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Dr. A. Raymond Boyle
Professor of Electrical Engineering
University of Saskatchewan
Saskatoon, Sask., Canada

"The Present Status and Future of Scanning Methods for Digitization, Output Drafting and Interactive Display and Edit of Cartographic Data".

ABSTRACT:

For many years, traditionally minded cartographers have preferred a digital vector or lineal form for line features. Advances in recent years, however, have broadened this viewpoint and now scanned, rasterized, matrix and grid cell methods are considered as being equal or even more important. Obviously, automatic photogrammetric methods have accentuated this change, but the writer and others have been able to show that raster scanning can be most efficient in purely cartographic processes including automatic digitization and drafting, as well as data editing and even storage. The writer is particularly involved in developing scan digitization and drafting systems and the methods and considerations of these will be described and put into the context of production mapping. The liaison of these cartographic methods with photogrammetry and with some aspects of photo-interpretation will also be covered.

Recent changes in approaches to digitization of cartographic data

For many years the scanning input of map data has been suggested but, for one reason or another, has not been usefully applied; the reasons are logical and can be summarized as follows:

a) It appeared that the input document had to be of very specified format such as a constant line weight.

b) Too much effort was centered on the handling of complex coloured paper maps, instead of the major application of separations from existing map series.

c) Cartographers demanded the output format to be in vectors, but the scan to vector conversion was deemed to be very expensive and time consuming.

d) The precision requested was greater than necessary and resulted in excessive costs.

e) Many programs were inefficient and badly conceptualized.

As the need for mass economic digitization became pressing in the mid-nineteen seventies, an analysis of the efforts to that date high-lights the faults in design as well as the occasional, but low-profile systems that had in fact been successful. Gradually the correct concepts were formed and the present possibilities are now more properly understood. However, it is useful to point out the advantages and disadvantages of alternative designs and the extra effort that a small change in specification can cause and the problems often created in times, throughput and costs.

The outstanding problem of any high resolution map digitization is the enormous number of pixels or picture elements to be handled - at least 100 million (10^8). The costs and times of the operation therefore depend appreciably on limiting the number of passes through the data. Increasing resolution in a 2:1 ratio, quadruples the number of pixels to be handled, so that it is inadvisable to request more resolution - even fractionally - than is absolutely necessary. Experiments show that the interesting range of precision produces times, costs and storage which vary from the fully acceptable to the unacceptable, and this over a very small range of requirements.

It seems unlikely that the number of passes could be reduced below two. One of these is needed to produce the vector line data from the raster data form; this change is regarded as essential for present day cartographers, although might possibly disappear in the future. This transformation is essentially a software line-following of adjacent pixels to form a line and is relatively simple to accomplish in one pass, once the pixel data has been thinned to a single pixel line width. To date, many line thinning routines have required multiple passes for edge nibbling and have absorbed large operational times in computation. It appears that there is no simple and economic way of handling very wide lines without high cost, but we are fortunate that, in topographic mapping at least, such wide lines only occur occasionally and it has been found possible to remove these photomechanically in preparation, using contact printing. Once this principle of sheet preparation is accepted, then the number of passes and thus the costs, can be reduced appreciably.

In order to decide whether digitization can be accomplished efficiently an examination must first be made of the form of cartographic data itself bearing in mind its essential resolution requirements. It is believed that any line drawn by a cartographer would be adequately recorded in absolute and relative precision of its position on a map, by accepting an engineering precision of ±0.05 mm. This entails a raster scan resolution of 0.1 mm and on a 100 cm x 100 cm sheet this would produce 100 million pixels. Moreover this precision infers that a 0.1 mm wide line could appear as one or two pixels in width, while a 0.2 mm wide line appears as 2, 3 or 4 pixels in width. This covers the majority of line weights encountered on topographic map separations except for a few on the culture sheet. The spot size is such that lines of only 0.05 mm in width would still be recorded and not missed. It has been found by a number of programming groups, that such line weights can be reduced to single pixel lines in a single pass; most other programs can operate in not more than two passes. If wide lines were allowed to be present, then either the extra cost of nibbling must be accepted or else an incorrect line central point.

It will be seen that to reduce scan resolution lines to 0.05 mm or 0.025 mm spacing would accentuate the problem and make multiple passes mandatory on almost all lines, as well as each pass having to operate on a much larger number of pixels in a square-law relationship. The resultant shape of the cost curve in this range is almost cubic.

