TOWARDS AN ELECTRONIC ATLAS

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INTRODUCTION

In 1981 the Geographical Services Directorate purchased hardware for an experimental Graphic Work Station (GWS). The main reason for this purchase was to develop an experimental system for thematic map processing. The system will be used for testing and evaluating the concepts and methods that, in the future, could be incorporated in a full-scale electronic atlas system. Such a system could support the Geographical Services Directorate in the design of conventional thematic maps, and could provide the capability for an extended form of cartographic presentation.

HARDWARE

The Graphic Work Station has the typical configuration of an interactive system for computer graphics. Its main processor is a micro-computer, the LSI 11/23 with 256Kb memory additionally supported by a large quantity of high-speed disc storage; a removable standard CDC disc with a 60Mb memory is used. The essential part of a graphic system is an interactive, intelligent, colour display. A device selected as sufficient for an experimental application is the raster graphic system, Lexidata System 3400, with a medium resolution display comparable to the standard North American television monitor. The System 3400 has a separate, programmable, high-speed memory controller and a microprocessor. It has 11 picture memories which can display selectively a map with 16 separate overlays. The Lexidata System chosen has a joystick for controlling interactive functions and a tablet for the input of summarized commands. The use of the graphic system reduces software development needs, since some operations, such as overlaying or colour manipulation, can be performed directly in the graphic system memory.

SOFTWARE

The contract to implement the Graphic Work Station was awarded to the Canada Systems Group (CSG), Advanced Technology Systems Division. In addition to writing the user requirements, the EMR development team worked in close cooperation with CSG personnel during the design, development, and implementation stages. Such cooperation was necessary for the development of the experimental system, so that the user specifications could be modified to take advantage of the specific characteristics of the hardware and the methods used could be ensured to be consistent with the methodology of geography and cartography. The Graphic Work Station software is written in Pascal, except for a few short programs that are written in Assembler in order to optimize the processing of some operations.

DATA BASE DESIGN AND STRUCTURING OF DATA FOR PROCESSING

The Graphic Work Station data files can be subdivided into the following major file types: **a** map feature coordinate files, in vector mode, **b** thematic attribute files, associated with each feature, **c** cartographic specification files, and **d** temporary or permanent output files, in raster mode, which are used for the manipulation and the display of electronic maps on the graphic monitor. Figure 1 shows in more detail the relationships between the major GWS data files.

The names of files that have been chosen for a given map are specified in a general file called MAP CONFIGURATION. This file contains, firstly, the names of the features to be used for a given map (it calls COORDINATE files), secondly, the

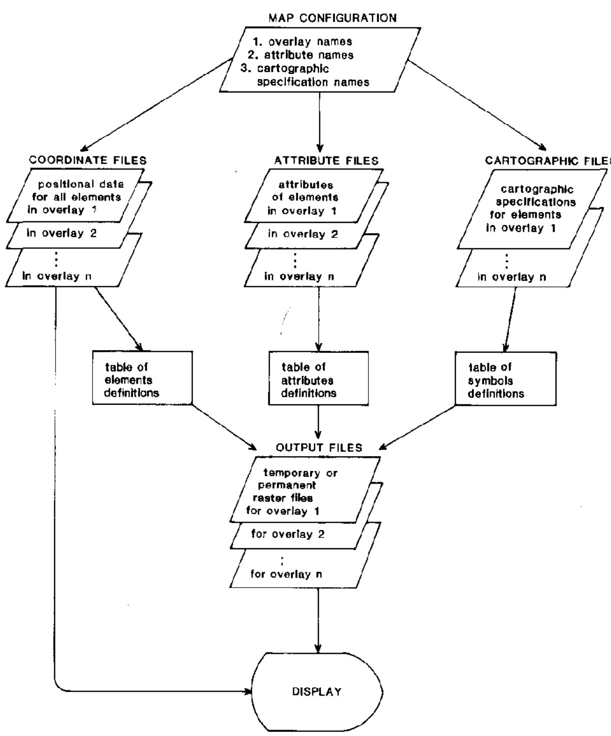

FIGURE 1. *Configuration of data files in graphic work station.*

attributes of those features to be displayed (it calls ATTRIBUTE files) and, finally, it specifies how all of these will be represented (it calls CARTOGRAPHIC representation files). Each of these files is associated with definition tables, which store respectively: **a** permissible element names; **b** permissible types of attributes; and **c** permissible cartographic specifications. If the chosen MAP CONFIGURATION parameters are in agreement with the definition tables, then the vector coordinates, together with the chosen attributes and according to the selected cartographic specifications, are converted into a raster-mode, pixel array file, which is stored in a buffer (OUTPUT FILES) for further processing and displaying. Most of the operations in GWS are performed in raster format. The exceptions are line editing functions, which are performed directly on the vector files.

