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LINES, COMPUTERS, AND HUMAN FRAILTIES*

GEORGE F. JENKS

ABSTRACT. **Geographers and cartographers, in their rush to implement computer cartographic systems, have tended to overlook problems of human error. Psychological, physiological, and logical errors seriously affect representations of naturally occurring lines such as rivers and coasts. Attempts must be made to understand and eliminate or reduce such errors because the man-machine interface will continue in the foreseeable future.**

IN their brochures, manufacturers of computer equipment focus the attention of geographers and cartographers on machine accuracy, with the implication that more precise equipment equates with more accurate maps. To some extent this implied improvement in quality is true, but one has only to turn to the current literature to find numerous maps of inferior quality prepared with very accurate equipment. In many instances the poor quality of published maps has little to do with the electro-mechanical capabilities of machinery; it can be traced directly to human error. Even in this highly computer-oriented society, maps are conceived by people and are subject to the physiological, psychological, and logical limitations of the geo-cartographer. Human frailties are clearly evident when mapmakers display representations of naturally occurring lines created by computer-driven plotters.

Two aspects of the man-machine interface dominate in this discussion of computer mapping. The first involves the potential for logical, psychological, and physiological errors in the process of digitizing linear features.[1] The second is concerned with the generalization of linear features and new errors that can enter into the system if sound cartographic practices are not followed.

Some of the logical, manipulative, and perceptual aberrations that occur in maps created by computer-driven devices can best be described graphically, and for this reason the following narrative is essentially an interpretation of illustrations. A short section of the White River in South Dakota was selected as an experimental line (Fig. 1). Using this line, shown in the upper part of the figure, an attempt is made to demonstrate that man-induced errors may exceed, indeed overshadow, errors attributable to equipment.[2]

Human Error in Digital Data Acquisition

At present, the most common method of recording digital data for linear representations is through the use of the semiautomated digitizing tablet.[3] Manuscript material is placed on the sur-

Dr. Jenks is Professor of Geography at the University of Kansas in Lawrence, KS 66045.

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[1] These human errors will continue to affect the digitizing phase of computer cartography in the foreseeable future. Automatic line-following digitizers and raster scanners have been developed but their use is limited to large laboratories and some cartographers are not satisfied with the cost and quality of the output.

[2] Others in the geographic/cartographic community have expressed similar ideas. For example see, "Panel on Human Problems of Conversion From Manual to Automated Methodologies: In the Shop and in the Marketplace," in D. H. Douglas ed., *Applications of Geographic Information Processing* (Ottawa: University of Ottawa, April 1977), pp. 61–65.

[3] For an excellent discussion of this topic, see David Rhind, "An Introduction to the Digitizing and Edition of Mapped Data," *Automated Cartography*, Special

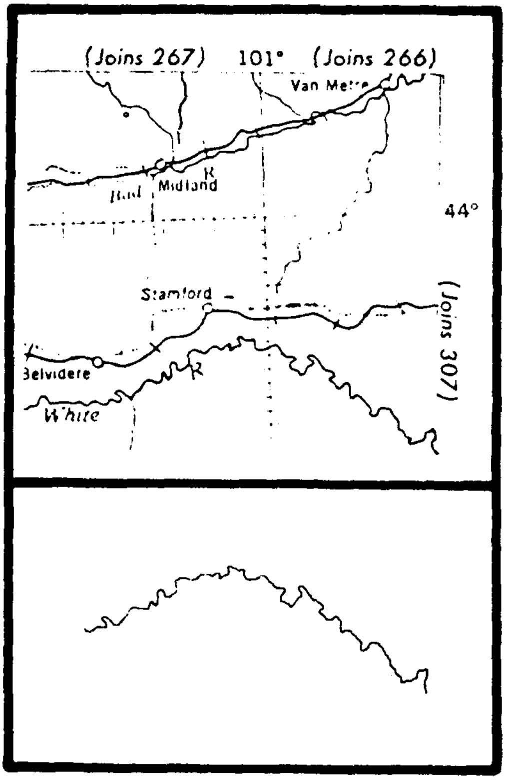

FIG. 1. The bottom line in the upper box is a short section of the White River in South Dakota selected as an experimental line. It was taken from World Aeronautical Chart, Laramie Range (306), published by the U.S. Coast and Geodetic Survey in April, 1945, and revised in November, 1955. It was produced by manual methods. The line in the lower box is a computer plot of the experimental line created by connecting 600 coordinate pairs with short, straight-line vectors.

face of the tablet and a sample of points is taken from the infinite set that comprises any line. The sample points are recorded electronically as x, y coordinates. Linear representations are created by connecting these sample points with vectors drawn by a computer-driven plotter. The representation of the experimental line, shown in the lower part of Fig. 1, was created by this method. Six hundred coordinate pairs connected with 599 very short, straight-line vectors were plotted in the representation.