The reasons for the apparent desire by cartographers for 0.025 mm resolution must now be examined in some detail. The first reason for this is based on a false premise; it is an attempt to store the data in such a way that it can be directly reproduced by a plotter using only linear vectors between the points. This produces an acceptable, although not high quality appearance. This problem would be more correctly dealt with by digitizing and storing data at 0.1 mm resolution and, for plotting, using smoothing routines to produce data at a finer resolution, but of course no greater accuracy, of 0.01 mm. The second reason is an attempt to distinguish between line weights. Occasionally this might be useful and in fact one map series (USGS 1:100,000) was set up using lines of various widths in the expectation that these could easily and automatically be distinguished one from the other. Obviously this infers that the scan resolution must be high and that the range of line weights present would be considerable at the higher resolution; both of these contribute to multiple passes and long CPU times and resulting high costs. In exceptional circumstances such line width discrimination can be accomplished with present techniques, but for most map series it is not worth the effort. The fact that intermediate and index contours on a contour sheet are of different weights is of some interest, but the real need is to know the elevation values and this is not adequately given by the line weight alone. In the culture data, line weights tend to be mainly 0.1 mm once the very heavy lines have been removed; the heavy lines are more efficiently digitized in most cases by manual means. It is suggested therefore that, in practice, line weight discrimination during scanning at this time does not produce advantages commensurate with the costs.

The results of line thinning followed by line following leads to a large bulk of data in vector form, each with long strings of coordinate pairs, the coordinates being spaced at the resolution interval. It is well known that, because of the work habits of most cartographers, the lines can often be well represented by points spaced further apart than the resolution increment, the gap being filled by a variable length and angle vector. The resultant cartographic line when drawn is, to acceptable visual levels, the shape of the original but with a reduced number of coordinates having to be recorded. Other systems have used cubic spline fits to the spaced points, but this tends to be less generally applicable in topographic mapping, partly because of the hardness of the spline which tends to produce bulbous ends to sharp promintary features. This process of data compaction, is usually known as 'weeding' and is an essential part of scan digitization. There are many existing algorithms to do this as it was often previously utilized for manual stream digitization; it is generally only a matter of selecting the one most convenient for the data format used.

Once the above necessary aspects have been taken into account, the greatest problem is concerned with the labelling of the lines produced. While this was a natural interactive process during manual line digitization there is no similar situation in automatic operation. The nearest approach is to display the digitized lines on a display and edit station and, after pointing to the appropriate line, key in the descriptor. If all lines were done this way it could be very time consuming and tedious while involving expensive equipment. However certain automatic time saving methods are now being developed and these should be used whenever possible. One of the most important of these is relative to the de-symbolization of lines.

A de-symbolization program can be written to connect the separate short lines of dashed, dotted and dash/dot lines into full lines. Obviously, this would involve examining the vector data for lines of certain lengths and then ordering them prior to concatenating them into a single line. A more complex operation would be concerned with the cross ties of railways or the double casing of roads; these are rarely an exact physical representation of the width on the ground but, instead, are pure symbology. Many such de-symbolizations can be handled completely automatically using a knowledge of the cartographic specifications. Not only can the lines be de-symbolized but, at the same time, labelling known from such work can be applied, for example to indicate that intermittent streams were de-symbolized.

A major problem in labelling is that of contours. Attempts are now being made to label all intermediate contours automatically after the index contours have first been labelled interactively on a display. It appears that this is likely to be successful particularly if the depression and fill ticks and the spot heights can be taken into account by the program.

One of the most important aspects of automatic digitization is the inspection, appraisal and preparation of the input document. While a few establishments have the need to scan digitize coloured paper maps in order to obtain cartographic data, this is an excessively complex process both in the physical aspect of colour separation and then in the feature analysis. Generally map data is best and most easily obtained from the black/white colour separations available for normal colour printing processes. These were originally drawn or scribed as separates, probably stored in photographic copy form and only become coloured entities because of the inks used when passing through the press.

The main separations usefully used with scan digitization are those containing an appreciable number of lines ie. contours, drains and culture. In the procedure described, the first two of these need little preparation as they are already in a suitable form. They only need inspection and possible correction for lines which are too close or corrections to allow for poor quality itself.

The culture sheet, however, has unwanted wide lines and 'blob' symbols representing buildings. These could possibly be removed by opaquing, but can alternatively be removed by a succession of contact prints, using line thinning and widening techniques in the normal manner with transparent spacers between the emulsions and a diffused light source. The removed wide lines and symbols are then most efficiently digitized by manual means as their character is usually very suitable for this.

The fourth sheet requiring automatic scan digitization in most map series is the timber or forest cover. The data appears not as lines but as 'open window' separations used to produce areas of colour. These can be handled by essentially the same process as the line work but in a somewhat simplified form, as it only has to detect the area edge and no thinning is required.

