Automated Data Capture for Geographic Information Systems: A Commentary

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INTRODUCTION

During the last fifteen years we have seen dramatic growth in the use of Geographic Information Systems (GIS) in a large number of disciplines. Costs for acquiring basic GIS capabilities have dropped to levels such that even local units of government can use personal computer (PC)-based systems to aid in planning and resource management functions. The PC itself may be justified for payroll, tax assessment, or accounting services, but it may also be used as the foundation for a GIS.

It is notable that most dollars invested in GIS projects do not go for hardware and software procurement. Far and away the largest cost in a GIS application is data capture. To make full use of the capabilities of a GIS, it must be provided accurate and up-to-date information. Data entry by using a manual digitizing tablet is exhausting, time consuming, and often tedious work. Techniques for automated and semi-automated data capture have been developed over the past several years and are currently used in production-digitizing by the U.S. Geological Survey (USGS) and other government agencies. Current "automated" techniques still need human intervention at various points in the data capture process.

This commentary will attempt to briefly review the state of the art in automated data capture. I will also speculate on the effects of recent and ongoing changes in hardware, software and media.

TECHNIQUES FOR AUTOMATED DATA ENCODING

Two major "automated" processes currently being used for data capture are line following and map scanning. Line following techniques are widely employed today for digitizing linear (vector) data such as stream networks or contours. The operator of a line following system positions a pointer on the line to be encoded, and the pointer automatically follows the line until one of three things occurs: 1) the pointer reaches the edge of the map, 2) the line closes upon itself, or 3) an impasse is reached where the line following software cannot decide in which direction to proceed. The latter may be caused by line weight problems in the original manuscript, breaks in lines for labeling, or lines which are so close together that the software is unable to make a choice. To minimize the potential for error in the line-following process, map separates are used for each variable of interest (e.g., elevation, vegetation, transportation). Editing and labeling of digitized lines are currently carried out by the operator.

Map or image scanning is the process whereby a computer controlled instrument with optics and detectors similar to traditional remote sensing systems, creates a digital image (i.e., a 2-D gridded array) of the source material. The resultant image is composed of a number of raster lines each composed of a number of image picture elements ("pixels").

If one is interested only in using video representations of a map or image for playback or as a backdrop for graphics, high accuracy in color and spatial resolution may not be needed. There are many video cameras available today that operate with commercial software on micro- and mini-computers. Digitizing of images from such a camera may be done in real time (video frame rate) or at approximately 1 second per frame rates if real time is not critical. Normally, an image will be digitized at a resolution of 512X512 pixels, though a few vendors now support higher resolution frame grabbing.

For inclusion in a GIS, any image collected by a video camera must be related to a geographic coordinate system. Digitized video images can be geometrically corrected using the traditional methods of ground control point selection from the digital image and identification and measurement of the same points in a standard map projection. However, a higher than first order geometric correction may be necessary to correct for distortions (e.g., lens distortion) introduced in the video camera system. Lighting effects have a significant effect on the quality of a video digitized image. Without balanced lighting, shadows and glare degrade any available greyscale information.

If one requires higher geometric or radiometric precision than can be obtained using a video camera, a flat-bed image scanning system may be used. In these systems internal detectors scan across the field of view of the sensor, building the image in a line by line manner into a digital buffer. Lenses used in such a system are designed to minimize geometric distortions. Radiometric corrections are also made using calibrated standards. These systems usually output an image size of 2048 × 2048 or 4096 × 4096 pixels, a much higher spatial resolution than that provided by video frame grabbers. Black and white systems having resolutions of 10,000 × 10,000 pixels are now coming on the market. The results from a scanning system may be very good, but the cost of such scanning systems is high ($20,000 to $35,000) compared to video ($1,000 to $5,000).

A third common type of scanning is the drum scanner. In such systems, a transparency or positive print is attached to the rotating drum of the scanner. An optical head is used to scan the image in one direction with the drum motion providing the other scan direction. By using rotation and direct scanning to create a digital image, many of the detrimental effects associated with digitizing an image through a lens are avoided. Drum scanners can digitize images at various resolutions, and produce high quality digitized images. Digitization of color images is accomplished by the use of filters and the scanning of the subject three times. Many drum scanners also have the ability to write digital data onto unexposed film mounted on the drum. The cost of a high precision drum scanner normally ranges between $50,000 and $200,000.

AN EVALUATION OF THE STATE OF THE ART

The two major techniques for digitization of map data both currently require extensive human interaction to provide digital data that may be used in a GIS. The hardware used in both processes seems to be adequate, however major deficiencies exist in software capabilities. For example, raster to vector conversion remains a complex procedure. Problems also exist with source data. Clean, single theme maps required for automated digitization often are not available.

For the line scanning method, new and innovative techniques are needed to automatically handle all but the most complex problems encountered by the system. A system should be "smart enough" to search for the next line to scan when it has finished with a given line. The procedure must assure that no lines are missed. Logic development must be able to handle "close contour," labeling interruption, and line weight problems without requiring the intensive services of an operator.

For raster scanning, the existing multistep-interactive procedure for creating point, line, and polygon structures with the appropriate attributes must be automated to a greater extent.

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Existing "raster to vector" conversion routines are generally not one single automatic routine, but a series of steps requiring operator interaction. In addition, they are not clever enough to supply the appropriate attributes associated with the vectors that have been formed. Automated techniques for edge finding, chaining, and smoothing must be followed by techniques that will define the topology of a map and associate it with line segments. The assignment of multiple attributes to nodes and lines will require sophisticated analysis of the spatial characteristics of the scanned map. For example, the system should be able to associate parking lots with buildings and runways with an airport.

Techniques being developed in the field of artificial intelligence (AI) have a great deal to offer automated data capture. Image understanding (IU), a subset of AI, is involved with recognizing the complex spatial, spectral, and temporal relationships that exist within images, and with exploiting those relationships in identifying discrete regions of interest within the images. "Expert systems" development may someday be able to tie together all of the discrete steps necessary for automatic capture of information from map data. Unfortunately, the human capability in image perception is difficult to model, and a great deal of research remains to be accomplished in understanding human thought processes.

Explicit conventions exist in maps, such as, for example, in regard to placement of text and symbology with respect to contours. In addition, line weights, colors, and text size all follow prescribed standards, at least for U.S. agencies' map products. These factors, and spatial relationships derived from IU processes, should provide a basic set of "rules" for expert systems. As development of IU matures, we may be able to approach a fully automated system.

CONCLUSIONS

Current advances in the speed and flexibility of microcomputer systems have minimized most concerns over the processing time involved in using raster-scan or vector data sets. In addition, with high density optical disk storage, microcomputer systems now have the capacity to handle the large data volumes of scanned data sets. Even users with limited resources may take advantage of high resolution scanning by working with service companies which will scan maps or images for as little as $200 to $500. If capture of vector data is necessary, service companies can also provide full capability for all the steps necessary for raster to vector conversions with attributes. Private sector involvement in data capture will supplement standard digital data products from U.S. Government agencies such as the USGS and the Defense Mapping Agency.

Advances in artificial intelligence over the next ten years will move us much closer to the goal of totally automated data capture from map sources. However, problems in translating the capabilities of human perception into discrete rules and mathematical formulas are by no means trivial.