Mapmaking, whether by traditional or computer methods, is a highly integrated procedure. From conception to the final map the cartographer makes decisions that are interconnected in much the same way as the individual strands of a spider web. Each new judgment must be based upon those preceding while at the same time considering those which are to come. Two important decisions face the cartographer at the data acquisition stage in computer mapping. The first and most important is the selection of the manuscript material because the quality of a computer representation can be no better than that of the sources used. The second is the choice of the density of the sampled coordinates that are to be recorded. If a dense data sample is desired, "stream mode" digitization is used and recording is done using a time or distance constraint as the cursor is moved along the manuscript line. Sparse data samples are usually taken in "point mode" during which the operator carefully selects and records each coordinate pair on an individual basis. Since the procedure for the selection of manuscript materials is essentially the same for traditional and computer cartography and is discussed at some length in cartography texts, further consideration is not deemed necessary here.

Stream Mode Digitization

Stream mode digitization is based on the assumption that a very dense sample of points records all of the intricate nuances of any naturally occurring linear feature. Furthermore, it is postulated that the very short vectors used to connect these points retain all of the smoothly undulating characteristics of the manuscript line. Advocates of the procedure emphasize that operators can be trained quickly and cheaply if they have good eyesight and the steady hand needed to accurately move the cursor along the manuscript line. A major disadvantage of the method is the large size of the data sample and the need for additional processing before the coordinate pairs are stored for future use.

The nature of the stream mode digitization has been simulated (Fig. 2). On the left you see a greatly enlarged section of the manuscript line and the digitizing cursor. The operator visualizes the center of the manuscript line (symbolized in white) and attempts to manipulate the cursor crosshairs along this centerline. Each digitizing tablet is constructed with a particular resolution capability that is shown as a grid in the middle part of the figure. A sample coordinate point can be taken only at the nearest grid

Publication Number 1 (London: British Cartographic Society, 1974), pp. 50–68.

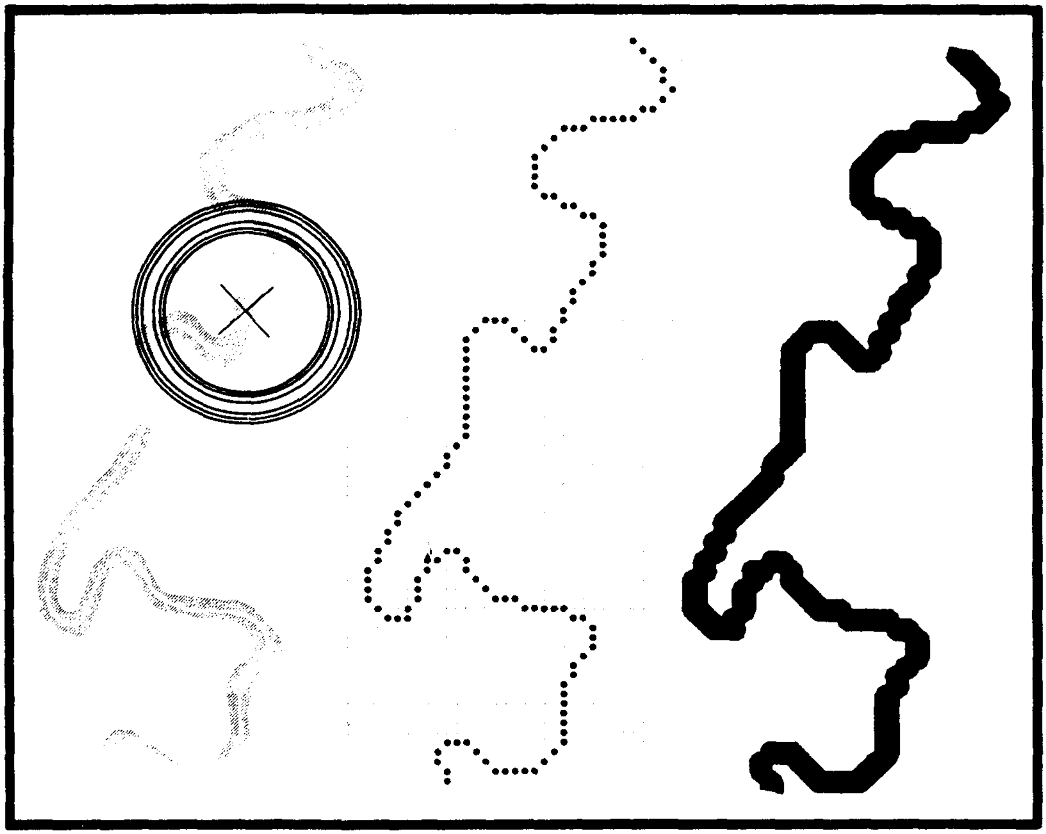

FIG. 2. A simulation of stream mode digitization. The operator positions the cursor on the center of the manuscript line, here emphasized in white, and as the cursor is moved along a sample of points is taken. Coordinate pairs are recorded electronically at intersections of the resolution grid of the digitizing tablet. Later these coordinates are connected by straight line vectors to create a digital representation of the analog source.

intersection. The 134 points shown at the grid intersections are those that would be recorded with a perfect passage of the cursor along the centerline. The line shown at the right is the most accurate representation of the manuscript line that can be produced using equipment with the resolution grid shown.[4] When reduced to the scale of the experimental line, no part of this line would lie more than 1/400 inch out of position (Fig. 1).

