AUTOMATION AND CARTOGRAPHY*

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AUTOMATION, it would seem, is here to stay. Advantages in speed and accuracy seem likely to make the use of computing machinery more common, despite the relatively high initial cost. In view of recent developments in automation and high-speed data processing, it is appropriate to ask, Do possibilities for automation exist in cartography? And if so, where can these possibilities be found? In order to answer these questions, the preparation of maps should be viewed as a complex data-processing system. Certain similarities then become apparent between data processing in general and cartographic processing in particular.

THE MAP AS A DATA-STORAGE ELEMENT

A data-processing system can be said to consist of four major steps: gathering of the data, manipulation, storage, and utilization (Fig. 1). Further, data manipulation can be subdivided into the components of input, memory, arithmetic, output, and control (Fig. 2).

We now redraw the schematic diagrams, Figures 1 and 2, inserting the word "map" where applicable, and we arrive, rather simply (but only conceptually), at three possible systems of automated cartography (Figs. 3–5).

The first analogy, the equating of a map to a data-storage element in a data-processing system, is the most comprehensive, and probably the most accurate. Here the function of the map is similar to that of a book. It contains information in symbolic form,[1] and, in particular, it serves as a graphic storehouse of selected information. It can be compared with the magnetic tape in a computer system with insufficient internal memory: the tape is used for interim storage of data and is called up as required. Obviously, data concerning spatially distributed phenomena need not be stored on a map but can be coded into other symbologies.[2] Whether advantages accrue is another question.

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[1] It has been referred to as an iconic model, as distinguished from an analytical or analogue model, by C. W. Churchman and others: Introduction to Operations Research (New York, 1957), p. 159. A further discussion is given by W. R. Heath and J. C. Sherman: Cartographic Expression in Geography, *Professional Geographer*, Vol. 10 (N.S.), No. 5, 1958, pp. 22–24.

[2] The question of unique (logical) mappings is avoided here. The author's personal feeling is that a symbolic logic (mathematics) is the most useful method of representing such data.

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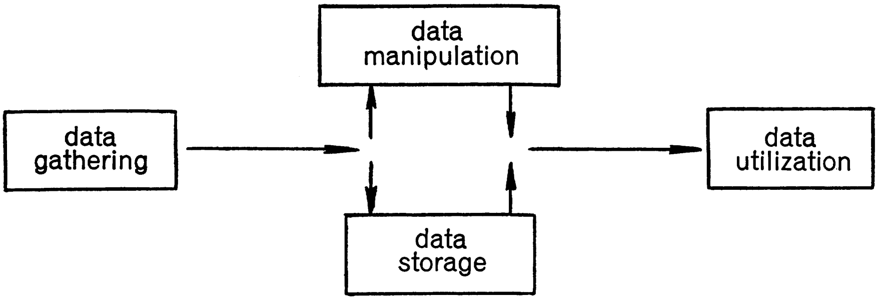

FIG. 1—A generalized data-processing system.

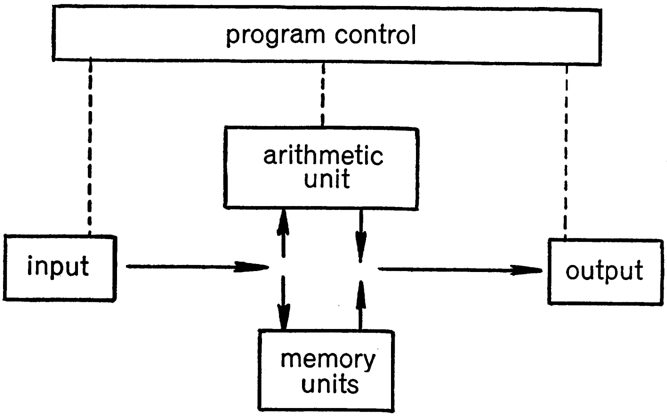

FIG. 2—The data-manipulation phase of a data-processing system.

