THOUGHTS ON LINE GENERALIZATION

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When one encounters the word frontier he tends to think of the border between two countries. On the other hand a researcher may think of a frontier as a barrier in knowledge which divides the known from the unknown. Today, I chose to use the term frontier in quite a different sense because I perceive a cognitive boundary between manual and computer cartography. This manual/machine frontier seems to be as much of a barrier to the passage of ideas among cartographers as does the Berlin Wall to the peoples of divided Germany.

Many of us have crossed and recrossed from manual to computer cartography and recently I have noticed that when I make this journey, the way I think and work seems to change drastically. If I were to categorize these changes in a simplistic fashion I would suggest that in manual cartography I think of the map and its symbology as a whole,while as a computer cartographer my attention is focused upon the bits and pieces of the map-making process. Having sensed this dichotomy in my personal work experience I have become aware of the need to transfer some of the philosophical and theoretical concepts from manual to computer cartography and that is the theme of the discussion which follows.

Before you gain the wrong impression let me give you one of my perceptions of the future of map-making. In the not too distant future, cartographic production laboratories as we know them today will cease to exist. They will be replaced by machines located in shopping centers and other advantageous sites where the customer will use the machine to create maps to suit his own needs. He will insert a dollar bill to activate the machine. A dialogue between man and machine will ensue and after a short period of time the machine will produce a multicolored map designed by the customer. If you think this is an impossible dream consider the fact that the machine and the technical linkage for such a system now exist. What is missing is an adequate software system.

My children used to say,"Daddy don't tell us about the olden days, things are different now!" So! Things are different now, but sometimes one can learn from these differences and here is a tale from the olden days. My recollections are directed to the time when I was a student learning to symbolize naturally occurring linear features such as rivers and coastlines. Our instructor implored us, over and over again, to look at the whole line; to study it, to try to understand its geographic character and to visualize how the line might be drafted. Afterwards, we created our version of the line in quick smooth strokes of the pen and then looked at our creation to determine whether we had put the visualization into our drawing. In every case we worked at manuscript or a smaller scale and either knowingly or unknowingly created a generalized version of the line using the process of simplification. As we gained experience our linear symbolizations exhibited the characteristics of those created by our instructor for how else were we to finish the course with a good grade.

When I first put on my computer cartography hat I rarely studied the whole line before I began to work. My objective was to use the plotter to draw an exact copy of the manuscript line. To achieve this goal I became engrossed in the problems of digitization,error analysis and the splicing of redigitized sections of the line into the digital file. When a visual edit of the plotted file satisfied me, I was elated by my success. Having satisfied myself that I could make the plotter sing and dance I turned my attention to the tunes that were being called by other cartographers. Somewhere along the way in this period of study, elation turned to concern and finally to disbelief. Highly respected cartographic colleagues seemed to have taken leave of their senses. They were creating computer plotted maps by exercising a new and rather loosely formulated cartographic logic which seemed to be based upon the need to economically justify massive equipment expenditures. You see, my traditional cartographic background reared its ugly head and I became determined to attempt an amalgamation of two mapmaking technologies based solely upon what I perceive to be sound cartographic practice. Some of you will no doubt disagree with this approach to computer plotted linear representations by expressing the notion that new technology requires new ways of thinking. So be it, but I still find it difficult to understand the use of point elimination algorithms which select or reject recorded coordinates on the basis of a generated set of random numbers, or the use of highly accurate digitizers to acquire data files which are then reduced by the selection of every Nth point.

I perceive two stages in developing a system for creating computer-plotter linear representations. The first is the creation of an accurate, error free minimal digital file which, when plotted, is a nearly exact copy of the manuscript line. The second involves the line at reduced scale. Two types of linear generalization accompany these activities, for in the first instance we deal with linear generalization in the imperceptible realm while in the latter, substantial and highly visible linear alteration may be necessary.

The lines in Figure 1 are organized in an orderly progression to display what I mean by generalization in the imperceptible domain. The first line was plotted using an edited digital file containing 1096 coordinate pairs. As the digitizer cursor was moved over the manuscript, line generalization by selection was taking place because only a sample sub-set of the infinite set of coordinates on the line was recorded. After the linear file was corrected by inserting redigitized segments to eliminate the more obvious errors, the data file was subjected to software which removed electronic and human errors, duplicate coordinates and un-needed coordinates on straight line segments. This latter step is, of course, a form of generalization by simplification, and the final product of these efforts is shown as Line A.