The other separation sheets are mainly used for informational sources when labelling. This might, for example, be for the 'red fill' separation for roads describing the type of road already digitized from the black road casings.

The scanners used for this automatic map digitization come in many forms. In general it is advisable that they handle a whole separation sheet at one time, although this is not essential, as scale and rotate and edge-join matching processes are now well known and straightforward. The main types of scanner can be described as drum, flying spot or comb. The first is generally similar to a standard facsimile transmission unit but larger and more precise, in which the map is mounted on a drum while this is rotated at synchronous speed. At the same time a photohead detector is moved continuously and linearly along the length of the drum. The main disadvantage is that the total travel time is usually of the order of one hour and this is rather too great for economic operation and throughput. The flying spot scanner can do the same work with black/white separations but, as it has a much smaller inertia, can operate at a higher speed, in fact up to the maximum that the associated computer or data store can accept. Typically a scan is of the order of 10 minutes although 30 seconds is feasible. If a very high resolution scan were desirable, then this method seems to be the only one able to meet economic map throughput requirements. The comb scanner consists of a strip of photodiode detectors arranged in a 'comb', usually about 2.5 cm wide and this is moved in strips across the sheet. As always there are many other systems which can be regarded as a compromise between the above types. One example is a flying spot scanner covering only 2.5 cm in width, and being used in the strip by strip mode.

The digitization of black/white map separations has some aspects of advantage and some of disadvantage as against the scanning of other documents. An aspect of disadvantage is that the sheets are large and this is accompanied by a requirement for high precision - at least 0.1 mm. A main aspect of advantage is that no colour or grey scale is required, so that the light detection need not be precisely normalized over the whole sheet area; only an on-off signal need be detected.

As the application of scanning becomes more general, the uses will expand for standard map data in digital form. However, before this can be done many down-stream problems have to be considered. Some of these are; efficient storage of the very large amounts of data to be produced; the design of extremely efficient storage formats to reduce the number of computer words to a minimum; much faster access display and edit facilities than those at present offered for the very large amounts of data; and automatic high quality and high speed output drafting. None of these were appreciated as problems until large quantities of input data became available.

Many so-called cartographic systems were not designed as such and do not have suitable or convertable data structures. In machine drawing and printed circuit work for which many of these systems were designed, the data is usually in the form of very short lines, sometimes only two end point coordinates, and at that a very small number of lines relative to a map content. Such systems could use an essentially unstructured approach of headers each followed by data in almost any order, and even in this form a typical data search would appear to be fast. However, in cartography the situation is very different, as the line data itself may contain many thousands of coordinates for one line and there may be many lines. In order to have fast searches, the data must be separated from the header information which is now set up in a directory form with cross referencing to the data. Separate disk scanners for the I/O and search operations do not appear to have much advantage in cartographic applications, as scanners only relieve the CPU of work during the disk operation time; if there were other work the CPU could undertake at that time, that is a great advantage but, unfortunately in cartographic applications, this is not generally so.

Almost all searches are I/O bound and, as each search depends within reason on the number of computer words rather than on the number of coordinates, efficient packing must be used, usually best in the form of incremental words following a starting absolute coordinate pair. In general absolute coordinate systems involving 32 bits X and 32 bits Y are preferred, with the incremental word being 8 bits X and 8 bits Y on 16 bit minicomputers. The absolute coordinates can be represented at any time by a simple and fast cumulative addition process as the line is processed.

The selection of the best incremental word size is limited by programming considerations but, from a statistical analysis of normally drawn cartographic lines, it appears that this size fits well with the series of straight line vectors approximating within the required limits, to the original line. The use of such incremental words gives a compaction of nearly 4:1, as against an absolute coordinate string without any other method being considered. While the storage compaction is important, the resulting speed advantage in data handling of 4:1 is even more so. Another aspect that must be considered is the size of the descriptive header for each entry in the directory. While there must be adequate data for normally requested searches, any extra data would slow up the directory search and therefore must be organized into another separate but cross referenced data set. These aspects of compaction along with others must be used, mainly to increase access time on the large amounts of data and avoid the excessive time use of expensive display situations, but more importantly perhaps in a non-machine environment - to prevent irritation to the operator.

Having looked at the needs carefully, and built a satisfactory format system, then it will be seen that data storage requirements are still very high, at least 10^7 bits per map. The optimistic prospect appears to be the laser written optical disk. The data once written on such a disk is archival and cannot be modified directly. The disks are reproduceable at low cost and the playback units are expected, when available, to be only of the order of cost of present magnetic cartridge disk units on a minicomputer. The method of use in cartography is to have a magnetic disk in unison with a laser written one, the former carrying a modifiable copy of the optical disk directory and any updates. At periodic intervals of probably several months or even years, a new optical disk would be made, either by the manufacturer or by a service bureau equipped with clean room facilities. The capacity of these disk is enormous and, after allowing for redundancy, at least 10^{10} bits are available, which with good data compaction might mean up to 1000 topographic maps. These disks are equally of interest for associated attribute data in textual form.