THE MAP AS A COMPUTER INPUT

The conceptualization of a map as a data-storage medium leads directly to the concept of it as a computer input element (Fig. 4). Here two methods of use seem possible. In the simpler, data are extracted from a map, translated into some symbology that available machinery will accept, and then operated upon by the data-manipulation unit. Examples would include the recording of positional data in terms of some coordinate system, punching this information on Hollerith-type cards, and feeding the cards to a data-manipulation system. A variety of equipment (often referred to as data-reduction equipment) has been built that will do this very thing. It will extract information from such material as graphs or photographs of oscilloscope traces—which to the machine are the same as maps—and automatically prepare punched cards or tapes. Little use of such equipment has been made in cartography, with the possible exception of photogrammetry, perhaps because the data are often available in more readily convertible form—that is, the information from which the maps are prepared.

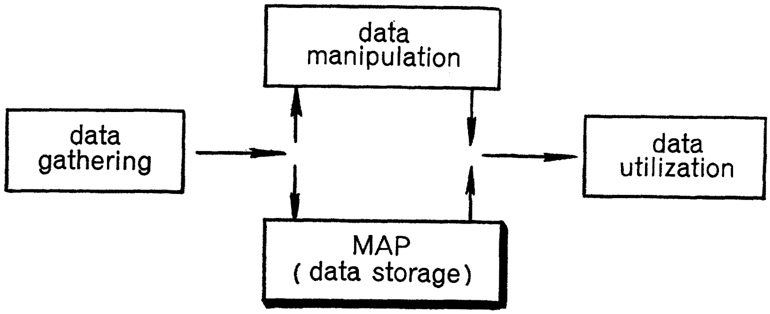

FIG. 3—The map as a storage element in a data-processing system.

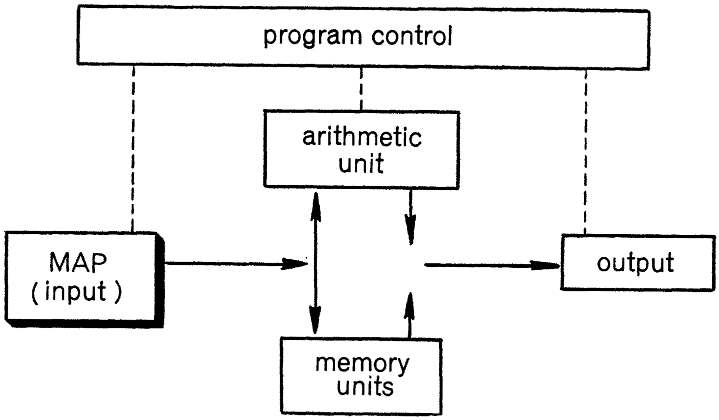

FIG. 4—The map as input to a data-manipulation system.

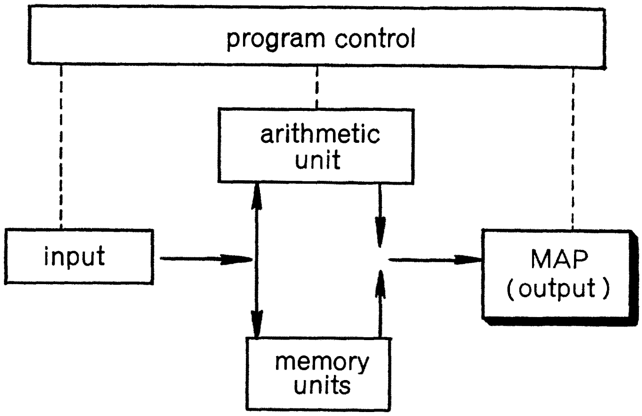

FIG. 5—The map as output from a data-manipulation system.