The logical division of the input data is consistent with the traditional division of maps into separate components for reproduction (cf. overlays in Figure 2). In the Graphic Work Station, the homogeneous features of a given map component form one file and can be manipulated as one map overlay. For example, all small, populated places, represented with point symbols are stored in one file and can be displayed separately. Examples of combinations of overlays are given in the section on visual structuring of electronic maps. This organization of data proved to be very convenient for dynamic manipulation.

The information stored on the maps represents a vast amount of data. Therefore, to improve the efficiency of processing, both the vector and the raster data files have been subdivided into small map-subsections called 'mapels'. In the Lexidata System, the mapel size of 1024 × 1024 digitization units (one unit = 0.02 mm) was optimal for processing. Hence one mapel corresponds approximately to 2 × 2 cm on the input material, and 32 × 32 pixels on the display screen. Such a division of data files is simple and convenient for computers, and is the most natural for spatially referenced data (Kestner J. Oraas S. 1976).

INPUT DATA

The thematic material being used to build a preliminary Graphic Work Station data base comes from the 5th edition of *The National Atlas of Canada* (previous editions of The National Atlas were published in 1906, 1915, 1957, and 1974). The fifth edition breaks with the traditional practice of producing bound volumes of maps and will be issued instead as separate map sheets with individual covers (Groot 1979). The information contained in these maps will eventually be available in digital form. The subjects chosen for the experimental project are energy, agriculture, and population. The energy topics are oil fields, oil pipelines, and oil refineries; the population data are Indian and Inuit communities. The last group, namely agricultural lands and soil capability for agriculture, was not fully implemented at the time of writing this paper (June 1983). The subjects included in the data base are just a small selection of the topics dealt with in the National Atlas program (Falconer 1983). Aside from the attractiveness of these topics to the Department of Energy, Mines and Resources, the chosen material represents the major types of symbols used for the presentation of thematic data. For example, oil refineries are point symbols applied to data of ordinal type. The oil pipelines represent quantitative flow line symbols at the interval-ratio level of measurement; the oil fields are examples of isolated areas and soil capability is of an interconnected-polygon type.

The thematic information is superimposed on the base map material. The Geographical Services Directorate is responsible for providing and maintaining up-to-date base maps for both its own use and use by other agencies. The base-map use is two-fold: it serves, firstly, as a general reference map, and secondly, as a reference framework for the thematic information. The base map components included in the GWS data base are: the graticule, rivers and lakes, provincial boundaries, roads, and selected populated places.

In the electronic atlas, a base map could serve the same purpose as in conventional cartography, but in a much more flexible fashion, since the user may select only those map components that are required for a given presentation. Moreover, this choice may be performed interactively, since visual evaluation is a very important factor in the design of a well balanced, visually pleasing, product.

CARTOGRAPHIC FUNCTIONS

Visual Structuring of Electronic Maps

Effective cartographic communication involves various methods for the visual structuring of map information (McCleary 1983). The Graphic Work Station provides a variety of functions for the designing and visual structuring of maps. One set of functions has been implemented for those who will use the system only for the manipulation of overlays already existing in GWS output files. These functions include the selection and display of individual map elements (or multiple combinations of such) or an enlargment of selected areas in a map inset. Another set of functions is implemented for users who would like to design their own maps. Those functions permit users to choose any set (or to create a subset) of input files and to display them according to their own specifications.

One important advantage of the raster display system for an electronic map is the existence of high-speed memory planes. Thus, besides displaying conventionally 'complete' maps, it is also possible to use the information associated with each memory plane selectively. In the GWS, the smallest accessible display unit is a map cell. A map cell may consist of one or more map overlays, and can be presented using a particular set of colours. The present version of the GWS permits at most six overlays to be combined into one display cell, and one output map may consist of at most eight cells. The order in which the map overlays are listed in a given cell, and also the order of the cells themselves, define their visual priority on the monitor. Figures 2 and 3 illustrate two possible ways of organizing map overlays. Figure 2 is an example of a flexible organization scheme where most overlays are individually accessible (the only exception is an overlay with hydrographic data, where lakes and rivers are handled concurrently). Figure 3 is an example of the scheme typically used for thematic maps. In this case, overlays with the base map components are grouped into two map cells, and will be displayed with only three colours. The majority of colours are reserved for the manipulation of the thematic attributes, whereas the base map will be used only as a reference.

