CONVERSION OF CONTOURS

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ABSTRACT

Converting contours is encountered while preparing new maps on the basis of existing maps (for example, conversion of feet into meters). It is assumed that the topography is given by the old contours and the hydrographic network in vector mode, and the contours have assigned elevations.

The new contours are generated by simulating the manual interpolation which skilled cartographers would perform, rather than by forming digital elevation models. This approach seems to be advantageous, since the new contours having been interpolated properly conform to the old ones, which in turn describe the terrain structure satisfactorily.

Generating new contours is performed as follows : Intersecting the hydrographic network with the old contours and assigning elevations to the points of the network elements; Locating for each contour all the neighbouring contours on each side of it; Subdividing the map area into subareas bounded by neighbouring contours of consecutive or equal elevations; Interpolating new contours within the relevant subareas.

INTRODUCTION

There is occasionally a need to insert new contours (generally speaking "isolines" of any nature) between contours of an existing map. Typical examples are converting contours from feet to meters, or changing contour intervals when reducing the scale of the map.

In order to preserve the quality of the given terrain representation it is required that the new contours should conform to the old ones. To meet that requirement, an attempt is made to simulate the manual interpolation, the way in which a skilled cartographer would fit new contours to those existing on the map.

Various aspects of that process are discussed in the following.

The following assumptions are made as to the data at our disposal.

- The area under consideration is a single map sheet bounded by a quadrilateral (rectangle or trapezoid), which is referred to in the following as the frame of the map.
- The existing digital terrain description consists of contours given in vector form, strings of points each string carrying an elevation which has been assigned to it. In addition there is a set of vectors defining the hydrographic network. These data are given in terms of planimetry (plane coordinates only).

The above assumptions are consistent with the procedure of digitizing maps by means of a scanner.

Prior to carrying out the actual contour interpolation several procedures have to be executed to prepare the data.

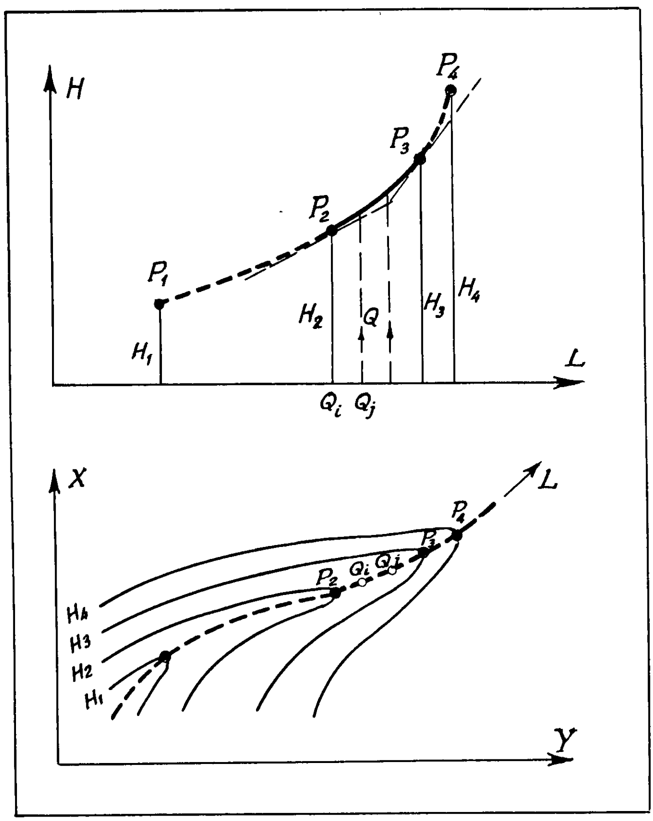

Figure 1. Intersecting a line with contours

<u>Assigning elevations to the points of the hydrographic net</u>

The drainage pattern is an essential component of the terrain description, and as such it has to be incorporated