Line B appears to be an exact duplicate of Line A but in this case the visually edited file was submitted to a gentle binomial smoothing operator prior to plotting. One could rightfully question this operation but after

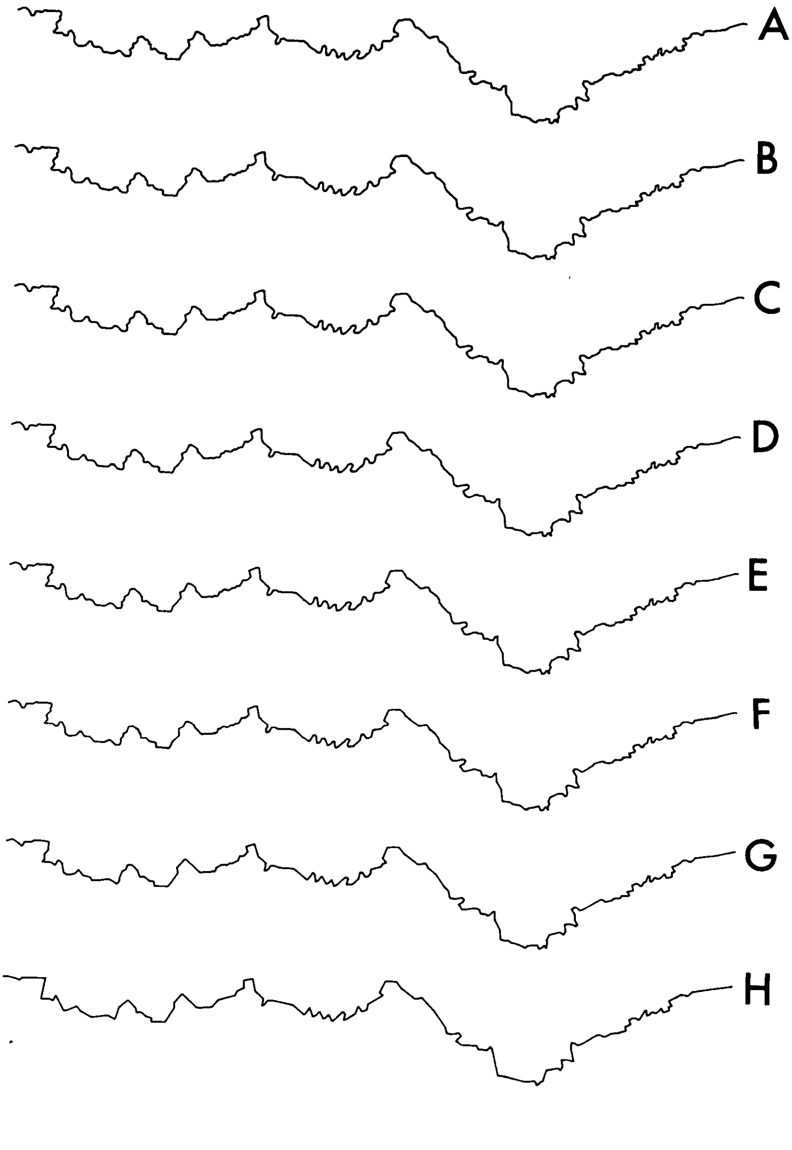

Figure 1

my review of point elimination algorithms it became clear that reduced data files are composed of two sets of intermixed coordinates. The first set are those coordinates which occupy unique positions on the line and give the plotted representation its true geographic character. The second and undesirable component of the reduced file contains coordinates which also occupy positions on the line but their uniqueness is due to the artificial angularity caused by the sampling process. These points are in reality artifacts of the interaction of the digitizer resolution grid and the sampling rhythm of the recorder. By using a gentle smoothing or simplification operator prior to the application of weeding algorithms one insures that the reduced data files will contain a higher percentage of the truly important coordinates positions on the line.

Lines C through H were plotted using simplified data sets selected from the file for line B. The weeding algorithm used is a sequential three coordinate operator which calculates a vector between the first and third points in the triad and compares the distance from the vector to the second coordinate with a parameter set by the operator. By changing the decision parameter simplified files which range from 691 coordinate pairs for Line C to 118 for Line H were created. The simplification or weeding procedure could have been carried further but I judged that almost everyone would notice the difference between lines B and H, that relatively few would notice the difference between lines B and G and that almost no one would consider lines B and F to be different.

I am not particularly happy to report that I had to rely on subjective judgement to determine the limit of generalization in the imperceptible domain, but little research has been done on the psycho-physical properties of lines and what causes map-users to perceive them as same or different. This is one of the reasons why I suggested that software was not yet available to make my prediction of maps by machine come true. Two other questions regarding this line series can be posed: Is this the most suitable weeding algorithm? Will any algorithm perform equally well on all types of lines and at all map scales? I have developed methods of psycho-physical testing which will aid us in finding answers to these questions, but my limited research indicates that high density files recorded on equipment with a resolution of .005 inch can be reduced 75 to 90% without leaving the realm of imperceptible generalization.