Besides the manipulation of the individual memory planes, other features that

MAP STRUCTURE

MAP NAME: basemap

CELL #	# OF COLOURS	OVERLAY FILES
1	1	gradicule
2	1	lakes, rivers
3	1	roads
4	1	boundary
5	2	city.s
6	2	city.l
7		
8		

FIGURE 2. *Organization of overlays for base map manipulation.*

MAP STRUCTURE

MAP NAME: oilproduction

CELL #	# OF COLOURS	OVERLAY FILES
1	1	gradicule, lakes, rivers, city.s
2	2	roads, boundary, city.l
3	16	oil
.		
.		
.		
8		

FIGURE 3. *Organization of overlays for thematic map manipulation.*

are unique for electronic maps are the real time scroll and the instant enlargement functions. The scroll function helps to overcome the limitations of a relatively small sized display. It permits browsing over the areas adjacent to those actually displayed on the screen. The instant enlargement function is very advantageous for displaying maps. With the ever-increasing speed of computing, it may eventually be used for the creation of a scale-independent digital map. The GWS permits two-fold and three-fold scale enlargements with strict control over the magnification rules for cartographic elements. Thus only the symbols with real spatial dimensions, such as lakes or large cities, can be expanded during magnification, whereas the other elements, such as symbols for roads or graticules, remain unchanged. Towards this end, it should be emphasized that, for the proper presentation of a map, the use of a 'mechanical zoom', which is unrelated to map scale, is not permitted in cartography, because in cartographic communication the presentation must closely relate to the accuracy of input data (see section on electronic map generalization).

Selection and Manipulation of Colours

Colour is one of the most important graphic variables in cartography. It increases map legibility significantly. The advantages of using an electronic display for thematic cartography began to be fully appreciated after the popularization of colour monitors. The black and white graphic displays have been used mainly for engineering plans and large scale maps.

The Lexidata System 3400 permits a large variety of colours. Each colour is created by specifying a combination of the additive colour components red, green, and blue (RGB) by giving percentages of each colour component to control their relative intensities. The colour value, as defined in cartography (Robinson, Sale and Morrison 1978), is altered by adding or subtracting all three primary colours in equal proportions. The third dimension of colour, called in cartography intensity, is derived by manipulation of hue and value simultaneously. The System 3400 permits creation of 16.7 million colours. However, using a large number of colours on one map is not recommended, because the human visual system reacts efficiently to only a limited number of colours. In the GWS the number of colours needed for a given overlay is specified in the MAP STRUCTURE record, which is a part of CONFIGURATION FILE. The total number of colours possible for a given map is

$$\Sigma_{i=i}^{8} n_i, \text{ where } \Sigma_{i=i}^{8} n_i \leq 127 \text{ and } \Sigma_{i=i}^{8} [\log_2 n_i] \leq 8$$

where n_i is the number of colours in the i-th overlay and where [ ] is the 'integer ceiling' function.

The GWS provides three techniques for generating colours. One permits the individual specification of colours associated with a given map element, a set of elements, or their attributes. Another function permits the 'automatic' creation of colour scale; and the last one permits an interactive manipulation of colour scales. To create an automatic colour scale the user sets parameters for the first and last colours in the scale, and the remaining colours are derived automatically in equal steps of colour value. The third method, which is implemented in the GWS, permits the interactive dynamic creation of a colour scale. In this function, each class is assigned a particular colour and the whole scale is interactively manipulated to obtain the desired size of class intervals (see section on interactive manipulation of class intervals) and the optimal combination of colours.

In order to relate to the conventional cartographic selection of colours, the graphic system should include the appropriate colour dictionaries. After testing the characteristics of a particular colour monitor, it is possible to calculate numerical colour transformations to standard colour systems such as the CIE or the Munsell scale. For the use of single colours, it is recommended that, using various perception tests, a set of 'focal colours' be established, i.e., the best set of basic hues for a given monitor (Cowan 1983). The creation of the colour scales is best performed interactively by controlling all three colour dimensions simultaneously. From the colour scales created automatically on the GWS, the best results were obtained either using a grey-level scale or a combination of single hues with white or black (black with blue, white with green, and white with red).