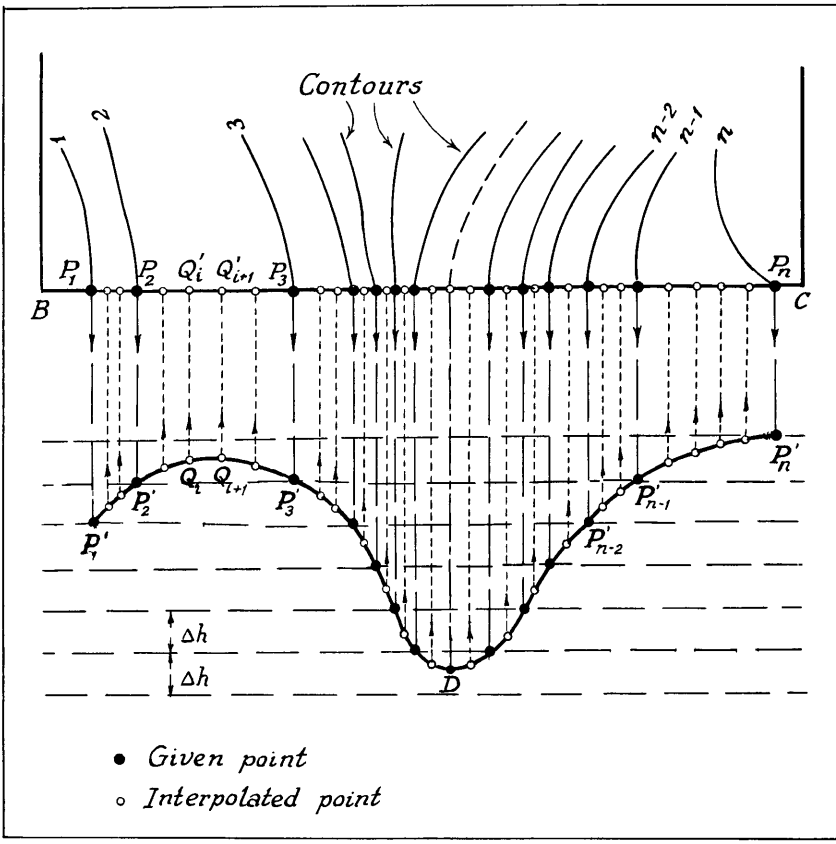

Figure 2. A side of the frame as a terrain profile

in any procedure aiming at the generation of contours. That requires to assign elevations to the points of the drainage lines, which necessitates to intersect these lines with the contours. Figure 1 depicts the intersection procedure.

The line L represents a segment of the drainage pattern. It is defined by points with known plane coordinates. Having selected contours situated in the vicinity of L, intersections are performed between segments of L and the relevant contours, yielding points whose elevations equal those of the respective contours. Usually, four points of intersection are determined (P_1,P_2,P_3,P_4 on figure 1). On some occasions three or two points are located. The points of intersection enable to carry out a non-linear interpolation (when there are more than two such points) to determine elevations for the intermediate points Q_i,Q_j positioned on the segment P_2-P_3 of the line L. Extremities of drainage lines positioned between contours assume elevations computed from the surrounding contours.

After completing all the intersections and the related interpolations, the entire hydrographic network becomes determined in terms of x,y,z coordinates.

Intersecting contours with the frame of the map

The frame of the map plays an important role in subdividing the area of the map into strips. To subdivide it properly it is mandatory that contours should terminate at the sides of the frame. Due to errors inherent in the digitized data that condition may not be met. Hence a search is made along the frame of the map to locate extremities of contours which are off the sides. Whenever such an event is encountered the appropriate segment of the related contour is intersected with the respective side, thus coercing the contour to terminate (or start) at the frame.

Sides of the frame constitute terrain profiles. Since the extremities of contours to be generated have to be positioned on the frame as well, the profiles are utilized for determining their locations. For that reason each of the profiles is subjected to a smoothing routine and complemented by additional points which are inserted between the original points of the profile.

Figure 2 illustrates the said above. $P_1, P_2, \ldots P_n$ are the extremities of the existing contours and Q_i, Q_{i+1} are the inserted points. Their locations are chosen in accordance with the intervals between the given points and their elevations are computed by the smoothing routine. If a drainage line intersects a side of the frame, point D on figure 2, the profile is divided into parts, each part being smoothed separately. The upper section of the figure depicts a side of the frame in the x,y plane, the lower represents the smoothed profile.