There is no doubt that when good data is available in large quantities, the need for efficient map generation will also arise to meet new needs. Part of this involves an improvement in data editing prior to drafting, but the large photohead XY plotter is then much too slow. It is not known to the author what printing methods will be used in the years to come, when smaller runs of maps will be the order of the day with more frequent updates, but it is certain that some type of output drafting onto film or directly onto plates will be essential. The making of separations will almost certainly be done - as is already occurring at this time by high speed scanners, either of the drum or the flying spot type. The main problem at this time is the efficient and economic conversion from line vectors (which is the chosen storage data format at this time) to raster format for the scanner, when the very large amounts of data involved in each map are taken into account. Even at 0.1 mm resolution, 100 million pixels have to be handled. This precision, while adequate for data digitization and storage, is not adequate for good appearance line work and the data has to be expanded by smoothing to approximately 64 times the amount. It is therefore essential to first convert the data to scan format and only then expand to the higher resolution needed in the plotting raster mode. The amount of data is then becoming extremely large, approximately 10,000 million pixels in one map; this is beyond the capabilities of present control computers if high speed output were required - as it would be. Special hardware interfaces appear to provide a viable method to obtain improved results and development work on these lines is proceeding.

The association of purely cartographic work with photogrammetry is taking a number of forms. It naturally comes mainly in the compilation of new maps. Many users have direct digitization from their manual photogrammetric units, but this method is slow and tedious, although necessary for some applications. As far as planimetric data is concerned much of this work can be done more easily by tracing from ortho photos, and then automatically scan digitizing these tracings. Contours can probably be best generated from DEMs (digital elevation models), produced automatically. In general the direct photogrammetric input method appears to be better for large scale engineering plans, while the smaller scale maps, requiring more generalization, appear to be better by first drafting and then scan digitizing.

An area where the scan input process may be very helpful is in the automatic digitization of polygon boundaries drawn by photointerpreters directly onto aerial photographs or on overlays thereof. The manual digitization work on these is appreciable at this time, although the gains in using computers for block adjustment and transformation to produce a map are valuable. However, for efficient scanning to be possible, some changes in the interpreter's work habits will probably have to occur, mainly in the use of different and easily distinguishable coloured inks, in order to allow for colour separation scanning. The generally lower precision and smaller size of a photograph have advantages for the scanning processes both in hardware and in computer processing time. These developments should enhance work in those systems involved with forestry and land use.

It will be noticed that scanning methods are at this time generally being applied to input and output, while retaining the central storage in the more compact vector format. This certainly meets the present requirements for cartography, but some groups are now questioning whether it is necessary; should the conversion processes be removed from the system and the somewhat larger data bulk accepted in the light of such developments as the optical disk? At this time it is only a suggestion, but it does seem that most of the cartographic requirements of computation and manipulation such as scale change and projection change, can be as easily or possibly more easily accomplished with data in a raster form. Moreover the data in raster form does remove one of the greatest arguments against digital vector data in that the latter loses the topological relationship between features; this has to be synthetically re-introduced in the form of special attribute linkages, whereas in raster form it is inherently retained in a manner similar to that of the human mind when reading a map.

Even display systems are changing to raster mode as we move to the use of high resolution colour displays, particularly for geographic information system use. Many of the cartographer's arguments for vector data disappear when he is allowed to work on a raster display where to him all aspects of handling and edit appear to be in the vector mode. For example, he may point to anywhere on a line and wish to know the attached attribute for that line. In vector mode the program tracks down the coordinates from the pointed position to the line start and finds the attached descriptor. In a raster operation it moves to the line end by a fast algorithm for line following tracking by adjacent pixels. The descriptor is attached to the first pixel in the line. The technique is not quite as reliable due to the possibility of near line adjacencies, but this problem is avoided by intensifying the line pixels on the screen to indicate the action taken to the operator. It is certainly as fast as working with vectors.

In general it is now considered that there are very hopeful developments in a completely raster format system. More work remains to be done, however, before this can be accepted for the wide range of applications at present handled by digital vector means.

The increasing use of scanning data acquisition and plotting devices creates an exciting environment for the cartographer's life in the next few years. Naturally the implementation of these techniques will raise problems but these, with good planning and an understanding of the need and technical situation, appear to be capable of solution.