A linear progression of RGB components gives a better impression of equal steps than does a linear progression of colours obtained using printing screens, since the voltages controlling the colour brightness have similar characteristics to light perception curves.

As an additional variable, not available in the conventional map presentation, the graphic displays permit the use of a 'blink' function, which is very advantageous for highlighting small areas. In the GWS this function is used extensively to identify overlapping regions when comparing features from separate overlays. Another similar function, which in future may be used for a rapid identification of symbols on an electronic map, is the use of motion. This function seems to be particularly relevant in enhancing the cartographic displacement technique used when locating symbols in 'overcrowded' areas. A good example is the displacement of oil refineries in the city of Edmonton. Due to the size of the symbols used for refineries, they have been displaced around the city symbol. The use of motion, which will indicate the true location of the refineries, could significantly enhance the cartographic communication by electronic maps.

Some Aspects of Cartographic Generalization

Generalization belongs to one of the most frequently misused cartographic operations in the field of computer graphics or even in computer-assisted cartography. Very often this complex multi-dimensional process of map simplification (Robinson, Sale and Morrison 1978) is reduced to the automation of one particular aspect, for example line smoothing. Generalization was one of the first problems addressed in computer-assisted cartography (Morse 1967) and still remains practically unsolved. At present, EMR conducts experiments to devise generalization methods which will permit the automated derivation of topographical features from the 1 : 20,000 scale to update the 1 : 50,000 scale maps (Fraser 1981).

One aspect of generalization chosen for the first experiments in the GWS relates to the theory of visual perception thresholds (Ratajski 1978). This aspect seems particularly relevant to the graphic display systems, since most of them have an inbuilt 'mechanical zoom' capability that permits the user to enlarge or reduce instantaneously the map image. This may result in serious distortions of the map's presentation since a 'scale independent digital map' can not be displayed satisfactorily without generalization. Thus, one of the most important issues in electronic mapping is to design the methodology for enlarging or reducing display maps. Two approaches are possible: the first is to use one data set and derive various maps using generalization procedures; the second is to create several data subsets, each associated with a band of scales each derived from a given data subset.

In the GWS the first approach was attempted, i.e., the automatic derivation of various scales from one data set. As mentioned in the section on input data, the GWS data base was obtained from maps in the 1:2M scales; however, for one overlay (Indian and Inuit Reserves), this scale was found too small to show the outlines of areas of all reserves. Therefore, maps at the scale 1:500,000 were also digitized, reduced to 1:2M, and merged with other files. Because of the disparities in the size of the reserve areas, they are represented with two different symbols. For the larger areas, the true extent of the area symbol is used, but for the smaller areas that are below 'visibility threshold' (in GWS a threshold of 7 pixels was selected) a point symbol was more appropriate. The conversion of an areal symbol into a point symbol is a scale-dependent operation; thus, after magnification to the scale of 1 : 1M, fewer reserves are represented with point symbols than at the scale 1 : 2M.

A possible extension of this function could be the creation of more complex rules for the conversion of symbols. Such rules could involve not only the areal but also the thematic dimension of data; for example, one could convert only those areas having large populations, whereas the others could be left out. Such modifications are technically straightforward and are considered for implementation in the near future.

GEOGRAPHIC FUNCTIONS

Data Base Query

The cartographic functions discussed in the previous section refer to methods relevant mainly to visual presentation. If graphic presentation is not required or else the user wishes to obtain more information about map elements than actually presented on the map, the electronic maps permit a large spectrum of 'geographical functions', some of which are not possible in conventional cartographic communication. In this category are functions that permit the user direct access to the data base.

In the GWS several types of data base queries are possible. If a user is interested in knowing all the attributes associated with a given map element, he may ask for the complete listing using either the computer terminal key-board or directly pointing to an element on the display using the graphic cursor. Another type of query permits the user to obtain a list of elements with specified criteria. For example, one may select only those oil fields which produce 10 or 20 million cubic metres per year. Data base queries are unique to information systems, and enlarge map communication capabilities. Besides the generalized visual information, users have access to the data files, which are unaffected by transformations needed for graphical presentation.