Determining positions and elevations of peaks

Some of the contours on the map are closed figures. The area bounded by a loop like contour, within which no other contour is present, usually contains a discrete point representing a peak (or the lowest point in case of a depression). In those cases when such points are missing they have to be established from the data of the surrounding contours. Again, such points are needed for proper generation of contours. Various suggestions can be made for how to determine the location and elevation of a peak. The procedure employed here is illustrated by figure 3.

The procedure starts with circumscribing a rectangle of minimal size around the inner contour h_2. Two profiles directed parallel to the sides of the rectangle can now be formed. Each of them consists of four points: E,F,G,I on one profile and J,K,L,M on the other. Each of those is an extreme point of the two contours with regard to the sides of the rectangle. Parabolas of the third order are fitted to the quadruples of points. The locations and elevations of the extreme points on those curves (P_1, P_2 on figure 3) provide data to position the peak and calculate its elevation.

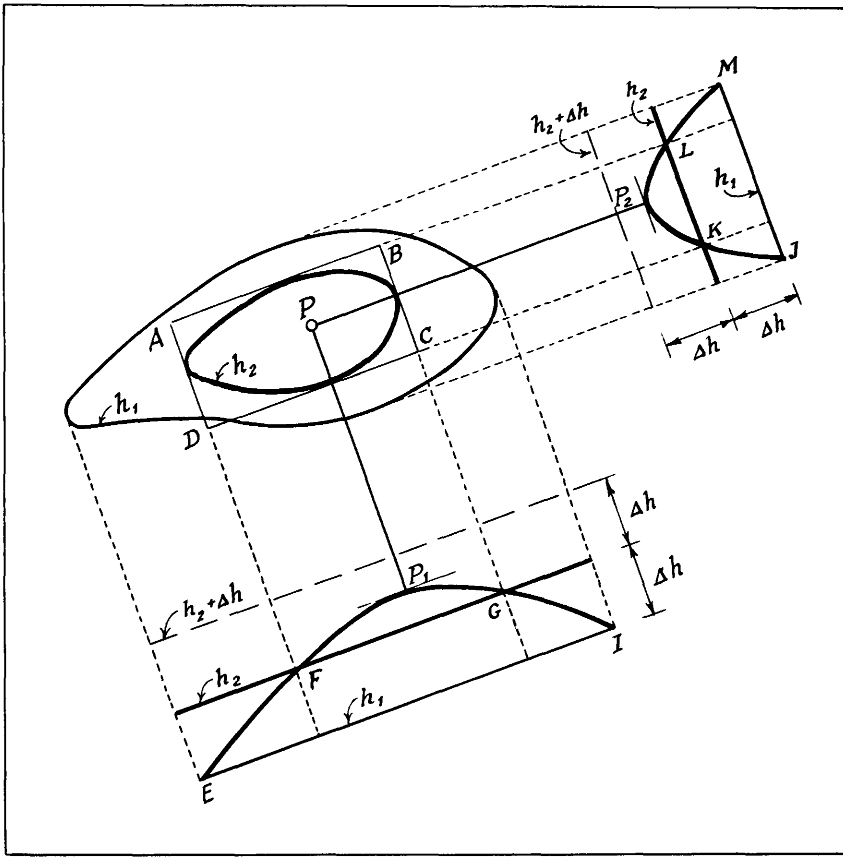

Figure 3. Defining a peak

Subdividing the map area into strips

A vital stage of the process is the subdivision of the map into strips. Contours usually terminate at the frame of the map and eventually close on themselves forming loops. Hence several types of strips have to be considered. Examples of different types of strips are depicted in figure 4.

One strip (no. 1 on figure 4) is defined by the contours a,b and segments of the frame i_i+1, k+1_D, D_k+2. Another is determined by the contours b,c,d and the related segments i+1_i+2, j_j+1, k_k+1. Regarding loop like contours, the strip is either an innermost loop, loop 3 on that figure, or a strip which assumes a shape of a ring (strip 4) bounded by the contours e and f.

