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DIGITAL MAPS AND DATA BASES: AESTHETICS VERSUS ACCURACY *

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I. Introduction

Of the many courses lectured by Immanuel Kant at the University of Königsberg, legend has it that one of the most frequently offered was a course on natural philosophy (that is, physical geography). It was argued that individuals could acquire understanding through three distinct perspectives: the perspective of formal logic and mathematics, the perspective of time (history), and the perspective of space (geography). The last of these — the perspective of space — acknowledges the importance of distance, site characteristics, and relative location in describing the relationships among several objects or facilities.

Maps are the primary means of representing such relationships. Maps are analytical tools which depict spatial relationships and portray objects from the perspective of space. The power of maps rests on their synoptic representation of complex phenomena. To paraphrase the Confucian wisdom, a map is worth a thousand words.

> "Recently it has become common to convert spatial phenomena to digital form and store the data on tapes or discs. These data can then be manipulated by a computer to supply answers to questions that formerly required a drawn map ... This stored geographic information is referred to as a [data base]." [1]

The maps produced from such data bases are termed digital maps. Computerized data bases, which may be queried and used by several people simultaneously, and digital maps are of immense value to engineers, comptrollers, planners, and managers. The combination of a digital map and data base is worth a thousand "mega-words."

The advantages of digital maps over manually drafted maps are most apparent in situations of frequent growth or change. Among these advantages are the ease and speed of revision and the fact that special purpose maps can be produced in small volume at reasonable cost. Moreover, digital maps offer greater precision in representation and analysis. "As more governmental bodies [and other agencies] expend the necessary one-time capital investment, and begin to reap the vast rewards of computer-assisted record and map keeping, others are likely to follow quickly."[2]

II. Basic Issues

After an agency or firm has decided to convert its manual records to digital map and data base form, several issues must be addressed.

The first, and most important question the agency must answer is related to the source documents to be used by the mapping firm. In general terms the choice is between cartographic sources and mechanically drafted sources.

Cartography is defined as:

> "The art, science and technology of making maps, together with their study as scientific documents and works of art. In this context maps may be regarded as including all types of maps, plans, charts, and sections, three-dimensional models and globes representing the Earth or any celestial body at any scale."[3]

In particular, cartography is concerned with the accurate and consistent depiction on a flat surface of activities occurring on a sphere.

It is not possible to duplicate, without distortion, the features on the surface of a sphere on any object other than a sphere. A surface of constant positive curvature may be represented on a surface of zero curvature only if distortion is introduced in the representation. As a simple illustration of this fact, consider the problem of "flattening" an orange peel: it will tear. If the orange was made of rubber, it would be possible to flatten it without tearing, but not without distortion of another kind — a topological transformation.

The methods by which cartographers represent the surface of the earth on a flat piece of paper are known as map projections. For any particular purpose, the selection of a particular projection (transformation) is based on the properties of a sphere that the projection loses or retains. Every method of mapping large areas is affected, whether it is continuous mapping or facet mapping. No coherent, distortion-free transformation exists, nor, given the theorems of mathematics, can it ever exist. [4, 5] However, cartographers can identify projections that suit a client's particular purpose.

Quite often appropriate cartographic source documents already are available to a public utility and mapping firm team. Indeed, such sources may have served as the base for the construction of existing records. In other cases, it may be necessary for the mapping firm to perform an aerial photographic survey and to translate these photographs into cartographic documents — a process known as photogrammetry.

It is also possible to produce maps from non-cartographic sources such as tax assessor sheets. Certainly the most common non-cartographic sources are mechanically drafted cadastral maps and engineering drawings or plans. These documents have been defined by the International Association of Assessing Officers:

> map, cadastral — A map showing the boundaries of subdivisions of land, usually with the bearings and lengths thereof and the areas of individual tracts, for purposes of describing and recording ownership.
>
> map, engineering — A map showing information that is essential for planning an engineering project or development and for estimating its cost. An engineering map is usually a large-scale map of a comparatively small area or of a route. [6]

Although such drawings have some value for small area design, engineering, and planning purposes, there are a number of problems associated with their use as source documents for large area mapping. The most critical of these is related to accuracy; tax assessor sheets in the United States, for example, are designed to be used as indices only and are subordinate to actual legal descriptions. They are highly stylized and, despite their appearance and name, highly inaccurate in terms of geographic placement.