Simulation Models

Another geographical function unique to the data base is the possibility of derivation of new information that did not exist in the input data but that has been calculated. This capability is particularly useful in data bases used for resource management and planning applications, since it permits the creation of a variety of simulation models.

Calculations in the GWS are limited to the basic arithmetic operations. These functions were used to calculate how long oil reserves will last based on the current production figures. The present version of software permits calculations using two variables at a time. However, the potentiality of the GWS to include more complex simulation models is virtually unlimited. One possible extension being considered is to use animation in the dynamic simulation.

Interactive Selection of Class Intervals

The last GWS function to be discussed in this paper is the selection of class intervals. This operation relates to both the geographic and the cartographic aspects of data bases. It can be used either for numerical or visual evaluation of quantitative characteristics of data. A large variety of methods exists for the selection of class intervals (Evans 1977). Most of these are available to computers in elementary statistical packages; for example, in SPSS (Statistical Package for Social Sciences). The choice of the most appropriate method depends strongly on the characteristics of the data to be mapped or analyzed.

The GWS supports several methods for selection of class intervals. It is possible to obtain class intervals of equal steps, or intervals based on mean and standard deviation values, or any user-specified classes. Additionally, the GWS provides a very flexible interactive function that can be used for the selection of class intervals or for the quantitative analysis of data. It is based on the real-time manipulation of the frequency distribution histogram, which is displayed in a map inset area along with three cursors. The histogram can be calculated from the full range of data values or from any subset that the user intends to analyze. The interactive manipulation is performed by changing the positions of those cursors that indicate the current position of class boundaries. Each modification of position is indicated by a change of colour of all elements whose values correspond to the histogram subdivision of data values. Additionally, the numerical values of the current positions of these class-boundary cursors are displayed in the map legend. The interactive manipulation of the histogram functions provides the means for a very flexible analysis of data. Besides the capability of displaying frequency histograms, it provides the means for visual analysis of spatial distributions, which is a very important factor in the proper selection of class intervals.

SUMMARY AND CONCLUSIONS

The functions discussed in the paper are just a selection of the capabilities of the GWS and give only an indication of the full potential of graphic systems for the design and manipulation of an electronic atlas. But these functions illustrate well the flexibility that the user can expect in the visual presentation and manipulation of map information in digital cartographic data bases. One important difference, when compared with a conventional cartographic presentation, is the capability of obtaining user-demanded or even user-created visual presentations, which will satisfy more user-specific demands. An electronic atlas will readily permit unlimited combinations of topics included in its data base and also an almost unlimited variety of ways to display them. However, the latter should be governed by rules for the most efficient cartographic communication. Aside from so flexible a visual presentation, the electronic atlas permits direct access to its data base. Further, it facilitates a variety of video-numerical analyses for evaluation of the spatial, thematic, and temporal dimensions of data. In an electronic atlas, such analyses could be performed directly on input data and not on output media, unlike the case for most of the measurements performed in cartography. This will ensure a higher accuracy of results. The calculations could include simulation models for mapping future distributions, an uncommon practice in conventional cartography.

The flexibility of display and the analysis of the electronic map are not possible without an application-oriented organization of the data base. The conceptual division of the GWS data base into three types of files (positional data, geographic attributes, and cartographic specifications) proved to be very appropriate for the creation of the well-balanced cartographic system. Existing map-processing systems have been devoted mainly towards processing positional data (e.g., automated drafting systems) or towards processing the geographical attributes (e.g., spatial analysis systems). The cartographic aspect was usually reduced to the use of display methods standard in the computer graphics field. Thus more effort is needed towards developing a cartographic system suitable for the creation and utilization of electronic maps. An important aspect of such a system would be the structuring of data according to the presentation mode, one example being the GWS organization scheme. Further, a cartographic system will require standardized sets of symbology needed for efficient visual communication and for a methodologically correct presentation, i.e., the use of symbols and display methods consistent with the nature of the data and with the type and the scale of the map. Another important aspect to be included in the cartographic system are rules for automatic scale change, i.e., rules for the presentation of data consistent with the map scale and for the derivation of other scales. The unique nature of the digital map is that its generalization process is reversible; for example, it is possible to regain the details apparently eliminated in a visual presentation during scale reduction.

It is the hope of the author that this paper might be a contribution toward a better understanding of the nature of an electronic atlas, an indication of the potential of graphic systems for thematic cartography, and the expression of needs for a new methodology in assuring effective cartographic communication through an electronic map.

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