement on maps with different scales (Fig. 3 and 4), is called a picture form. They come as a result of generalization or topological changes.

Populations of symbols which form cartographic images are characterized in the two-dimensional space by constant dimensions, form and mutual distribution of components. These populations can be characterized by sets of numbers (which express the values of coordinates), vectors or functions which make up the so-called numerical description of an image. The numerical description of an image makes it possible for the computer to recognise, analyse, compare and reproduce the image with required accuracy. Therefore, the numerical description of a cartographic image is its mathematical model, which substitutes the image in the process of the analytical form recognition. A two-dimensional description in the form of a list of pairs of rectangular coordinates x, y, which localize signs belonging to a given image, is the simplest natural description of cartographic pictures.

Pictures are recognised in the course of comparison of the pictures description with a standard, or a comparison of characteristic marks occurring in the image with adequate quantities previously stored in the computer memory. Programmes working according to both methods do not differ, because in both cases they consist of the determination of compatibility (similarity) between sets of numerical quantities (as adequately prepared mathematical models which substitute definite images) and assigned numerical criteria of standards (characteristic signs) of these pictures. The form is identified when compared numerical quatities in the image and their standards are found equal.

A simple universal method of forming a mathematical description of the map content is given below without going into the theory of mathematical modelling of pictures.

Maps which describe a plane area contain pictures consisting of individual conventional symbols. Hence, it will be most convenient to use

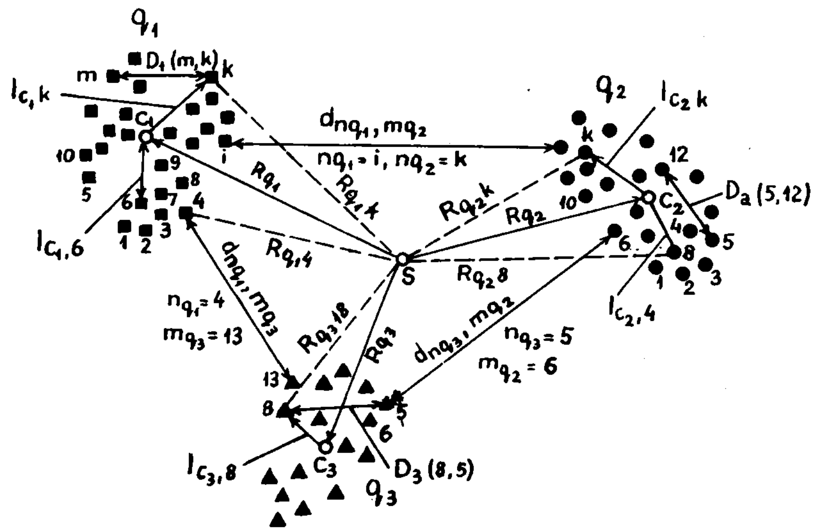


Fig. 1. The geometrical illustration of a plane area of image description

plane coordinates x, y, of signs belonging to a given image in order to describe them.

Fig. 1 presents a geometrical illustration of a plane area of image description. It shows pictures of three objects, q_1, q_2 and q_3, in the form of populations of various signs, r_1, r_2 and r_3. Thus defined space of description is characterized by numeric quantities directory related to these pictures. These can be: coordinates x_q, y_q of individual signs, distance R_q of centres of gravity c_q of whole pictures from the common centre of gravity of these pictures S; or the distance of each sign, $l_{qn}=(x_n-x_{cq})^2+(y_n-y_{cq})^2$ in each picture q from its centre of gravity c_q. Letter n denotes the serial number of a sign in picture q.

The position of the centre of gravity c_q of an image q, characterizes the distribution of the particular signs in the image in a general manner. The scattering of the centres of gravity of pictures, σ_c^2, is taken as the measure of the picture resolution. The greater the scattering, the greater the picture discrimination and as follows, the probability of including in a given picture of a sign belonging to a picture neighbouring to it (by convention called foreign picture).

The scattering σ_r^2, of the particular signs, r, in a picture under consideration, q with relation to its centre of gravity c_q is the inverse of picture resolution. The picture resolution becomes worse with an increase of the scattering of the particular signs.