The reality of stream mode digitization is shown in the tenfold enlargement of a section of the experimental line (Fig. 3). The author created the black vector plot using a file that was thought to have been recorded by an accurate and careful manipulation of the cursor. Had the task been successfully carried out, the black line would have been plotted on top of or very close to the white centerline. Two possible types of human error, psychological and physiological, are apparent in the illustration. A psychomotor (line-following) error may have occurred either because the true centerline could not be perceived or the cursor crosshairs could not be moved accurately along it.[5] Either of these psy-

[4] The equipment used to create the illustrations presented in this paper consisted of a digitizer, a microprocessor, and a plotter. The resolution capabilities of the digitizer and plotter are .005 inch.

[5] Line following error has always been a concern of computer cartographers and it is the only type of human error that is regularly recognized. G. E. Mart says "Errors inevitably occur both in line following and in entering related information." "The Use of Digitizers in Hydrographic Cartography," *Automation in Cartography, Technical Working Session* (Enschede, Netherlands: International Cartographic Association, April 1975), p. 357. Also see S. B. M. Bell and D. P. Bickmore, "Interactive Cartography at ECU: Regional Geography A La Mode," *Proceedings of the International Symposium on Computer-Assisted Cartog-*

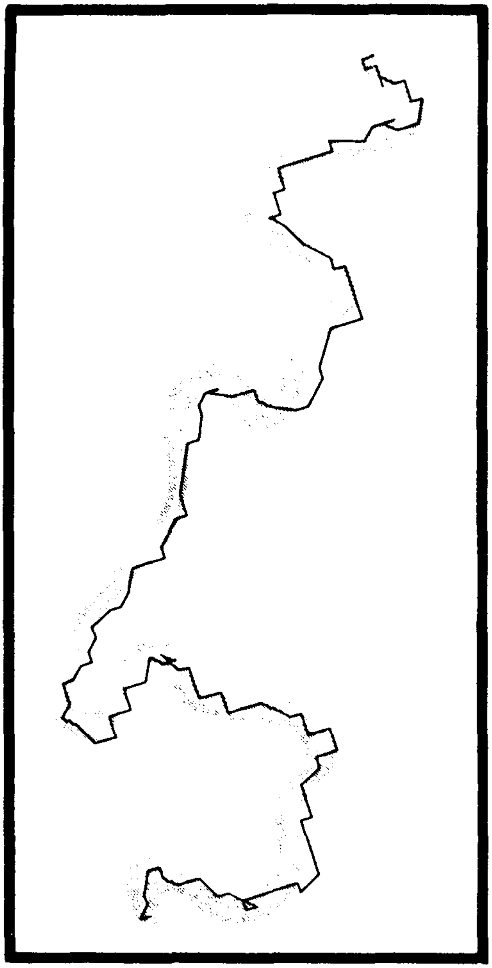

FIG. 3. The black vector plot was created from a data file created by the author. This black plot should lie on or very close to the white center of the experimental line but line-following and tremor errors cause the misfit.

chological errors could cause the plotted line to be offset laterally from its intended position. The second type, physiological error, resulted from involuntary muscular spasms (twitches and jerks) as the cursor was moved. Physiological errors are difficult to discern in a vector plot because they tend to parallel the longitudinal or lengthwise axis of the centerline. Most often these errors involve retracings of sections of the line already sampled but they may also take the form of spikes and polygonal knots as shown in the enlarged portion of the top line in (Fig. 4).

Every dense data set, whether acquired using time or distance constraints of stream mode digitizing seems to contain latitudinal and longitudinal errors. Some mapmaking establishments, where equipment with resolution capacities of .001 inch is used, attempt to achieve an error standard of .004 inches but Traylor has found that errors often exceed this standard by a factor of five and in some cases by a factor of ten.[6] In any case, latitudinal and longitudinal errors, if not corrected, alter the "look" of the line and may lead to misinterpretations by the mapreader.

Point Mode Data Capture

Proponents of point mode data acquisition argue that a sparse but carefully selected set of sample points can be used to create a faithful representation of any line. This assumption, generally accepted by both cartographers and psychologists, is based on the notion that there are highly significant points, variously known in cartography as characteristic, critical, or feature points, that define the geographic configuration of a line.[7] Given this assumption, one must assume further that the digitizer operator can locate and record the position of these characteristic points.