As a computer cartographer contemplates the generalization of linear features which are to be reproduced at a smaller scale he may be reminded of the patterns he sees on an oscilloscope. They are composed of many wave lengths superimposed one upon the other. The twists, bends and curves of naturally occurring features exhibit these same kinds of varying wavelengths and in generalization the cartographer wants to preserve the long waves while discarding the more numerous shorter waves. Everyone, cartographer or non-cartographer, seems to perceive the more important features of a line and if asked they can mark a hierarchical series of points which they feel are necessary if one is to preserve its geographic character. Such positions are variously known as the feature, critical, characteristic or salient points. Two types of characteristic points are known to exist. The first are those points which are inherent in the linear configuration. Good cartoonists see these points and use them very effectively to draw caricatures of prominent persons. These are the points or features that traditional cartographers use in generalizing a linear feature that traditional cartographers use in generalizing a linear feature and one might suggest that a good generalization of a river is in fact a river caricature. The second type of characteristic point exists because a position on a line has great geographic,geomorphic, geologic, economic, social or political importance. Positions of this type include the intersections of national boundaries, the location of a bridge, the points of tangency of a river and a city, etc.

While almost all cartographers and psychologists recognize the existence of characteristic points, their use by computer cartographers seems to be limited. In the usual practice of creating digital data banks of linear features, some characteristic points are marked as nodes at the ends of line segments. If, as is often the case, the cartographer holds these nodes inviolate, he is using a subset of characteristic points which occur at these nodes. I have begun to look into this possibility using the Douglas-Peuker Corridor Algorithm reported in the proceedings for Auto-Carto II for this purpose.

Fortunately, I have a reference base for this study which was developed by Jill Marino.

In her psychological study, Marino used two experimental groups to mark characteristic points on lines. Here you see two histograms of experimental responses. The top histogram is a record of the responses of 30 non-cartographers while the bottom histogram is a record of the responses of 30 cartographers. Her findings indicate that these two groups selected the same set of characteristic points on the line and that points selected in a hierarchical series are in agreement.

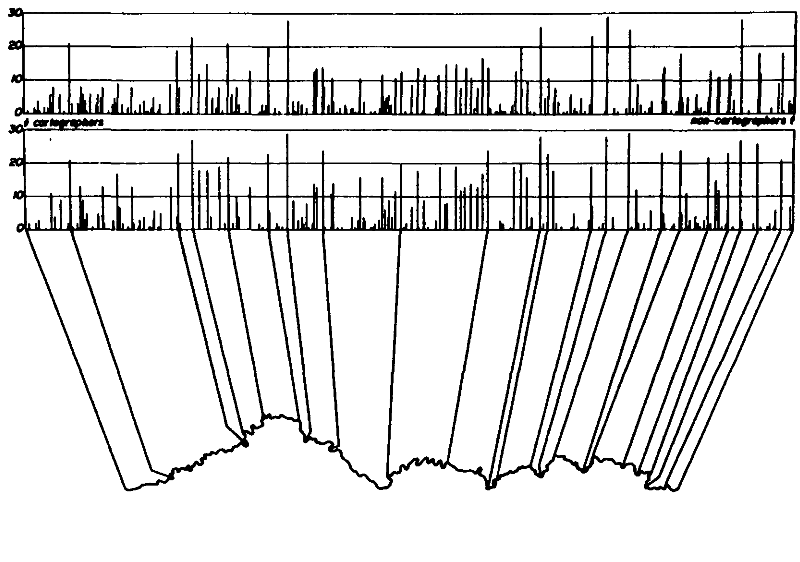

Figure 2

The top line shown here, a section of the Mancos River in Colorado, was taken from Marino's research. Below are three hierarchical sets of characteristic points selected using the corridor algorithm. The upper two of these lines contain 39 and 23 points which are in close agreement with those selected by the respondents in Marino's study. The location of the 13 points seen on the bottom line were selected using a coarse parametric setting and are disappointing. Application of the corridor algorithm to the other five lines in Marino's study yields similar results. I have no certain explanation of this, except that it may be due to some peculiarity in my version of the algorithm.