On the basis of the analysis of these qualtities the algorithm of recognition and interpretation of a definite situation on a map can be built. Such an algorithm should make it possible to determine the attachment of an arbitrary sign, r, to the proper picture (q_1, q_2 or q_3) with high probability. It can also be used to identify and locate a chosen conventional sign in an adequate place on the map.

The calculation routine of the attachment of every sign to its proper picture (as a mathematical model of the standard picture) is applied in the algorithm of map content recognition and interpretation. A plane area limited by a convex curve is a standard picture in a two-dimensional space of characteristic signs. This area includes all homogeneous conventional symbols which constitute pictures of a given object. The attachment function should be so defined as to place signs which belong to a foreign (neighbouring) picture out of the range of this area.

Therefore, the attachment function $P(n)$, is a measure of the conformity of the position of a recognised sign which belongs to the space of characteristic signs, and the position of a standard sign which represents the picture under consideration. A point identified as a point belonging to a given picture is temporarily accepted as the centre of the standard. The value of the attachment function reaches the maximum value of one in this point. The value of the attachment function decreases monotonically to zero on the line determining the range of the standard when the distance from its centre increases. Usually one of the signs in the recognised picture is the centre of the standard.

The attachment function can be presented in the following form:

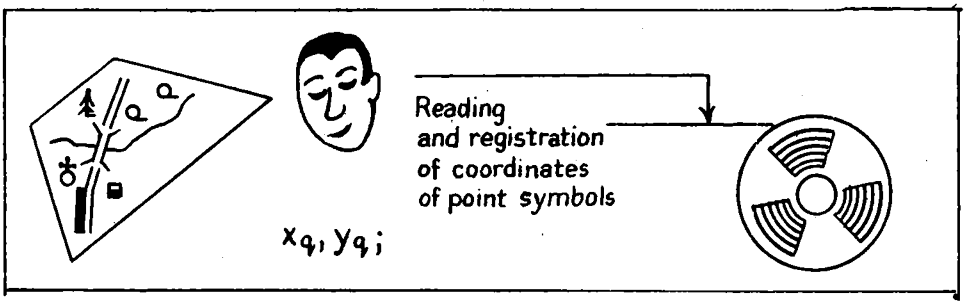
$$P(\mathrm{n}) = \begin{cases} 1 - \dfrac{D_{nm}}{d_{n\bar{q}}}, & \text{when } D_{nm} < d_{n\bar{q}} \\ 0, & \text{when } D_{nm} \geqslant d_{n\bar{q}} \end{cases}$$

whereas, in numerical form the attachment function is a square matrix of attachments. Distances, D_{nm}, between every sign and all other signs in analysed picture, transformed according to the above equation, are elements of this matrix. Subscripts, n and m, denote serial numbers of signs in the set of signs occurring in the recognised picture, while quantities, $d_{n\bar{q}}$ denote distances between every sign r_n which belongs to picture (set of signs) q and closest sign which belongs to the neighbouring "foreign" picture (set), $\bar{q}$ (read: not q).

The interpretation of situation signs on a map, i.e. assigning the attachment of considered signs to the proper picture, consists of the determination of a positive extremum of the attachment function, $P(n)$. It is not necessary to use all standards in the determination of the attachment of signs to a given picture, because some standards can coincide fully or partially. This is not contradictory to principles of forming of cartographic pictures which, with a decrease of map scale, become more and more simplified, also due to the reduction of the number of signs.

A large number of standards requires computers with vast memories in order to record coordinates of points and distances, dimensions of standards, and to carry out numerous complex calculations. The minimal number of standards is determined according to the programme of finding minimal normal forms of the *OR* functions of the Boolean algebra[1].

Formulated on the basis of the above—mentioned theoretical considerations the algorithm of recognising and interpreting a cartographic situation[2], consists of the following stages (Fig. 2).



2		$\|D_{mnq}\|$	
3	R_o, n_o		$\max \|D_{mnq}\| = \|D_{mq}\|$ $\min \|D_{mq}\| = R_o$ n_o
4		$\|d_{n\bar{q}}\|$	
5	$\|0.\ 1\|$		$P_{mnq}\ \begin{array}{l}1-\frac{D_{mnq}}{d_{nq}}\\ 0\end{array}$
6	Elimination of rows and columns of zero-one matrix of attachment		m, n
7			R_k, n_k

Fig. 2. Algorithm of recognising and interpreting of cartographic situation on a map

[1] A detailed description of this problem can be found in the following papers: W. V. Quine, "The problem of simplifying of truth functions", *Mathematic Monthly,* Vol. 58, 1952, No. S, and Mc E. Gluskey, "Minimizations of Boolean functions", *Bell system Technikal Jr.*, Vol. 35, 1956, No. 6.