Two types of characteristic points are known to exist. The first are points that occupy significant economic, political, or cultural locations. Examples include points at the intersections of boundaries of countries, the location of rivers in relation to cities, and such economically important locations as San Francisco Bay and the Oslo fjord. The selection of this type of characteristic point evolves from the subject matter of the map and the author chooses those points he considers necessary to convey the message of the map.

raphy (Washington, D.C.: U.S. Department of Commerce and American Congress on Surveying and Mapping, Sept. 21–25, 1975), pp. 303–17.

[6] Charles T. Traylor, Department of Geography, State University, Memphis, Tennessee, personal communication, 1979.

[7] This concept is discussed in detail by Fred Attneave in "Some Informational Aspects of Visual Perception," *Psychological Review*, Vol. 16, No. 3 (May 1954), pp. 183–93, as well as in Chapter 2 of Rudolf Arnheim, *Art and Visual Perception, A Psychology of the Creative Eye* (Berkeley: University of California Press, 1971), pp. 485; and Jill S. Marino, "Characteristic Points and Their Significance in Cartographic Line Generalization," unpublished master's thesis, University of Kansas, 1978.

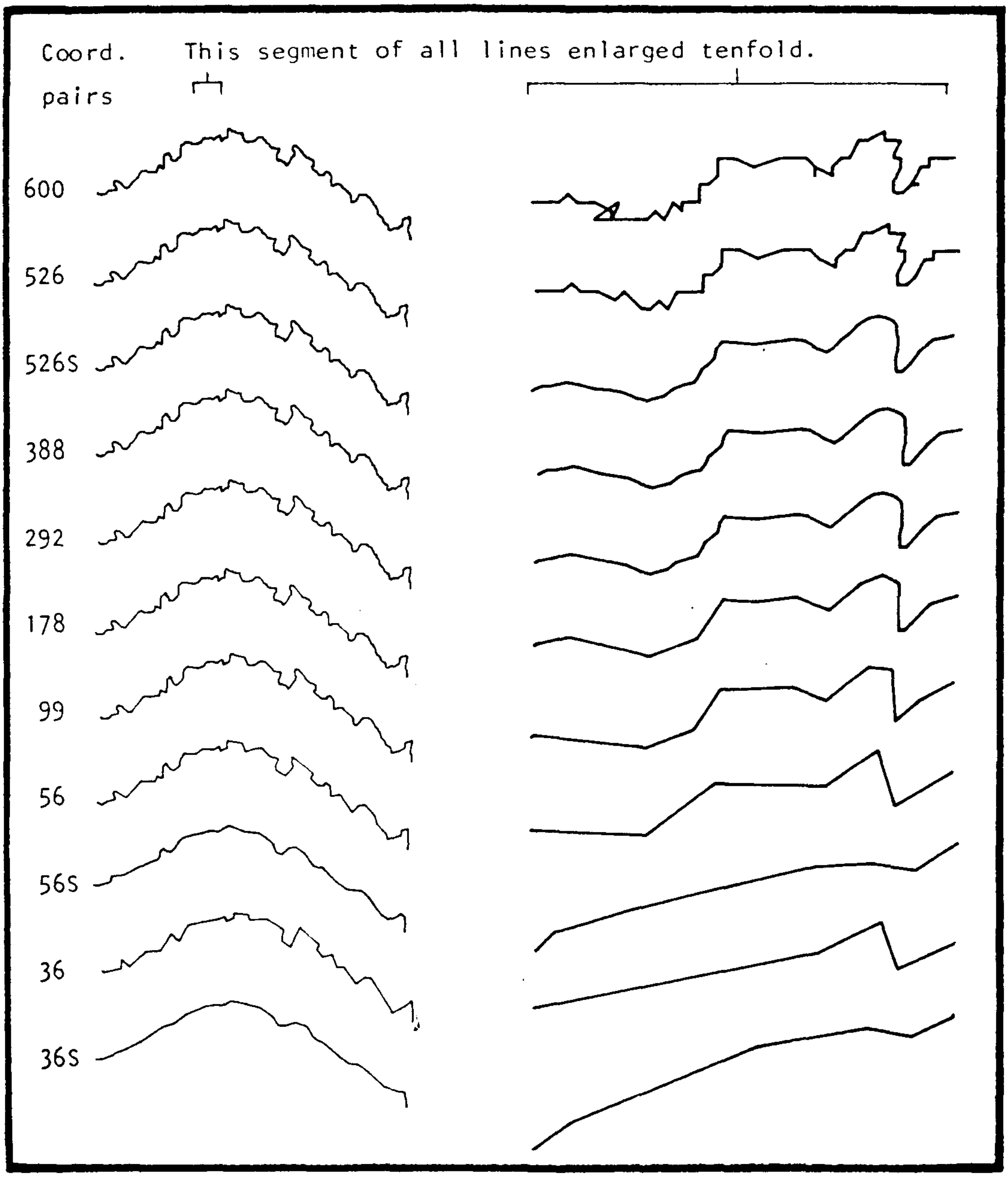

FIG. 4. These eleven rows of linear representation were selected to illustrate various post data-capture processing techniques. The bracket over the top line of the left column indicates the positions of each of the tenfold enlargements shown in the righthand column. Line 600 is a plot of a visually edited file, line 526 is a plot of a software edited file, and line 526S illustrates the use of a gentle smoothing algorithm. Lines 388, 292, 178, 99, 56, and 36 are plots of files created by a point elimination algorithm applied to file 526S. Lines 56S and 36S illustrate the use of a more rigorous smoothing operator when preparing lines for substantial reductions of scale.

The second type of characteristic point is natural, important, or basic to the structure of the line. These points are innately perceived as giving the line its individual or distinctive form. They are points on cartographic lines that are as necessary as those skilled artists use to sketch caricatures. The location of these inherent characteristic points seems to be related to changes in linear trend or to relatively large undulations in the line. Experimental data obtained by Marino indicate that this type of characteristic point is seen on naturally occurring lines and that mapreaders generally agree on their location.[8] It is also clear from her data that there are inconsistencies in characteristic point selection within the work of individuals as well as between individuals. These discrepancies are logical errors (errors of judgment) because the axial points needed to define the geographic character of the line may be poorly chosen or omitted.[9]

Significant errors are found in digital files recorded by both stream and point mode data acquisition. Latitudinal errors dominate stream mode data files because the points are recorded while the cursor is in motion. Operators in this mode tend to "overshoot" or "undercut" corners, and when they observe that their manipulation is in error, they tend to sneak back to the centerline rather than make an abrupt correction. On the other hand, longitudinal errors in stream mode tend to be small and of considerably less importance. Errors in data files created by point mode data capture methods may be equally as significant as those found in stream mode. As a general rule, however, longitudinal errors dominate point mode data capture while latitudinal errors tend to be relatively small and few in number. This is no doubt directly attributable to the data acquisition process itself, for in point mode the data are recorded while the cursor is in a stationary position.