Small plans "look" correct primarily because they correspond to the limited range of vision of human beings at ground level. However, these documents also suffer from the transformation problem. Non-uniform, interpretive, subjective corrections by a draftsman make this problem appear to vanish on individual sheets. But such corrections preclude accurately merging sheets for a large area.

In the language of the philosophy of science, the distinction is one between an iconic model and a symbolic model. An iconic model (the mechanically drafted plan) is designed to look, in some metaphorical fashion, like the object of study. Often, the closer the similarity in appearance, the less valuable the model for analytical purposes. A symbolic model (the map) is designed to facilitate quantitative measurements of characteristics of interest to analysts, managers, and engineers.

A second issue that must be considered by public utilities is the use to which the digital maps will be put. This will determine the type of output the mapping firm will generate. This also will determine the accuracy levels needed. [7] In general terms, the types of output products correspond to the types of input products: maps and plans. [8] In our experience, public utility clients generally have expressed a preference for digital maps related to spatial relationship data bases because they facilitate the more accurate analysis of physical plant attributes and distributions over a large area in a geographic information system.

The primary purpose of most digital map and data base conversion work is to provide a means to manage corporate assets. Often the actual maps produced are used for index only, not for scaled or direct measurement. This is in part a function of the distortion inherent to any mechanical production or reproduction process, in part a function of the demonstrated superiority of a fully digital, displayable linked-attribute data base management system (see Section 5), and in part a function of the distortion inherent to all map projections (the transformation problem previously discussed.)

In some cases, an agency may wish to construct a geographic data base that will support a computerized plan generation and facilities management system. As an example, consider the case where facility data will be superimposed on a merged cadastral and land base. The data base must guarantee the geographic locations of features and their connectivity, relationships, and other characteristics. The final digital plan and data base may include information on street, road, and highway names, centerlines, and rights-of-ways; political, legal, and natural boundaries; township, range, and section lines; river, stream, and creek centerlines and names; and legal lot and parcel lines and numbers, among other data. [9]

III. Map Production

Regardless of the type of source document or output product, several stages in cartographic production remain relatively constant. These are considered first in a general manner and then as they apply to digital map production per se.

First, we must define the purpose and accuracy standards of the map. For example, will the map be used for scaled measurement? Or will the map be used as an index? Second, we must identify the features and activities to be mapped. The nature of these features will influence the amount of detail appropriate for the base map and the finished map. The strength of a map may be diminished by displaying too much detail.

Third, we must prepare or obtain a land base or base map. In this regard, it is important to consider the variety of map projections and coordinate systems available for particular tasks. Using a widely accepted system such as the UTM grid or latitude and longitude coordinates has a number of advantages, including ease of data exchange and reduced production time and cost.

The next step is to collect and compile the data to be mapped. The basic rule is to compile data at the most detailed level of measurement possible and to aggregate the data only at later analytical stages. Finally, we must design and construct the map. This is a two step process that involves: (a) the design of symbols, patterns, legends, and other cartographic devices, and (b) the location and actual placement of the features and activities.

IV. Digital Maps

As in traditional cartography the first step in constructing a digital map is to establish accuracy levels and to determine which attributes should be displayed and which should simply be stored.

A displayable linked-attribute data base system (discussed below) allows for the construction of a fully digital geographic information system for data management, as well as for the construction of index and general route maps. For such maps, placing items of plant "on the right side of the street" generally is adequate: in the real world, a utility pole 60 feet tall is clearly visible at an intersection. The critical attributes of each item of plant appear as numbers or words on the map and also as manipulable information in the data base. On the other hand, if the map is to be used for scaled measurement, accurate placement of items of plant is paramount. It should be noted that this second approach implies considerable supplementary manual adjustment and therefore substantially higher production costs.

The next question is the method of land base construction. Land bases, or base maps, may be constructed in a variety of ways. It may be possible to develop an accurate land base by digitizing existing source documents. The information may be captured by board digitizing vectors (line strings and endpoints) or by raster scanning. If the quality of the source documents is high, these methods are extremely cost effective.