In order to permit defining the strips, proper successions of contour extremities have to be established on each side of the frame. Starting at the side AB of the frame, sequential numbers are assigned to the extremities positioned on that side according to ascending northings. Hence, the extremities of the contours a,b,c assume the numbers i, i+1, i+2. The counterpart extremities of those contours assume temporarily the same numbers. Having completed the sorting along the side AB, we proceed with the side BC and assign sequential numbers according to increasing eastings. At that stage the previous numbers are replaced by the new ones. As a consequence of that step it becomes known that the contour c for example starts at the side AB at a point carrying the number i+2 and terminates at the point j lying on the side BC. Proceeding in the same manner proper sequential numbers are attached to the contours, so each contour is being identified by the numbers of its extreme points and the sides on which those points are positioned.

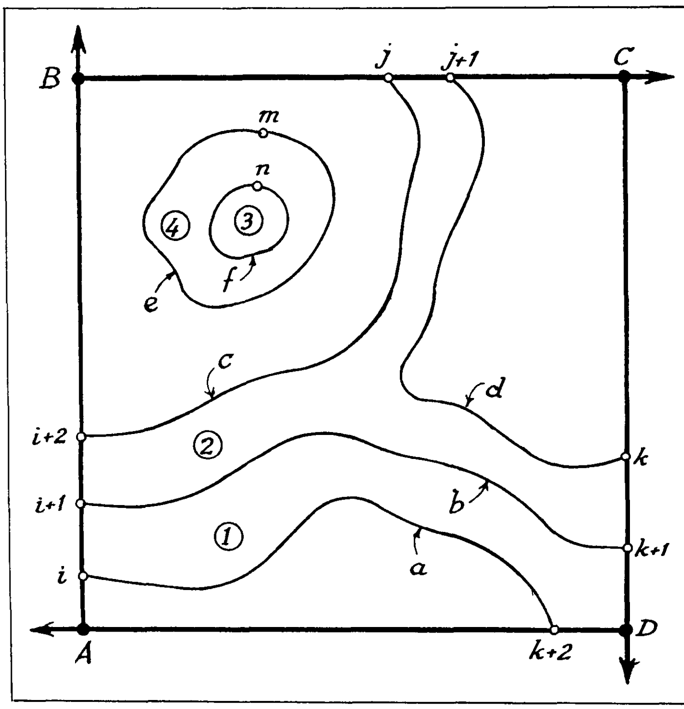

Figure 4. Forming strips

The information about the contours so obtained assists forming the strips. Consider strip no. 1 on figure 4. One of its boundaries is the contour a with extremities i on the side AB and k+2 on DA. In order to determine the second boundary, we look for a contour starting at the point i+1 which differs in elevation by one contour interval from the previous one, check whether it terminates at a point preceding k+2 and carrying the number k+1. If that is the case we conclude that the strip 1 is delimited by the contours a,b and the respective segments of the frame. In order to define the next strip (no. 2 on figure 4), it is necessary to find the counterparts of b. Examining the point i+2 on the side AB and the contour associated with it, it is found that the contour terminates at the side BC at the point j. This gives rise to a conclusion that the strip in question is branching. If the next point in the sequence j+1 on side BC has the same elevation as j we examine whether the contour starting at j+1 terminates at a point carrying the number k. Having been satisfied that that is the case, we establish the fact that the strip in question is bounded by the three contours b,c,d and the respective segments of the frame. Should the point j+1 have an elevation not equal to that of j, then we had to examine the point k on the side CD. If the elevation of the contour starting at k were equal to that of the contour b it would constitute a boundary of the strip being formed. In such an event it is apparent that the strip in question contains other contours. The outermost of these are the remaining boundaries of the strip.

Upon completion of examining strips with boundaries terminating at the frame, the loops are being considered. We start with the identification of the inner loops. Such a loop is characterized by the fact that within its area only one point may be present (a peak). Having found an inner loop we inquire if it is encompassed by another loop. If so, a ring-shaped strip is at hand. The said above is exemplified by the contours e,f (see figure 4).

So far a limited number of cases have been discussed. In our opinion these suffice to elucidate the considerations of the strip formation. As a result of the above procedure the entire area of the map can be subdivided into strips. Such a subdivision is shown schematically on figure 5.