One might assume the existence of a very close relationship between the level of physiological error and the age of the operator but this seems to be less important than the general emotional well-being of the equipment operator. Boredom and fatigue enter into the data acquisition process in a very significant manner. One cartographer expresses his concern as follows:[10]

> Digitizing requires concentration and considerable strain on the eyes of the operator. The human engineering of our system is designed to give the operator as many aids as possible, making his work comfortable and therefore minimizing errors.

A manufacturer of digital equipment concurs: "The primary problem of digitizing is user fatigue."[11] Supervisors of digitizer operators are aware of the boredom-fatigue problem and that human errors tend to increase as the day wears on. In at least one major mapping establishment, personnel are assigned multiple responsibilities so that they can alternate tasks. This apparently relaxes muscles, rests eyes, and generally improves performance. Many other types of emotional stress also contribute to errors in data acquisition. Rhind has reported on one particular type of emotional problem related to the reassignment of experienced cartographers to digitizer operation.[12] Their experience seems to cause them to move the cursor along the same paths that they might have followed while drafting or scribing. Thus, even though directed not to do so, they generalize during data capture. Stresses related to personal problems have also been observed but these are not normally reported in the literature.

Error Reduction Through Training

Although the size and frequency of human error in digital data files can be quite startling, recent research has shown that substantial improvement in accuracy can be attained. This work was carried out by Traylor who used a system of positive feedback in his experiment.[13] A digitizer trainee recorded a data file that was then analyzed by a careful mathematical matching with the master file from which the manu-

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[8] Marino, op. cit., footnote 7.

[9] George F. Jenks, "Thoughts on Line Generalization," AUTO CARTO IV, Proceedings of the International Symposium on Cartography and Computing: Applications in Health and Environment, Vol. I (1979), pp. 209–20.

[10] Klaus Tuerke, "Computer Aided Digitizing of Boundary Networks," *Automation in Cartography, Technical Working Session* (Enschede, Netherlands: International Cartographic Association, April 1975), p. 87.

[11] Frank P. Carau, "Easy-to-Use, High-Resolution Digitizer Increases Operator Efficiency," *Hewlett-Packard Journal* (Hewlett-Packard Co., Dec., 1978), p. 3.

[12] Rhind, op. cit., footnote 3. Rhind describes the problem of changing the attitude of trained cartographers when they first are assigned to the task of digitizing. The following comment is particularly significant: "but persuading operators to 'change gear' in response to this diminished responsibility is often a lengthy process," p. 56.