If the quality of the available source documents is unknown or suspect, it is common to conduct an aerial photographic survey and to compile the photographs into a "model" of the region (the air photos are rectified to generate a plane view of the photographed region similar to a map projection). These models are then stereo digitized and used as highly accurate source documents for land base construction using the digitizing or scanning methods noted above. (± 10 feet accuracy is standard, but ± 1 foot accuracy is possible.) Although more expensive than working from existing source documents, such an approach guarantees extreme accuracy. Moreover, the end product often has resale value which will offset the initial cost incurred by the end user.

Data sources also may be combined to form a hybrid land base. For example, individual assessor sheets at a wide variety of scales can be overlaid on a stereo digitized base. The stereo digitized street centerline network can be modified to agree with cadastral maps so the assessor data will scale properly and satisfy aesthetic criteria.

Because such a hybrid is, by definition, unique, it is appropriate to discuss in detail at the outset of the project the problems likely to be encountered in production. Disadvantages of such an approach include the substantial cost to make the map "look" like the source documents, many difficult production problems (e.g., warp of cadastral data and fitting cadastral information to an accurate land base), and the volume of source documents required.

Nevertheless, some utilities wish to use a hybrid approach because it gives them a product that is internally acceptable from an aesthetic viewpoint. We have encountered many situations where end users are uncomfortable with the computer-plotted version of a geographic data base because it does not "look" like the product they have used for many years. The issue of user acceptance is of critical importance to the ultimate success of a conversion project. The cost and problems associated with a hybrid approach may be justified in the long run because the end user is comfortable with the "look" of the product. However, care must be taken to avoid simply computerizing existing problems.

The process of generating a hybrid combines land base construction and data compilation. When a data base management system approach is used, the distinction between these two production processes is much clearer. After a land base is assembled, a decision is made to define some selection of "attributes" of facilities or items of plant as displayable. Displayable attributes are those attributes that actually will be plotted on a map. Other attributes may be stored in the data base, but not, as a matter of course, be displayed on maps. (Information of interest to comptrollers may be of little use to engineers. Conversely, attributes that facilitate engineering procedures may be unimportant to comptrollers.)

Once agreement on the attributes to be displayed is reached, the data are coded and laid out on the source document. Some of the information will be recorded interactively at a board digitizing station. Other information will be keypunched and bulk loaded at the construction phase. After construction, updating normally is performed interactively. One significant advantage of a data base management system approach is its ability to grow or change with technical advances.

> "Maps today are strongly functional in that they are designed, like a bridge or a house, for a purpose. Their primary purpose is to convey information or to 'get across' a geographical concept or relationship ... The mapmaker is essentially a faithful recorder of given facts, and geographical integrity cannot be compromised to any great degree. Nevertheless, the range of creativity through scale, generalization, and graphic manipulation available to the cartographer is comparatively great."[10]

Given its pragmatic character, it may be surprising to learn that the physical appearance of a map is a common point of disagreement. Most frequently such disagreement arises because different sets of aesthetic principles have been applied by the client and the mapping firm.

The general question of aesthetics is not at all simple; as the art historian Ivins has argued, the notion of simple geometric relationships is not invariant in aesthetic assessments. [11] Indeed, aesthetic issues are involved in both the creation and the appreciation or perception of a work of art. Within cartography, the term "aesthetics" is reserved for consideration of the placement of elements such as compass rose, legends, and scales; the balance of these elements vis-a-vis the map object; the selection of type faces from the range of standard or customary fonts; and similar elements of visual display. To equate "correct" with cartographic aesthetics is inappropriate, except in the limited sense that some features are required by cartographic convention (e.g., italic type fonts for bodies of water). Styles as to what is "correct" from a creative standpoint also vary from one academic discipline to another: the geographer prefers a fine-line drawing while the urban planner uses heavy lines to focus attention and the landscape architect employs pictorial symbols. Differences in styles of map creation help to condition the manner in which maps are appreciated by consumers; that is, aesthetics is more than simply giving the consumer what he is used to. For example, many public utilities have developed a sense of aesthetics conditioned by experience with manually drafted, subjective, and highly symbolic plans. Unless discussed at the beginning of a conversion project this point can become most difficult, because a mapping firm must assume that map accuracy takes precedence over map symbology, visual appearance, and the superficial aesthetics of the perception of appearance. Often in cases of this sort, the aesthetics of appreciation of the consumer give way to concerns of accuracy on the part of the mapping firm which in turn may rest on the aesthetics of cartographic creation.