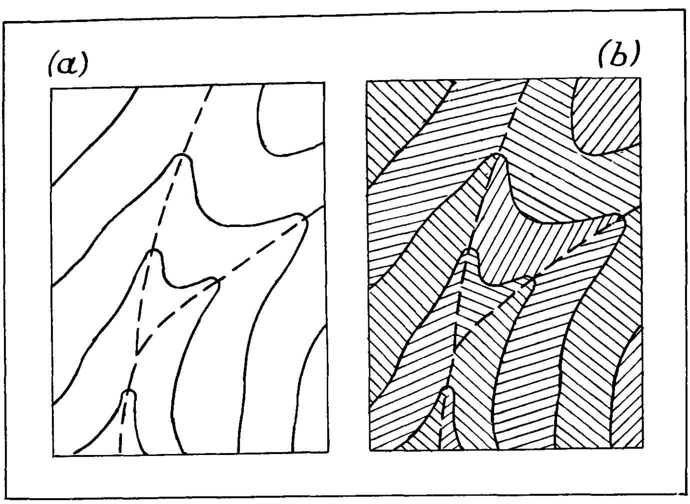

Figure 5. Subdividing the map into strips

INTERPOLATING NEW CONTOURS

A new contour is characterized by its elevation. Examining the sides of the frame it can be found within which strip the contour has to be formed and which are the adjacent contours. To locate the contour, the strip in question is divided into sections in accordance with the shape of the contours delimiting it, while considering the presence of drainage lines crossing it. The shape of the contours are analyzed as follows (figure 6).

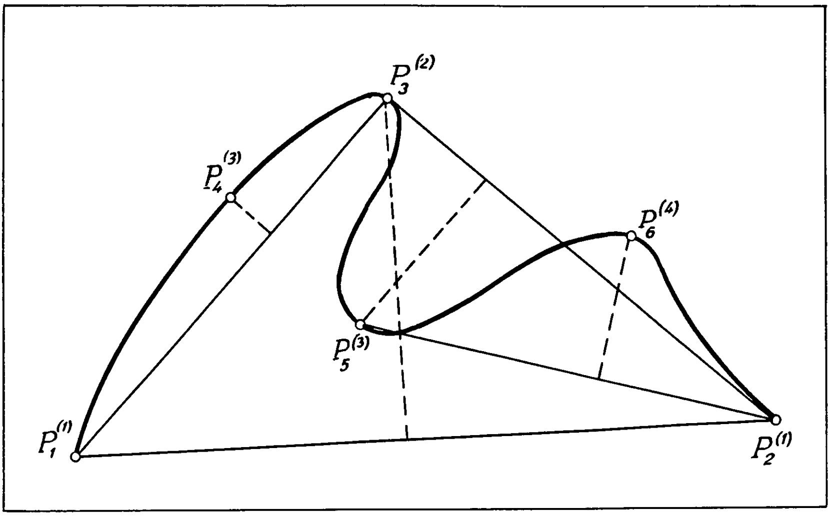

Figure 6. Segmentation of a contour

The aim of the analysis is to identify points which divide the contour into segments having a uniform trend in the xy plane. These are located iteratively by considering the offsets of the points forming the string, in relation to chords of the contour. At the first step, offsets are computed with regard to the chord joining the two extremities P_1, P_2. The point which yields an offset of a maximal absolute value is assumed as an extremity of a substring, subject to the condition that it exceeds a predefined magnitude. The latter is imposed in order to avoid dividing the contour into too many substrings. Referring to figure 6 a point satisfying the above requirements is found to be P_3. At the second iteration we examine the offsets related to the chords P_1-P_3, P_3-P_2. As a result, two additional points P_4, P_5 are found. Lastly, the point P_6 is located with respect to the chord P_5-P_2. Thus, the contour is divided into substrings: P_1-P_4-P_3, P_3-P_5-P_6 and P_6-P_2. Executing analogous operations with regard to an other contour bounding the strip, establishes pairs of corresponding substrings which enables to divide the strip into sections. The new contour is then interpolated piece by piece in each section separately and joined thereafter to form one continuous line. Eventually, a drainage line passes the strip being processed. In such a case, the suitable segment of that line defines a boundary of a strip section. Since it is common to two sections, generating the contour in one of them terminates at that boundary and continues from it onward into the other section. That ensures locating the new contours in agreement with the drainage pattern.