[13] Charles T. Traylor, "The Evaluation of a Methodology to Measure Manual Digitization Error in Cartographic Data Bases," unpublished doctoral dissertation, University of Kansas, 1979, pp. 60–63.

script line used in the experiment was plotted. The magnitude and location of errors in relation to the linear configuration and direction of movement of the cursor were recorded. The instructor and the student then studied the error measurements and speculated how they might be reduced. Upon completion of several trials followed by feedback, the operator had reduced his errors by approximately fifty percent.

Some cartographers have assumed that errors made in digitizing linear features are random events related to an erring eye and a shaky hand, but Traylor's findings indicate that much of the error in digital files is highly correlated with the direction of the movement of the cursor. Furthermore, his analysis shows that individuals have a personal and repetitive error signature. Equally interesting is the finding that the error signatures of different individuals are so similar that he was able to create a universal error signature. Based upon these findings one is led to speculate on the benefits of his digitizer training methods and the acquisition of an error signature. Might it not be possible and advantageous to develop software that would use a personal error signature to correct a sampled data set? Thus if an operator was known to cut corners or overshoot curves one might be able to use such a program to shove the erroneous coordinates in his file back into more accurate positions.

Error Reduction Through Editing

The last step in the data acquisition phase of linear computer mapping involves the use of one or more editing procedures because cartographers recognize that newly acquired digital files may contain psychological, physiological, and logical errors. Furthermore, one can logically assume that these errors ought to be eliminated before other processing takes place since one does not want to retain erroneous coordinate pairs in a reduced data file.[11] Additionally, data files that have been cleaned of errors tend to be significantly smaller than raw data files and thus cheaper to manipulate and store.

Linear data files can be "cleaned up" by either visual or software edits. The visual edit is designed to locate line-following errors and is initiated by plotting the newly captured data file on translucent material. This plot is laid over the manuscript line so that errors that need to be corrected can be marked. Small errors can be corrected interactively on a CRT display but larger error segments are usually redigitized and the new coordinates spliced into the file. The line labeled 600 (Fig. 4) is a visually edited version of the raw file that was recorded by digitizing the manuscript line in stream mode (Fig. 1). As one studies this line (600) it becomes quite apparent that many small errors still remain. These errors were not removed during the visual edit either because they were unseen at the manuscript scale or the effort was considered to be too expensive in terms of operator time. The line labeled 526 shows the results of a software edit that removed knots, glitches, switchbacks, and any duplicate coordinates that may have remained in the visually edited file. This form of edit is quick and relatively inexpensive. The cleaned file now contains twelve percent fewer coordinates than the visually edited file.

At the conclusion of the edit a linear digital file is considered to be complete and ready to be stored for future use. Some might think that such a file is "error-free," but this is a relative notion based on the percepts and judgments of the individual. Error-free digital files rarely if ever exist, thus the concept of accuracy must be based on an understanding of the quality of the equipment and personnel and the costs involved in further editing. Rather, one ought to consider an edited file as being "acceptable" for the uses to which it is to be put, fully recognizing that additional edit inputs will increase the level of accuracy at an ever decreasing cost-benefit ratio.

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[11] R. B. Southard and Jean Baradat, two practicing cartographers, concur with these concepts. Jean Baradat of France notes, "at any step in the operation, the operator can request information about a particular track including alphanumeric codes, line width, number of points, direction of data flow, etc., and can by using preprogrammed buttons, add, delete, or modify alphanumeric or coordinate data." Southard of the U.S. Geological Survey says, "The digitization may be checked:—either during the digitization phases by software checking of coherence, based upon profiles redundancy,—or after digitization, by comparison procedures, for the position and allocation of each plot, between map and final file." These statements were taken from unpublished papers presented at the meeting of the International Cartographic Association, July 26–August 2, 1978, College Park, Maryland: Jean Baradat, "Nacor System for Automatic Map Digitization Developed by LMT," and R. B. Southard, "Digital Cartographic Development in the National Mapping Program of the United States."

Human Error in Linear Generalization by Computer

Cartographic generalization takes many different forms but for the purposes of this presentation the discussion will be limited to generalization by point elimination and smoothing. Simplification as defined by Robinson, Sale, and Morrison includes:[15]

> the detailed examination of characteristics of the data being mapped and the determination of the data to be retained. The elimination of data is the most often used form of simplification.

