Planning for Optical Disk Technology with Digital Cartography*

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ABSTRACT: Since the late 1960's, cartographers have recognized the potential of modern computer technology for making revolutionary changes in conventional mapping processes. During the decade of the 1970's, computer systems diminished in physical size and cost, but dramatically increased in processing speed and capacity. Such progress in the computer field continues to suggest that the transition from traditional analog mapping systems to digital systems has become a practical possibility. A major shortfall that still exists in digital systems is the need for very large mass storage capacity. The decade of the 1980's has introduced laser optical disk storage technology, which may be the breakthrough needed for mass storage. This paper addresses system concepts for digital cartography during the transition period. Emphasis will be placed on determining U.S. Geological Survey mass storage requirements and introducing laser optical disk technology for handling storage problems for digital data in this decade.

INTRODUCTION

Since the late 1960's, cartographers have recognized the tremendous potential of modern computer technology for making revolutionary changes in conventional mapping processes. The time-proven methods, utilizing analog and (or) analytical instrumentation and aerial and lithographic films, have enjoyed several years of cost-effective economic success that have contributed to their longevity as the best approach to the mapping process.

In the 1960's, the emerging influence of digital computers associated with interactive manipulation, display, and analysis of cartographic data seemed destined to replace the conventional approaches. But it was not until the 1970's that advances in computer technology began to suggest a challenge to conventional approaches in terms of cost effectiveness and more efficient responsiveness. The digital influence has accelerated considerably since the late 1970's, with rapid advances in micro-, mini-, mainframe, and super-computer technology. In fact, the five components of a computer system, i.e., processor, random access memory (RAM), input devices, output devices, and auxiliary storage, have each been remarkably improved over the past decade and there is more to come. These advances have been associated with a downward trend in hardware prices that may be placing digital cartography within the reach of most organizations engaged in Earth science, resource management, and mapping. Main memory processor cycle times have gone from microseconds ($10^{-6}$) to nanoseconds ($10^{-9}$) since the 1960's. Also, the phenomenal growth from the 4K-bit RAM to 1 million-bit RAM in ten years is shown in Figure 1. Figure 2, performance of super computers (Davis, 1984), shows a remarkable upsurge in processor capacity measured in million floating point operations per second for mainframe computers. The Cray* and Cyber 205 super computer systems lead the super pack in the United States. The next decade promises even more speed and capacity from these fifth-generation giants.

Figure 3, network architecture, illustrates four of

*This is a follow-on to the article, "Mass Storage Estimates for the Digital Mapping Era," which appeared in the March 1986 issue of this Journal.


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The peak performance of supercomputers has progressed steadily during the past two decades. Performance capabilities will jump dramatically over the next several years, however, if the various projects planned meet their goals. This chart approximates each machine’s theoretical peak magnitude (million floating-point operations per second) rating, which is rarely attained in actual operations. For example, the 64-processor Illiac IV never came close to its theoretical peak performance.

Fig. 3. Network Architecture.

Simultaneous with these processor hardware advances, the decade of the 1970’s brought on input device development (Pingry, 1984) as shown in Fig. 4. Note that the keyboard has given way to high-technology scanners and vector digitizers for input. Scanners, digitizers, and voice data entry systems are already in operation in the U.S. Geological Survey’s (USGS) Mapping Centers.

A wide variety of output devices are available also. Line printers are capable of 900 lines per minute. Perhaps the most significant output plotter at the USGS is the Scitex Laser Plotter. This large format, map size plotter is being upgraded to permit plot...
Optical disk technology has the potential for being the breakthrough needed for the success of digital cartography in the next decade. In view of this, it is interesting to address the vital issue of mass auxiliary storage requirements for digital mapping in our own area of responsibility—the United States.

**Storage Requirements for Mapping the Lower 49 States at Scale 1:24,000**

A previous paper (Light, 1986), studied the digital storage requirements for cartographic data for the lower 49 States. For this project the assumptions were:

- Approximately 54,000 7.5-minute standard topographic quadrangle maps at 1:24,000 scale cover the lower 49 States.
- Technological advances in the 1980s may permit these 54,000 quads to be stored in digital form as an archive for digital mapping data. Considering these 54,000 quads, two different approaches were derived to estimate the terrain cell size \( C_s \) required to adequately represent these data in digital form. Method 1 in this paper assumes a slightly different criterion than that previously used (Light, 1986); Method 2 is the same. Both methods are summarized as follows.