[2] Cartographic images are characterized by the fact that the information about all elements of the image is determined in advance by their co-ordinates. In such a case a statistical or determinate method can be applied in the course of optimization of particular stages of the process of picture recognition. During statistic calculations only some distribution parameters concerning representation are taken into consideration, while in the case of the determinate method the information about the whole population is considered. Only complicated distributions which are practically impossible to realize in practice can be a good approximation of a representation. Therefore, usually simple distributions (e.g. normal distribution) are applied, but then the approximation is less accurate.

1. Reading and registration of coordinates, x_q and y_q, of all signs which belong to the investigated picture (set), q, and coordinates $x_{\bar{q}}$ and $y_{\bar{q}}$ of signs which belong to neighbouring sets, $\bar{q}$.

2. Calculation of mutual distances

$$D_{nm}^2 = (x_n - x_m)^2 + (y_n - y_m)^2$$

between all (n) signs of the set under consideration, q, and building a square, symmetric matrix, of attachment $\|D_{nm}\|$, from them.

3. Determination of the size (range) and centre of one general standard $\{R_0, n_0\}$ of the recognised picture. They are found according to the following routine:

(a) finding the greatest distance in every row of the attachment matrix and formation of a one-column matrix of maximum distances from them

$$max\{D_{nm}\} = \|D_m\| ;$$

(b) finding the smallest distance in the one-column matrix $\|D_m\|$. It determines radius R_0 of the general standard in the form of a circle (Fig. 3)

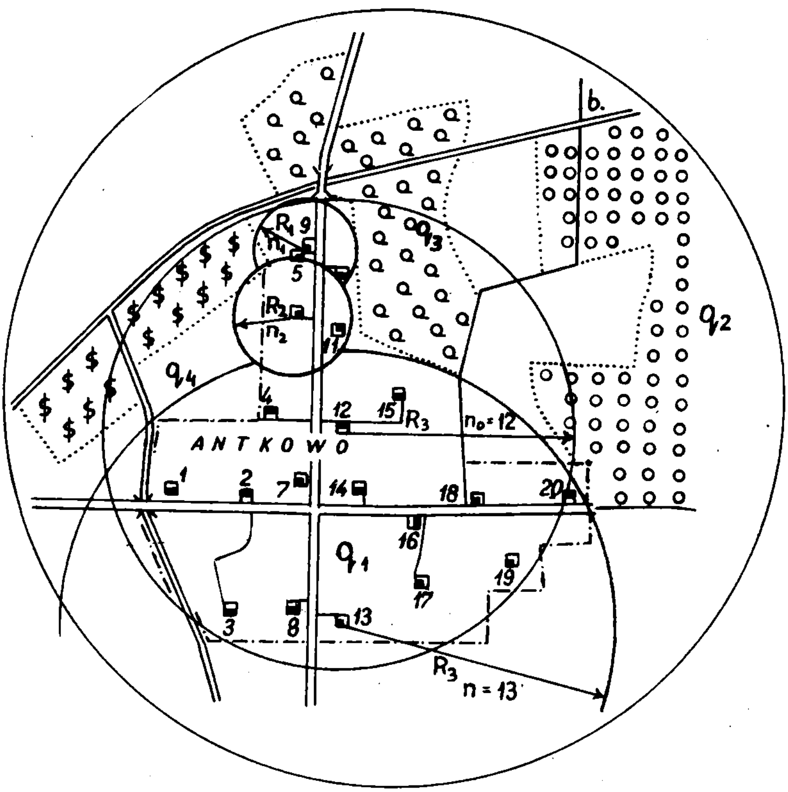


Fig. 3. Various conventional symbols constituting specific cartographic image structures in the form of certain conglomerations, such as settlements or various forms of patterns. Scale: 1:25,000

$$min \{D_m\} = R_0 ;$$

(c) determination of location co-ordinates of the centre of the standard in the form of a circle according to the row number n_0 to which quantity R_0 belongs to

$$n_{R_0} = n_0$$

4. Specification of the range of the general standard $\{R_0, n_0\}$, i.e. exclusion of all signs which do not belong to the investigated q from its range. To this end it is necessary to:

(a) calculate distance $d_{n\bar{q}}$ from every sign r_n in picture q to the nearest sign of the neighbouring picture $\bar{q}$;

(b) select smallest distances $d_{n\bar{q}}$ and form a one-column matrix $\|d_{n\bar{q}}\|$ from them.