V. Computerized Data Bases

> "Computer systems are increasingly used to aid in the management of information, and as a result, new kinds of data-oriented software and hardware are needed to enhance the ability of the computer to carry out this task. [Data base systems are] computer systems devoted to the management of relatively persistent data. The computer software employed in a data base system is called a data base management system (DBMS)." [12]

Of the several methods of classifying data bases used by software engineers, one most important dichotomy is that between network (hierarchical) and relational data bases. [13] Certainly the most useful approach for many users is the relational data base, because this approach permits a larger variety of queries. Regardless of the approach, the method of manipulating the data base remains a critical issue.

As noted in the quotation of Blasgen [12], the software used with a data base is known generically as a data base management system (DBMS). Such a system generally will have provisions for data structure definition as well as for data base creation, maintenance, query, and verification. Blasgen observed that in 1981 an estimated 50 companies were marketing 54 different DBMS packages. [14]

In our experience, as noted earlier, most public utility clients prefer working with a "displayable linked-attribute" DBMS. This term describes a system in which selected attributes or characteristics of the company's physical plant are stored in the data base, where they may be manipulated by users and also displayed on the digital map. For example, the age, length, size, and identification number for a piece of cable may be stored and displayed. Because the length of cable in a given span is known from installation and stored in the data base, scaled measurement is unnecessary.

A second approach to building and maintaining a data base is termed the "hybrid" approach. Consider the following example.

Analytics technicians select National Geodetic Survey monuments and photo identifiable points which provide a network for accurate control of the area. On-site field survey crews accurately survey these points and target them for aerial photography. After the flight, analytics technicians assemble these points into an accurate control network and place them in a digital file. Using the network file, features defined in contract specifications are stereo digitized from the photography in a digital format. The major features are portrayed in the form of a detailed centerline network of interstate highways, public roads and private roads. The file then is divided into facets (corresponding to individual maps) and plotted at a scale of 1:100'.

Tax assessor sheets and the 1:100' stereo digitized centerline plots are joined at the next production phase. The 1:100' plot is overlaid on individual assessor sheets, intersections are held for control, and the stereo digitized road centerline network is adjusted to match the cadastral maps. The revised centerlines and additional features such as rights-of-ways, lot lines, boundaries, and text are board digitized.

The product is the best of the digital and mechanical worlds. It is accomplished in digital format so future modifications can be made easily, and it is aesthetically pleasing — it looks like an engineering drawing or cadastral map. The information is accurate, the data can be scaled, and bearings can be extracted.

The success of endeavors of this type depends on an excellent vendor and client relationship. For such a project, it is recommended that a test or pilot study in a pre-selected area be completed prior to final contract negotiations. It is the responsibility of the client to define his needs as accurately as possible and convey these requirements in understandable language to the vendor. Vague terminology and ambiguous specifications can compound production problems. The vendor, based on his background and experience, must make meaningful suggestions to the client as early in production as possible as alternative options may be considered.

VI. User Community

In summary, a comprehensive digital map and data system has many advantages. In order to fully realize these advantages, users must consider and resolve several questions related to actual needs and aesthetic conditioning. Users should understand that digital maps and data bases constructed using highly accurate aerial photographic source documents will not, as a rule, look like familiar graphic products. They must consider the distinctions between mechanically drafted products and cartographic products and decide at the outset of the project whether they are comfortable with the graphic specifications.

Close communication between the utility company and the mapping firm is critical. The more carefully specified the project is at the beginning, the fewer the changes that will be required. Changes in specifications made during production, no matter how trivial they appear, generally affect production schedules and costs adversely.

Thus, the creation of a digital map involves not only the mastery of current technology, in order to produce an "accurate" map, but it also involves an awareness of aesthetics, as well. Attention to aesthetics, as appreciation of the map by the consumer will ensure a satisfied client; to this end, considerable education of the client with attention to close communication is appropriate. At the other end, the mapping firm needs to consider the aesthetics of map creation. When the aesthetics of creation help to guide the choice of technology, an accurate and satisfying digital map is generally the end product.

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