When carried out manually, simplification is a holistic process during which the cartographer simultaneously examines the naturally occurring line from a number of different contexts. The line is, simultaneously, a geomorphological entity, a perceptual entity, and because a transform is taking place, an anticipated representation. During one integrated activity, points or features to be retained are selected, unwanted details are eliminated, and the new version of the line is drafted. Conversely, the computer cartographer must deal with the linear simplification process as a logical seriatim. He may view the line from the same contexts as the traditional cartographer but he must also place it within the limitations imposed by the computer, the plotter, and the sampled data on file. For him the line exists, not as a continuum, but as an ordered set of discrete coordinate pairs that must be processed by one or more sequential algorithms. Thus, unlike the traditional cartographer, the computer cartographer visualizes the simplification process in reverse order in that the data transform takes place within the machine. It is only after plotting that he can perceive the new version of the line and judge whether it satisfies the geomorphological and perceptual characteristics he wished to achieve at the onset. In either case, manual or computer, the quality of a simplified representation depends on an understanding of, and adherence to, good cartographic principles. Departures from these principles, whether intentional or unintentional, are logical errors. Two methods of simplification, point elimination and smoothing, and possible associated errors are discussed below.

[15] Arthur Robinson, Randall Sale, and Joel Morrison, *Elements of Cartography*, 4th ed. (New York: John Wiley & Sons, 1978), p. 151.

A Model of Linear Simplification by Point Elimination

Mathematicians tell us that any line is composed of an infinite set of points. Fortunately this is not the case with digital files, which are used to create lines by computer-driven plotters. A line can be plotted using a minimal data file consisting of two coordinate pairs. The maximal file, on the other hand, contains the densest data set that can be recorded considering the resolution of the digitizer and the parametric limits set by the operator. In the case at hand, the maximal file contained 600 coordinate pairs that were reduced to 526 by editing. Thus, all linear representations of the experimental line must be created from files that lie within the finite limits of 2 and 526.

Recognition of the finite limits of digital files provides a useful basis for the creation of a model of linear simplification by point elimination.[16] The model is based on cartographic objectives and limitations within which the computer cartographer works as he reduces and edits digital files to working dimensions. Three perceptual thresholds, which divide all plotter drawn representations of simplified lines, are hypothesized (Fig. 5). To the right of the first threshold are representations that are perceptually indistinguishable from the original line plotted using the maximal file. On the lefthand side of the second threshold is a group of representations that is so abstract that the lines cannot be recognized as simplifications of the experimental line. In between, the third perceptual threshold creates two groups of representations that are perceived to be simplifications of the experimental line. The streams of small arrows connect the appropriate uses with the minimal files in each category of acceptable representations.

Unfortunately the specific details needed to make the linear simplification model operative are unknown at the present time. The tests of the efficacy of the various point elimination algorithms and the perceptual experiments needed to define the three thresholds have yet to be done. It is possible, however, to illustrate how the model might function by empirical methods.

[16] George F. Jenks, "Perceptual Thresholds in Linear Generalization by Computer," *AAG Program Abstracts, New Orleans, 1978* (Washington, D.C.: Association of American Geographers, 1978), pp. 229–30.

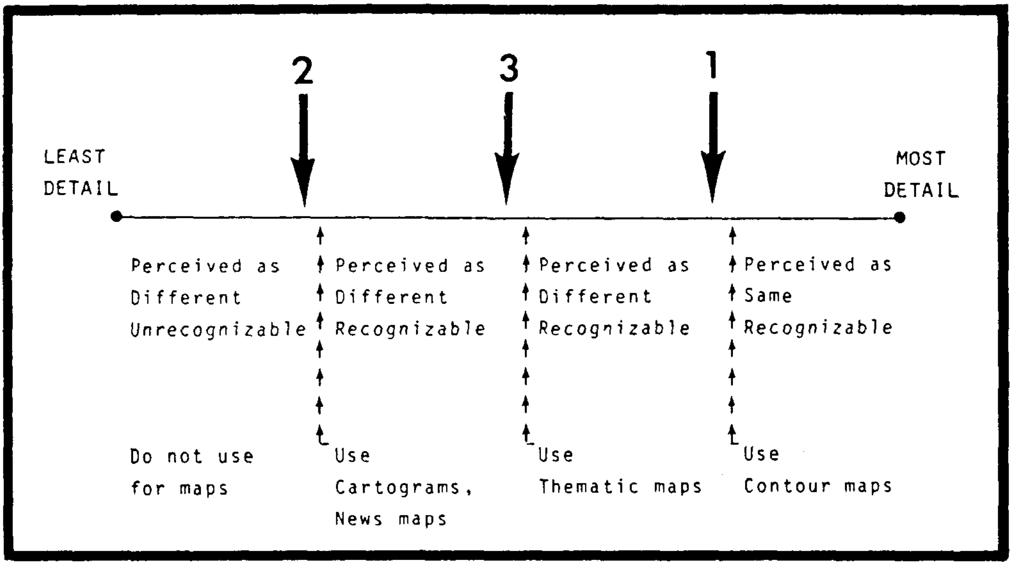

FIG. 5. This perceptual model of linear simplification contains three thresholds that subdivide the simplification continuum into four categories of representations. Each category is described in terms of potential uses. The upward streams of small arrows indicate the points on the continuum where one would find acceptable and the most economical representations.