5. Transformation of the elements of the attachment matrix $\|D_{nm}\|$ into zero-one elements and formation of an attachment matrix of the $\|0, 1\|$ type. The formulae mentioned below are used in the course of this transformation:

$$P(n) = \begin{cases} 1 - \dfrac{D_{nm}}{d_{n\bar{q}}}, & \text{when } D_{nm} < d_{n\bar{q}} \\ 0, & \text{when } D_{nm} \geqslant d_{n\bar{q}} \end{cases}$$

and

$$P'(n) = 1, \text{ when } P(n) > 0$$
$$P'(n) = 0, \text{ when } P(n) = 0$$

In the case under consideration, the zero-one attachment matrix consists of 20 rows and 20 columns. This corresponds with the number of farm signs included in the ANTKOWO settlement.

6. Minimization of the number of intermediate standards by means of elimination of rows and columns of the zero-one matrix. This is done through the comparison of successive rows and columns and exclusion of these from the matrix, in which the same arrangements of zeroes and ones occur in the same positions in other rows and columns. The matrix is reduced to three rows and three columns as a result of the elimination of rows and columns according to the algorithm of finding normal forms of Boolean OR functions.

n \ m	5	10	20
6		1	
9	1		
13			1

7. Determination of the final shape of the standard $\{R_k, n_k\}$ which would include all signs belonging to the considered picture of a settlement and exclude any sign belonging to neighbouring pictures. The shape of the standard is delimited by partially overlapping areas of three circles. Parameters, i.e. location co-ordinates of centres and radii, of these circles are determined on the basis of the previously reduced attachment matrix.

Shape of standard	Sign co-ordinates	Length of radius
$\{R_k, n_k\}=$	n_6	$R_6 = 7$ mm
	n_9	$R_9 = 8$ mm
	n_{13}	$R_{13}=37$ mm

The method of investigating the attachment of individual signs to a given picture is in a way a generalized solution to the problem of reading, interpreting and synthetizing of a definite cartographic situation on the map. As we can notice point signatures are the object of analysis here.

Minimization can be used as a method of objective selection of point parameters which are to be pictured on the map by an automatic machine. The simplicity of the determination of the standard of point signature selection accounts for the above statement. In a general case the distance between the particular signs (different on every scale) will be the standard.

Figs. 3 and 4 illustrate the selection of point signs on a 1:25,000 and a 1:100,000 map according to the discussed algorithm. A map on the scale of 1:25,000 (Fig. 3), which in this case is the source material, includes all occurring farms. The other map on the scale of 1:100,000 (Fig. 4) was transformed by a computer on the basis of the map on the scale of 1:25,000. The number of farms presented in the 1:100,000 map was selected with the application of the above — mentioned algorithm. In the course of cartographic picture synthetisation a double enlargement of the average distance between farms on the prepared map in comparison with distances on the source material was accepted as the generalisation principle.

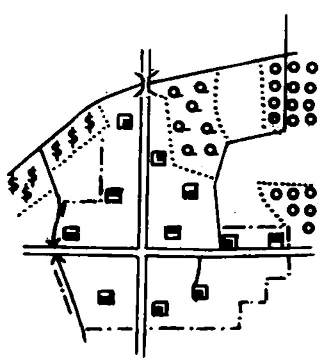


Fig. 4. The map on the scale of 1:100,000 showing the number of farms selected with the application of discussed algorithm

Hence, the problem of faultless reading and generalisation (selection) by an automatic machine of conventional point signatures is relatively simple from the theoretical and technological point of view.

The recognition by an automatic machine of graphic signs is only one of the aspects of practical computer application in cartographic science and practical work. The ability of quick and faultless recognition of various complex situations, taking decisions and conducting strategic games predestinate such automatic machines to replace man in his intellectual activities which require quick analysis and many-sided evaluation of phenomena.