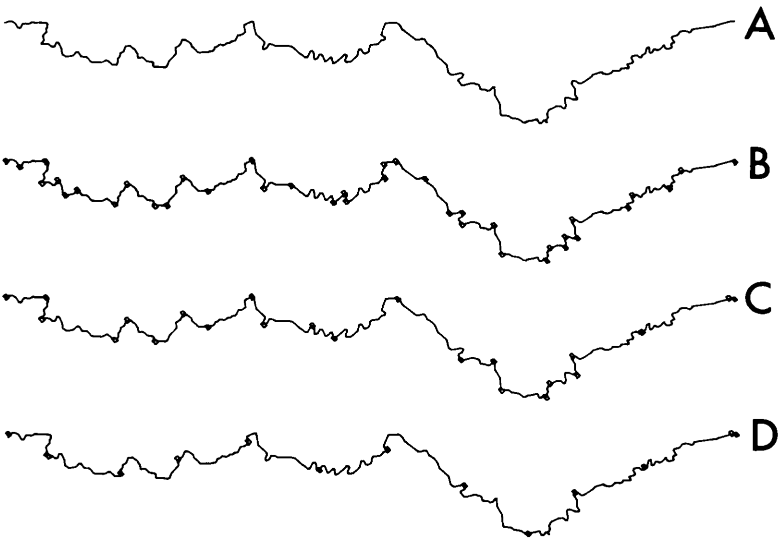

Figure 3

Here you see the same segment of the Mancos River that was displayed earlier and in line B and subset of 23 points selected using the corridor algorithm. Line C is an illustration designed to show how a rather stringent generalization of a line can be driven through a set of characteristic points. Lines D and E are reductions of ¼ scale of lines A and C so that you can evaluate the quality of the end product of the procedure.

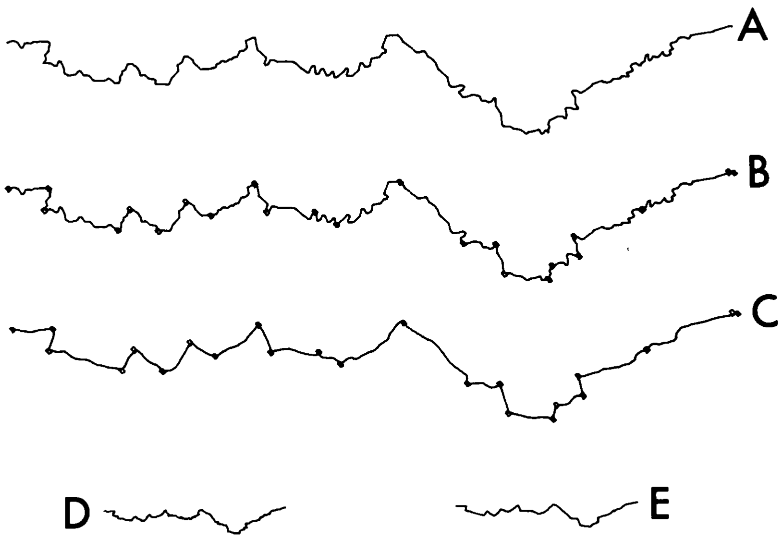

Figure 4

The series of lines presented here was created to show how lines not controlled by characteristic point sets wander about in geographic space. Each line has associated with it the 23 characteristics point set seen previously and as one proceeds from top to bottom in the illustration the linear generalizations are seen to move farther and farther away from the original position and configuration of line.