**Method 1. An Image Mapping Criteria - 300 lines/inch**

- Accept that standard quality halftone printing is usually done with a 175 lines per inch (7 lines per millimetre) screen. Assume that the current concept of screenless printing allows at least a 1.7 \( \times \) improvement over the halftone process. Some researchers claim as much as 2.5 \( \times \) improvement. This improvement means that screenless printing may produce a product equivalent to using a 300 line/inch (12 l/mm) screen. Screenless printing represents the state-of-the-art in high-resolution printing, so it is used here to represent the best case when using an image mapping criterion.

- Using 300 lines/inch as the smallest terrain element that can be represented by printing on an image map, the cell size of the ground corresponding to 300 lines \( (l) \) is computed as follows:

  \[
  C_s = \frac{1}{300} \times \frac{1}{39.37} \times \text{map scale}
  \]

  \[
  C_s = 8.47 \times 10^{-5} \text{ m} \times \text{map scale}
  \]

  \( \text{For example, at a scale of 1:24,000} \)

  \[
  C_s (\text{m}) = 8.5 \times 10^{-5} \times 24,000
  \]

  \[ C_s = 2.04 \text{ m} \]

  Thus, 2.04 m is the terrain cell size that the digital data must represent in order to meet the high-resolution 300 line/inch capability assumed for screenless printing. This makes the digital word unit stored in the mass storage media capable of representing the high resolution screenless printing.

**Method 2. Cell Size from Digital Stereophotogrammetry and Contouring Criteria**

This method utilizes national map accuracy criteria for contouring by stereophotogrammetric methods. The method computes the proper \( C_s \) to permit
stereocontouring from the data, and that Cs will be represented digitally in the mass storage media. The equation derived (Light, 1986) is

\[ Cs = \frac{1}{K} \cdot \frac{B}{H} \cdot ah \]  \hspace{1cm} (2)

Where
\[ K = \text{a nondimensional number which expresses the degree to which stereocorrelation can be achieved}, \]
\[ H = \text{the flying height of the sensor above the ground}, \]
\[ B = \text{the base distance between exposure stations}, \]
\[ ah = \text{the error in determination of height in a stereointersection}. \]

To meet the criteria for 90 percent of elevations to be correct within one-half the contour interval (CI), National Map Accuracy Standards imply that

\[ CI = 3.3 \cdot ah \]

Then, as an example, for the 10-foot (3-m) contour interval which is common on 1:24,000-scale maps,

\[ ah = \frac{CI}{3.3} = \frac{3.0m}{3.3} = 0.91 m \]

As an example, let \( K = 0.40, B/H = 0.6, \) and \( ah = 0.91 m. \)

Then, using Equation 2,

\[ Cs = \frac{1}{0.4} \times 0.6 \times 0.91 m \]

\[ = 1.36 m \]

Now that cell size has been established by two different methods, what remains is to structure and count the binary bits required per cell and to calculate the total bits of storage capacity needed for the 54,000 quads. Figure 6, cell data storage concept, illustrates a vertical layering concept for a variety of products such as thematic, image, and topographic maps. Notice in Figure 6 that the layers are allocated bits such as thematic, image, and topographic maps. Table 2, optical recording technology, tabulates the basic characteristics of each. The subject of this paper pertains to the Laser Optical Disk only as given in the right column. The operational concept of this disk is

- Focus laser beam to a micrometre size spot,
- Selectively burn holes (pits) in the disk surface to record information—a binary 0 or 1, and
- Play back (read) recorded pits using a lower powered laser.

This technology is called the “direct read-after-write” (DRAW) concept. The disk is not erasable as are magnetic media. Erasable disks are expected in a few years.

One means of visualizing the high capacity of optical recording technology is to compare it to other commonly known media. Table 3 compares the storage Technology Corporation's (STC) optical disk capacity (32 × 10^9 bits) with other magnetic media. Note that one optical disk is equivalent to about 100 standard 1600 bpi minicomputer tapes.

Table 4, number of storage units required for 10^14 bits, tabulates the number of storage units (disks or tape reels) needed for each of storage media listed. Note that 3,100 optical disk platters are needed for 10^14 bits. Because this tabulation does not consider any inefficiency in recording, it seems more correct to increase the platter estimate from 3,100 to 4,000. It is reasonable to assume for planning purposes that 4,000 platters can hold the data for 54,000 quads.