The second method of using maps as a data-manipulation input consists in transferring the map data directly into a computation system. This is much more complicated technically, and less well developed today. By this method a map might be fed into a "slot," processed, and "discarded," its entire informational content having been stored in the memory element of the machine. An elementary illustration is furnished by the so-called "video mapper."[3] Here the map is a negative image and is redisplayed almost immediately without being manipulated by a computation system. The concepts are nevertheless the same. Facsimile transmission of weather maps is another example. Of course, a similar processing occurs in the transformation of color separations into a multicolored product by photo-offset lithography, but there is a great difference in the amount and kind of data manipulation that can take place. An offset camera can change the scale of a map and, to a limited extent, the projection. It cannot, however, give the distance between two points on the map, nor can it choose the optimum location, route, or area for a given purpose. Certain stored-program computers can do all these logical operations and many more, if the map image is stored in a convenient manner. But herein lies the difficulty. Although many techniques are now in use for the wholesale transformation of maps into optical, electrical, magnetic, or other images, the conceptual problems of machine pattern recognition have not been solved.[4] The inputting of geographic information to the computer in analytic rather than graphic form avoids this problem but in many cases is quite difficult.

The Map as Data-Processing Output

The third possibility of automating cartography derives from the conceptualization of a map as an output of a data-processing system (Fig. 5). This is perhaps of most practical interest. Most of the currently available data-processing output units provide information for viewing or reading, and, as maps are visual displays, it follows that they can be prepared with this equipment. Radar mapping, for example, makes use of a cathode-ray tube, which is much like the tube used in a television set.[5] Similar applications

[3] "Plastic Engraved Aeronautical Video Plates," *ACIC Tech. Rept. No. 72*, Aeronautical Chart and Information Center, St. Louis, 1955.

[4] This problem is related to the automatic machine recognition of written or printed information, which is of considerable practical importance. See "Design of the Perceptron," *Datamation*, July–August, 1958, pp. 25–27. Recently announced map "reading" equipment in map-matching guidance systems constitutes a similar development.

[5] The topic of radar mapping is adequately covered in the literature. See, for example, J. S. Hall, edit.: Radar Aids to Navigation (New York and London, 1947).