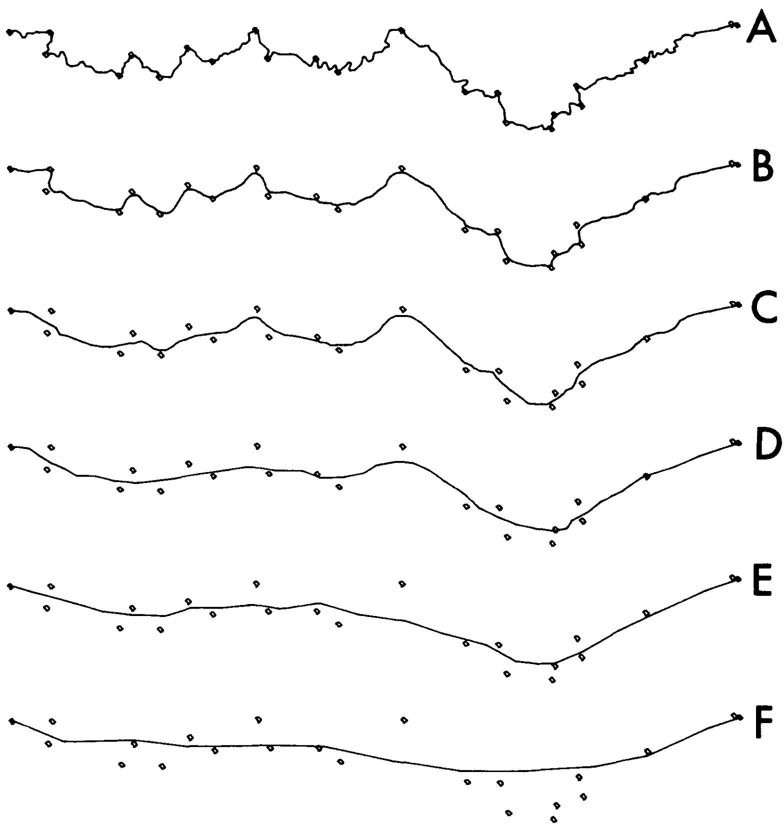

Figure 5

In computer cartography, as in manual cartography, one often wishes to maintain certain features on a line while subjecting the rest of the line to substantial generalization. For example, when creating a generalized map of the recreational resources of Oregon, a cartographer might wish to retain some of the details of especially significant sites such as the state parks and beaches at Cape Arago, shown as line A. Here, in lines B, C, and D you see various versions of a line which were created in attempts to achieve this goal

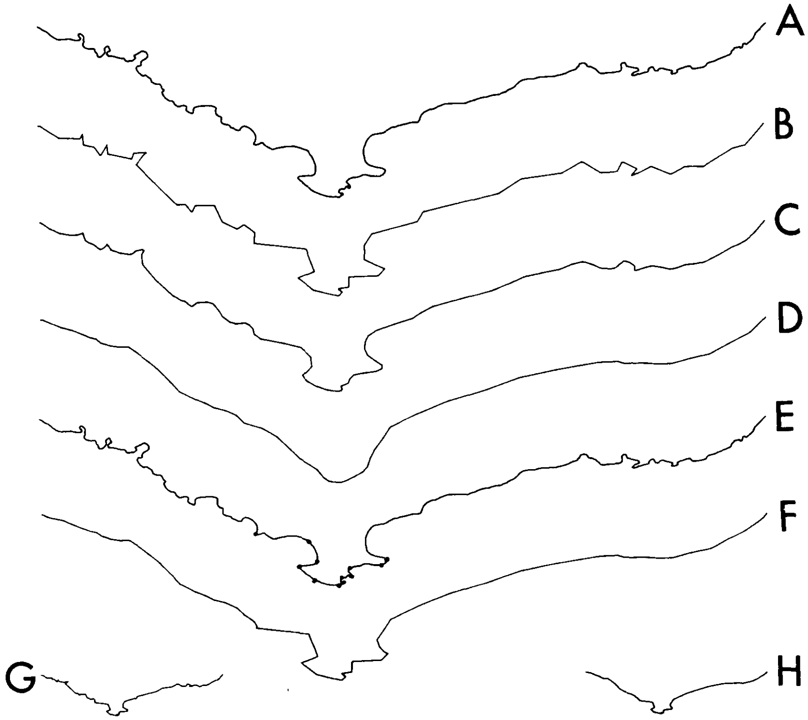

Figure 6

without using characteristic points. Line B was plotted using a weeded 55 point subset of the 949 coordinator used to plot line A. Line C shows a basis spline smoothing of line B and line D in a plot of a 5 point running average smoothing of B. The representations of the cape are judged to be acceptable on lines B and C but the rest of these lines contain too much detail. The reverse is true of line D.

If one selects a few characteristic points on the Cape as shown in line E and then drives the 5 point smoothing through these points, the desired characteristics of the generalized line can be retained as shown in line F. The two small scale versions of line B and E are shown at the lower left and right as lines G and H.

The series of linear representations that I have shown illustrate how one can maintain cartographic integrity as one moves back and forth across the manual-computer cartographic frontier. Each procedure that has been presented comes from an amalgamation of manual and computer technique and each is based upon concepts which have validity in carographic theory. You must remember, however, that I am an academic and that I ran computers on play money, but I do not accept the notion that we must use poor algorithms on the sole basis of economics.

I am also aware of the need for more empirical and theoretical research on linear generalization by computer. We need to know for example, which algorithms provide us the most acceptable generalizations from a perceptual point of view and how to set parameters to achieve these plots. This means that we must develop better means of measuring the "wiggliness" of lines and how to cope with both vector and raster data sets. My concern is not for the future of computer cartography but for the quality of the maps computer cartographers produce. Quality comes, not from machinery, but from cartographically logical and soundly based algorithms.