The first step in this procedure is based on the realization that the plot of an edited digital file contains a high degree of angularity (see 526 in Fig. 4). Point elimination algorithms tend to save coordinates that lie at the apexes of these angles and discard those that lie closer to the "general flow" of the line. Line 526S in Figure 4 illustrates the changes obtained by applying a gentle smoothing algorithm to the one (526) plotted using the edited file. Note that, at manuscript scale, the two plots (526 and 526S) appear to be identical and that changes in the geographic location or the geomorphic character of the lines are so small they are essentially imperceptible. Substantial changes can be perceived at the enlarged scale and it follows that points selected from the smoothed file will of necessity fall closer to the main stream of the line than those taken from the edited plot. Proof of this statement can be found as one studies the lines labeled 388 through 36 which were all plotted using simplifications of file 526S.

The point elimination algorithm employed to create the simplified lines in Figure 5 is based on the examination of a triad of coordinate pairs. A vector is calculated from the first to the third point and the perpendicular distance between the second point and this vector is found. The perpendicular distance is then compared to a parameter set by the operator and if the distance exceeds the parameter the second coordinate is saved and the triad moved forward one step along the line. In the case of line 388, the operator set a very small decision parameter while larger ones were used for the lines that were plotted from files containing fewer coordinates. The lines in Figure 4 would all fall to the right-hand side of the second threshold of the simplification model but their specific location in the perceptual continuum is unknown. Preliminary testing indicates that the first threshold probably lies between the plots labeled 292 and 178 and that the third threshold might well occur between plots 99 and 56. Speculations of this type are not very satisfying, however, since they cannot be validated by hard evidence.

The need for a better understanding of linear simplification by point elimination is well documented.[17] Unhappily, specific guidelines are

[17] The need for data reduction is clear from the following: "Also, many of the interactive commands would run far too long with a data base of 2½ million points. But this may very well be on a simple topographic map sheet (at least in one with Swiss mountains)." Christian Hoinkes, "Usefulness and Limitations of a Small Computer Graphics System in Map

unavailable at this time but it is clear that cartographers may commit logical errors if they select inappropriate simplifications for the map that they are compiling.

Smoothing Operators in Linear Simplification

"Smoothing operator" is a term used to encompass a variety of different computer algorithms that can be used to give plotted lines a smoother or more natural look. Often such operators are some form of running average but they may also be "best fit" mathematical terms applied to a subset of the coordinate pairs in a file. Two orders of magnitude of smoothing operators are particularly useful in the generalization of naturally occurring lines on computer plotted maps. As was discussed earlier, a gentle smoothing can be used to prepare a line for point elimination. In this case, generalization (smoothing) takes place in the imperceptible domain and, as was noted, neither the geographic position nor the geomorphic character of the line has been altered significantly by its use. More stringent operators, intended to simulate manual generalization, can be used to perceptibly alter the look of the line. This type of generalization alters the x, y location of coordinates in some sections of the file causing the plotted representation to take new positions in geographic space.

Production," Swiss Institute of Technology, Zurich, paper presented to the Ninth International Conference on Cartography, 1978, College Park, Maryland, 17 pp. (typescript). For a more in-depth analysis of simplification algorithms see David M. Brophy, "Automated Linear Generalization in Thematic Cartography," unpublished master's thesis, University of Wisconsin, 1972, and David Douglas and Thomas Peuker, "Algorithms for the Reduction of the Number of Points Required to Represent a Digitized Line or Its Caricature," *The Canadian Cartographer*, Vol. 10, No. 2 (Dec., 1973), pp. 112–22.

The reasons for using smoothing algorithms in preparing computer-plotted representations of naturally occurring lines varies from cartographer to cartographer and from map to map. Logically they should be used to enhance a representation and one might appropriately employ them for purely "cosmetic" purposes so that a plot more closely resembles a manually drafted line. Additionally, smoothing operators could be properly used to eliminate high frequency aberrations in a line, to emphasize its geomorphological character, or to prepare it for plotting at a greatly reduced scale. Unwisely, some cartographers have committed logical errors by using smoothing operators in an attempt to eliminate or obscure errors made in data acquisition. The end result of this misapplication often results in a smeared representation that has been drawn in an inaccurate location.

Resumé

In the rush to implement a new computer mapping technology, cartographers and geographers have paid too little attention to their own logical, physiological, and psychological frailties. Different types of human error that affect the quality of linear representations of naturally occurring features have been illustrated and discussed and methods of error reduction have been suggested. Since man is an integral part of the mapping process now and in the foreseeable future, cartographers must be aware of the importance of the man-machine interface. Cognizance of the role of people must also be made in light of the reality that the precision of machinery has exceeded the perceptual capabilities of mapmakers and mapusers. Recognizing this fact, it becomes clear that the manufacture of more precise equipment cannot make human frailties disappear from the cartographic laboratory.