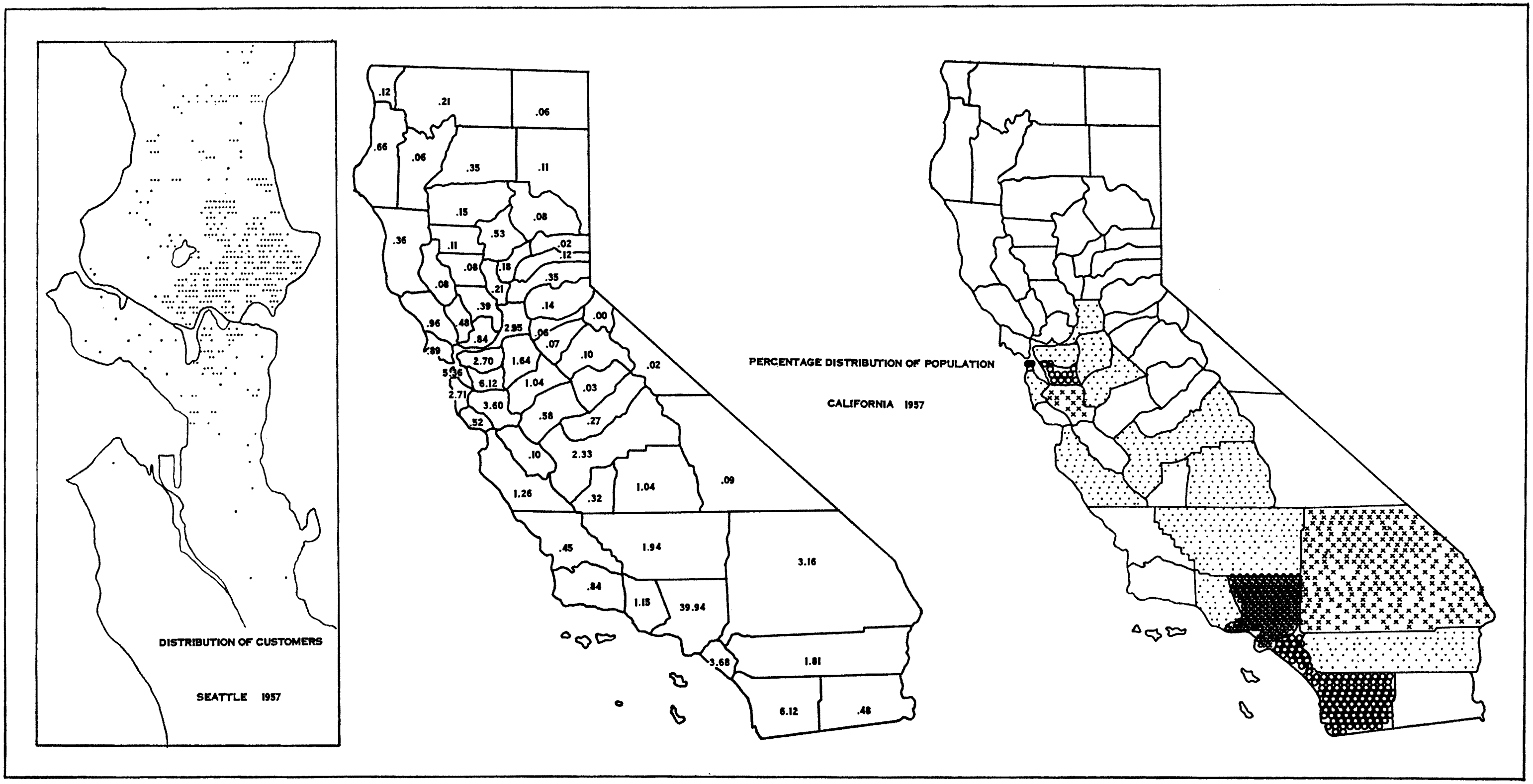

FIG. 6—Dot map, map compilation, and choropleth map with information placed on a base map by mechanical equipment.

have been reported in geodesy,[6] geology,[7] and geography.[8] High-speed permanent recording of the display from such a device on film or offset plates is, of course, possible. Other available mechanical devices plot symbols and/or draw lines automatically.[9] Figure 7 was drawn by just such a machine.

Two types of computer-generated map output may now be distinguished. In the first, the information is recorded on a prepared base map. Figure 6 shows three such maps. The plotting device used to produce these maps was a typewriter, and the input data were in tabular form. Although crude, the maps illustrate the feasibility of preparing maps on a typewriter. The point is not, however, that this is an advisable method of producing maps, but rather that most tabulating equipment currently used to record computer output operates in a manner analogous to the typewriter; in fact, typewriters are occasionally used for the purpose. Such equipment has the advantage of automatic positioning of the printing (that is, plotting) according to the prearranged scheme. Maps prepared in this way might be used as compilation copy, for preliminary analyses of data in a spatial context, or for the recording of census data. When used in conjunction with a computer, for example, the generation and printing directly on a map of such data as index numbers, sales figures, and average rainfall could become almost one operation. It seems probable that maps printed on continuous form paper will become common in the future in this type of application.

Other examples of plotting on a prepared base map can be cited; an interesting one has been recorded in the engineering literature.[10] The impact point of a missile being tested was continuously predicted by a computer, and a trace of this point was automatically drawn on a map. If the trace crossed the boundary of the firing range as shown on the map, the missile was exploded in the air. Another current use is to plot[11] the course of a moving vehicle on a map of the general vicinity, so that its position is known at all times.

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[6] S. M. Simpson, Jr.: Least Squares Polynomial Fitting to Gravitation Data and Density Plotting by Digital Computers, *Geophysics*, Vol. 19, 1954, pp. 250–257; reference on p. 255.

[7] M. B. Dobrin: Introduction to Geophysical Prospecting (New York, 1952), p. 336.