Figure 7, STC 7600 Optical Storage System, shows the disk drive which was scheduled to undergo evaluation and tests at the Geological Survey. The cartridge which holds and protects the disk and its

<table>
<thead>
<tr>
<th>Data Item</th>
<th>Bits</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lines</td>
<td>2</td>
<td>One bit would suffice</td>
</tr>
<tr>
<td>Imagery</td>
<td>8</td>
<td>256 shades of gray</td>
</tr>
<tr>
<td>Elevations</td>
<td>16</td>
<td>Spans from lowest to highest elevation on Earth in metres</td>
</tr>
</tbody>
</table>

A total of 64 bits is required to describe all layers of one ground cell in Figure 6. Considering topographic mapping, including both line and image maps, 34 bits per cell adequately represent the five overlays, the image map, and the elevation value for each pixel cell. No allocation has been made for attribute codes or topological linkage; only the map content is represented by 34 bits. Table 1, cell size and storage estimates, shows that the lower 49 States have an area of 7.84 × 10^{12} m^2 and gives a tabulation for cell sizes of 2.04 m (Method 1) and 1.36, 1.82, and 2.28 m (Method 2). It is established that cell sizes ranging from 1.4 to 2.3 m emerge as the requirement, with 2 m being a reasonable rule-of-thumb size. From observing the right-hand column of Table 1, it is clear from both methods that the estimated mass storage requirements for the lower 49 States is on the order of 10^{13} to 10^{14} bits.
The USGS is continuing to evaluate the technology for application to its Digital Cartographic Data Base. Fig 7 as shown is no longer in production by STC.
TABLE 2. OPTICAL RECORDING TECHNOLOGY. [Laser pitting technology is basically the same for video and digital data storage disks. The major difference is in how the laser beam is modulated during recording.]

<table>
<thead>
<tr>
<th>Video Capacitance-Electronic Disk (CED)</th>
<th>Video Disk</th>
<th>Laser Optical Disk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resembles a phonograph record, except it stores video images.</td>
<td>For video recording, the length of the laser pulse is determined by the amplitude of the analog video signal.</td>
<td>Digital data is encoded by turning the laser on and off—a binary system.</td>
</tr>
<tr>
<td>Images are encoded as tiny grooves in a continuous spiral track on a vinyl platter. During playback, a diamond stylus rides along the track, sensing variations in its surface as fluctuations in capacitance. Very high capacity, but subject to wear.</td>
<td>Low amplitude signals produce short pulses, and thus smaller holes. High amplitude signals produce long pulses, and corresponding larger holes.</td>
<td>The presence of a spot (pit) signifies a 1, the absence of a pit signifies a 0. Data stream may be organized in 8, 16, 32, or N-bit words.</td>
</tr>
<tr>
<td>Most suitable for feature length films.</td>
<td>During playback, the varying spot size can be used to re-create the original analog signal.</td>
<td>Bit error rates are much lower than video recording.</td>
</tr>
</tbody>
</table>

TABLE 3. COMPARISON OF MAGNETIC STORAGE MEDIA WITH OPTICAL DISK.

<table>
<thead>
<tr>
<th>Storage Media</th>
<th>Capacity (Bits)</th>
<th>Comparison-Optical Disk Capacity</th>
<th>Other Media Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical Disk</td>
<td>$32 \times 10^9$</td>
<td>OD</td>
<td>$1 \times 10^9$</td>
</tr>
<tr>
<td>300 MB Mag Disk</td>
<td>$2.4 \times 10^9$PACK</td>
<td>OD</td>
<td>$13 \times 10^9$</td>
</tr>
<tr>
<td>CCT 1,600 BPI</td>
<td>$0.3 \times 10^9$</td>
<td>MD</td>
<td>$107 \times 10^9$</td>
</tr>
<tr>
<td>CCT 6,250 BPI</td>
<td>$1.3 \times 10^9$</td>
<td>OD</td>
<td>$25 \times 10^9$</td>
</tr>
</tbody>
</table>

but it portrays the approximate size that can be expected for optical disk drives.

Given that computer technology and storage capacity is increasing and becoming more available every year, it is time to plan for future online digital mapping systems. Figure 8, USGS/NMD cartographic mapping processes for new mapping (future system), shows a concept for mapping systems in which the data collection devices all collect digital data properly formatted for editing and attribute coding. The data could then be stored in the 4,000-platter online mass storage system. To minimize setup time, it is most important to capture and store all topographic data in the mass storage system at the time of compilation. This conceptual system could produce both the traditional line of graphic map products and the newer line of digital products from one source on call by means of the data management system.

The concept depicted in Figure 8 describes a planning concept. It represents the flow of data that we may expect when more digital systems and proce-
SUMMARY

In summary, with computers getting smaller in size and greater in speed and capacity, and with optical disk technology recognized as a breakthrough in mass storage media, it is feasible to plan a cartographic system as shown in Figure 8. Such configurations may be commonplace in the 1990's.

REFERENCES


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