The last stage of the process is the actual interpolation. As already said, it is performed within sections of a strip. The main question here is how to select pairs of points, how to associate a point of one string with a point of the other, in order to locate a point on the new contour being generated. Recalling the fact, that the section of the strip is delimited by contours of a nearly uniform trend, it was found convenient to adopt the following approach (see figure below).

Figure 7 depicts a section of a strip bounded by the contours b,c with the adjacent contours a,d on either side. Two curves are fitted to the contours delimiting the section (the lines $\bar{b},\bar{c}$ on the figure). These two are averaged to form a single curve $\bar{m}$ which represents the general trend of the section. The curve is divided into a number of intervals according to the average number of points of the two contours. A perpendicular to the curve

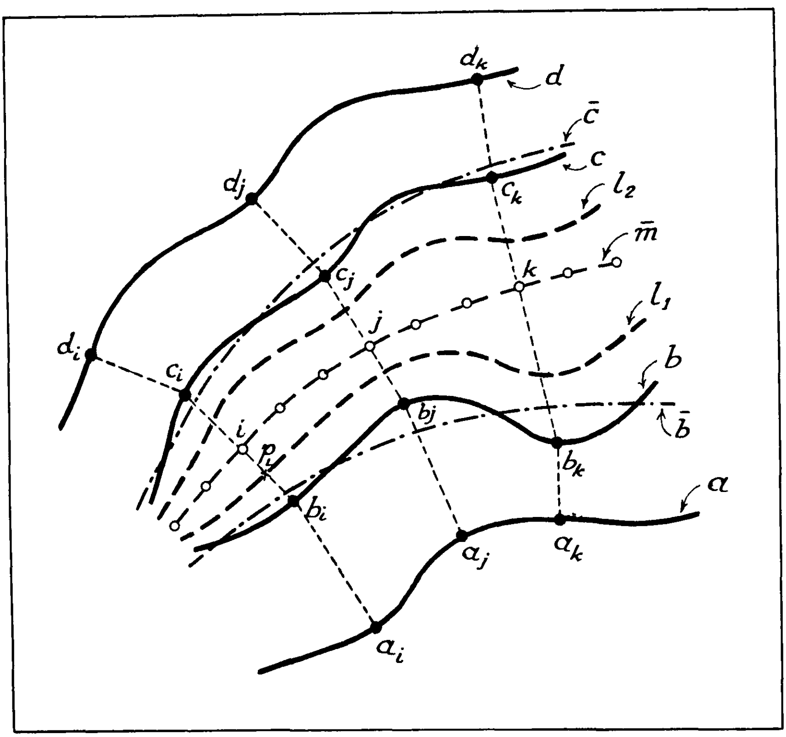

Figure 7. Generating a segment of a new contour

passing through an end point of an interval (the point i on figure 7) intersects the two contours at b_i and c_i. Two more points a_i,d_i are selected from the adjacent strings, the criterion governing their selection being the shortest distances from b_i,c_i to the respective strings. The quadruple of points so obtained forms a X-section of the terrain. From it a point p_i of the sought contour can be computed. To simplify the computation, it is assumed to regard the X-section as if all four points were lying on a straight line. A parabola of the third order is fitted to the X-section and the point p_i of the new contour is located on the line b_i-c_i. The position of p_i is determined from the equation of the parabola, while taking into account its known elevation. A more sophisticated approach would have been to consider the curvature of the X-section (in the xy plane) and to determine the position of p_i accordingly. The feasibility of that approach has not yet been examined.

Applying the above routine to all points on the average curve representing the trend of the strip provides a set of points which constitute a segment of the new contour (l_1 on figure 7).

Proceeding in the same manner, segments of the contour are generated in all the sections of the strip yielding the required contour.

CONCLUSIVE REMARKS

Various aspects of the interpolation process have been discussed and essentials of the different stages presented. A comprehensive exposition of the subject would exceed the space allocated for the paper.

It has to be admitted that certain problems related the subject have not yet been solved satisfactorily. These refer to local irregularities (noise) peculiar to contours representing certain types of terrain. Nevertheless, it can be said that on the whole, most of the problems of the computerized simulation of the cartographers skills have been solved adequately.

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