[8] S. Cameron and H. Kantner: A Hybrid Data Processor with Magnetic Tape Input and Direct Pictorial Output (Armour Research Foundation, Chicago, 1958). See also J. D. Carroll, Jr., and others: The Cartographatron, *C.A.T.S. Research News*, Vol. 2, No. 6, Chicago Area Transportation Study, Chicago, Mar. 28, 1958, pp. 3–20.

[9] A large number of such devices are recorded in *Instruments and Automation*, Pittsburgh, May, 1958.

[10] See A. S. Locke, edit.: Guidance (Principles of Guided Missile Design, Vol. 2; New York, 1955), p. 46.

[11] The plotter and associated navigational equipment are handled by the Bendix Aviation Corporation. Similar devices are available from other concerns.

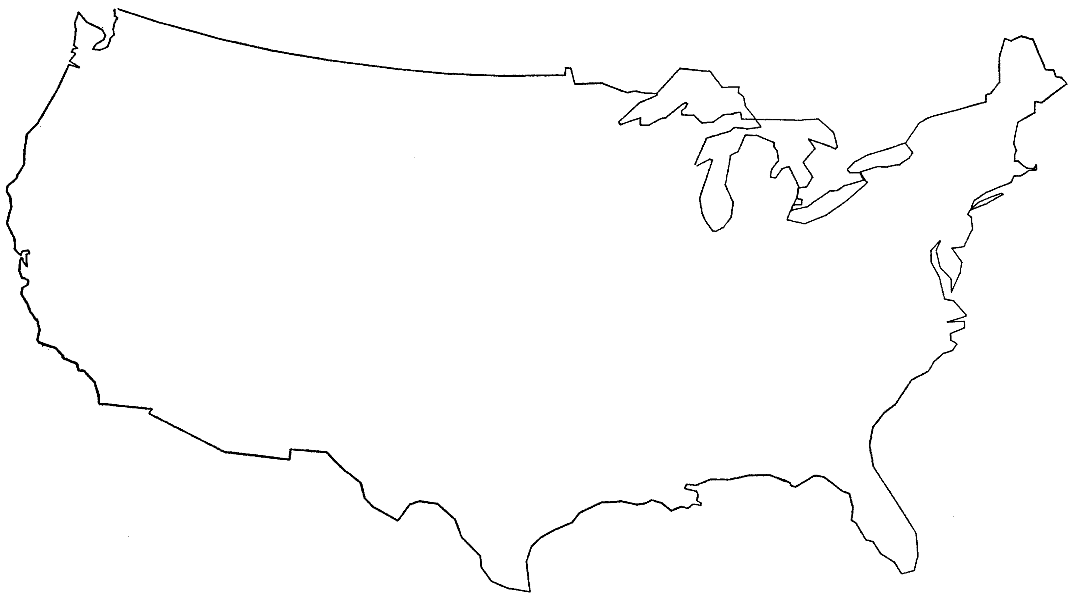

FIG. 7—Map of the United States drawn directly by machine from a deck of 343 punched cards. Plotting time, approximately 15 minutes. The map has been reduced, but not retouched. Bipolar oblique conic conformal projection (outline of original map from the American Geographical Society's Map of the Americas, 1:5,000,000). (Plotter courtesy the Benson-Lehner Corporation, Los Angeles.)

In the second type of computer-generated map output the map is reproduced on a blank recording medium, probably film or paper, instead of on a prepared base. Figure 7 is an example of such a map. Its preparation embodied the three elements discussed in this paper: use of a map as a storehouse of data; translation and inputting of the map data to a machine; and automatic preparation of a map from these data. First, an appropriate map of the United States was chosen, and a transparent overlay with an orthogonal grid was placed over the map. The coast line was then broken into straight-line segments, on the principle that any curve can be approximated by a series of straight lines. The end points of the segments were sequentially recorded in terms of the grid overlay and these coordinates recorded as punched holes in IBM cards, which were subsequently fed to the plotting machine that drew the map. No computer was used, and, although the plotting machine contains controls for changing scale, all the machine did was to draw straight lines between the points. Computer manipulation of the input data in terms of a stored program could have changed the projection and reduced the scale, generalizing the outline if necessary. The outline could also have been made to look "better" if the coast line had been taken from a larger-scale map.[12] Cartographic establishments may someday stock standard decks of punched cards containing basic geographic information for such plotting. A separate deck for each category of geographic information, such as coast lines, state boundaries, cities, contours, railroads, and population, is entirely feasible. Possibly some such method will be utilized to alleviate storage problems where maps are used as legal records (for example, platting). Many other applications should be apparent to the reader.

Other Applications of Data-Processing Procedure

So far, this discussion has been concerned with the conceptualization of a map as a storage medium, a data-processing input, or a processed output. Other parts of the cartographic data-processing procedure might also be automated (Fig. 1). In topographic surveying, for example, partial automation is taking place in precise data gathering (geodimeter, etc.). Feedback control and inertial guidance are evolving toward complete navigation systems—an example of automated data utilization. Many additional kinds of data manipulation are currently feasible with stored-program digital computers. These machines have been popularly referred to as "giant brains." They can compute intersections of planes and surfaces (on a flat map these intersections might be contours), change map scales and projections, and perform other logical operations easily, rapidly, and accurately. Indeed, many much more complex transformations of data can be performed with currently available techniques.

There are, however, a large number of difficulties in any attempt to automate cartographic procedures. For example, the drawing of isolines from sampled data has been shown by Mackay[13] to contain a logical ambiguity in certain cases. Still other problems are involved in the artistic aspect of cartography. The machines cannot at present do as nice a job of relief shading as an airbrush artist. However, new equipment and procedures are being developed so rapidly that this may soon be possible. As another example, the heuristics of generalization, balance, and contrast seem complex and difficult to define. The history of cartography also shows clearly

[12] Analogue to digital techniques or analogue memory devices, both beyond the scope of this paper, would also have produced better results and are certainly more practical for extensive data reductions of this type.

[13] J. R. Mackay: Some Problems and Techniques in Isopleth Mapping, *Econ. Geogr.*, Vol. 27, 1951, pp. 1–9.

that opinion as to what constitutes a "good" map can, and does, change. Further work, such as that done by Williams,[14] concerning the perceptual response to visual stimuli would assist in the design of map-making machinery.

The use of high-speed computing devices will often demand a more extensive mathematical understanding of map projections than has been commonly required in the past. Considerable savings can frequently be effected by converting back and forth among several projections in an internal machine program to solve specific problems (thus taking advantage of the properties of each projection) before arriving at a projection for display purposes. It is well known that projections having desirable visual properties may require involved computations. The use of Mercator's projection to solve navigation problems graphically provides the classic example.

The Possibilities for Automation

Let us now return to our initial questions: Do possibilities for automaion exist in cartography? If so, where can they be found? It has been demonstrated that possibilities for automation do exist, that machinery is currently available to perform many of the more tedious tasks in cartography, and that certain problems have to be solved, a few of which have been indicated. It seems that some basic tasks, common to all cartography, may in the future be largely automated, and that the volume of maps produced in a given time will be increased while the cost is reduced. The machinery is expensive, but it is becoming more common and less expensive. Many of the cartographic uses of computing machines take only a few minutes of machine time, and in these cases the practice of renting time on a machine will probably continue. In other cases, available machinery purchased for other purposes can be used to advantage in preparing maps. Tabulating equipment in particular is common in this country. Other types of plotting equipment will possibly find their greatest use in large cartographic establishments, initially in compilation and map plotting. Other applications appear likely in meteorologic, geologic, geographic, or other research in which maps are used extensively.

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[14] R. L. Williams: Statistical Symbols for Maps: Their Design and Relative Values (Office of Naval Research Project NR 088-006 Nonr 609 (03); Yale University, New Haven, 1956). See also A. H. Robinson: The Look of Maps (Madison, 1952).