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Donald day

The University of New South Wales, d.day@acm.org

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Image Generation for GIS: Experimental Mapping Principles and Techniques

Donald Day

School of Information Systems, The University of New South Wales, Sydney, NSW 2052 Australia
d.day@acm.org

Abstract

The objective of this study was to describe principles and techniques of experimental mapping which may affect the implementation of geographic information systems (GIS). Based upon a series of interviews with domain experts, this paper discusses the sources of image data, data manipulation and reproduction techniques, computer capabilities and limitations, map design considerations, and user responses to experimental maps.

Introduction

In the rush to apply GIS to everything from tax assessment to natural resource management, it is useful to keep in mind the aerial and satellite remote sensing bases of this technology. The appropriate interpretation of GIS images is aided by a knowledge of principles and techniques applied to intermediate data before images appear on GIS workstations. An awareness of these principles and techniques will help users to assess the reliability, precision and accuracy of GIS images, regardless of whether the data are presented in interactive, drill-down implementations with extensive navigation aids (Blades, 1993) or as dynamic hypermedia (Buttenfield & Weber, 1993).

Method

This study is a qualitative, exploratory, and descriptive effort to investigate technical issues in image generation which may affect implementation of GIS. It draws upon in-depth but informal interviews of domain experts at the U.S. Geological Survey (USGS), as recommended by Marshall & Rossman (1989).

Subjects were selected because of their expert (and first-hand) knowledge of USGS experimental mapping projects and of developing technology. Interviews were conducted in two rounds, separated by approximately two weeks. The first set concentrated on preliminary data gathering and focused upon experimental mapping of international regions. The second set of interviews was guided by an outline of concerns developed from the literature and from the previous interviews; this set focused upon experimental mapping within the (U.S.) national mapping division. The scheduling of multiple interviews separated by a review of literature and by conceptual outlining worked well in focusing the research and in identifying issues that were not apparent at the outset.

Sources of Image Data

Although images for experimental mapping come from a variety of sources, the most common is satellite remote sensing. Since February 1979, the USGS EROS Data Center has made available Landsat images, distributed on film and pre-processed with basic geometric and radiometric corrections.

Landsat imagery is sensed in a series of energy frequency (wavelength) bands. These blue, red and near-infrared bands must be filtered for a variety of sensor anomalies before being used (Chavez & Gupatil, 1986). However, that such filtering can create distortions. In one experiment developed by William Haxby of Columbia University's Lamong-Doherty Geography Laboratory, technicians could not fit known shorelines to their image map, and islands were created that didn't exist.

Data Manipulation Techniques

Landsat data delivered to USGS have undergone first-order geometric corrections. This cubic convolution data correction process at the EROS Data Center results in a striping effect across the image that is noticeable to a trained viewer. In some cases, cubic convolution can even shift image element position. In one image, data correction totally reoriented a spit of land protruding into a gulf from one angle to another vis-à-vis the mainland.

Problems with satellite imagery have been addressed by resampling techniques, interpolation of missing pixel values, and manipulation of contrast ranges. All manipulations are artificial adjustments of the imperfect reality provided by data sensing instruments. Therefore, maps generated from remotely sensed imagery may not represent reality.

Digital image filtering inherently involves a (sometimes intentional) loss of data, regardless of the graphics application. Adjustable filtering can be useful in geographic mapping tasks when a wide variety of scenes (e.g., open water vs. land) occurs in the original image. This results in the display of more detail in all areas than would have been possible with one sensor band and one algorithm (Chavez & Guptill, 1986).

One data manipulation technique developed by USGS is nearest-neighbour interpolation (also known as "rubber sheeting"), used for filling data gaps. The values of known data points to either side of an information gap are averaged, and a pixel of the interpolated value is inserted to fill the gap.

A more sophisticated treatment of missing data is solid platform model correction, in which an error factor is calculated for an entire image, then applied systematically to all pixels.

Resampling is another common manipulation technique, in which image data frames are redefined from those assigned originally by ground station pre-processing. For example, EROS MSS images of 57 by 79 metres are resampled to a ground area of 57 metres square before being recorded on black-and-white photographic film (Kidwell, 1983).

High contrast within the image makes it difficult to display both dark and bright regions simultaneously. The problem is most severe when it occurs in an image that is very dark in one portion, changing gradually to a bright area in another portion. A technique known as "contrast stretching" attempts to average vastly differing contrast.

Spatial filtering can be used to perform edge enhancements or to suppress high contrast within an image to enhance local detail in dark and bright areas (while retaining most of the colour information). Using standard spatial filtering techniques will result in a loss of brightness or colour information, however (Chavez, McSweeney, & Binnie, 1987).

Images from remotely sensed data also may be improved by merging digital files from disparate but highly correlated sensors, to fully utilise complementary information. Combining data from different sensors may allow the creation of a dataset that maximises both spectral and spatial information (Chavez & Guptill, 1986).

The merge process involves formatting the two datasets to approximately the same "pixel size" before registration is performed. The results are smoothed using a low-pass filter. Then, geodetic control points are selected to register the TM image to the digitised aerial photograph. Nearest-neighbour sampling is used on the photograph.

Digital rectification is not a data correction technique, but rather a means to make wider use of existing digitised image files. Pixels are digitally scaled to match the pixel size of the final intended display. However, there are lower limits to the practical size of pixels, because ringing may result. Ringing, a general lightening of hue around parts of the image, is caused by filtering. It will show as a complementary colour in a colour-dense area of an image. A high-pass filter must be used on the data to generate the

image, but when contrast is poor when there are wide variations in image representation. As the filter is enlarged, relief must be simplified, eliminating detail.

Reproduction Techniques

Satellite images seldom frame exactly the area desired. The solution is mosaicking: the seamless butting together of adjacent images to make the desired whole. Historically, mosaicking has been accomplished by scaling images to control points and matching detail through photographic processing. The resulting image would have the appearance of a single continuous scene. tone and scale matching performed in the process.

Colour selection is affected by users' abilities to discriminate colour coding meaningfully as well as by their expectations about feature classing (a colour correspondence among related features). Complex colour often cannot be used because the limit to coding features meaningfully seems to be six-to-nine colours.

Computer Capabilities and Limitations

The computer manipulation of data and command of production devices has replaced drafting and photographic technology throughout experimental mapping. Traditional photographic processes using a graphic arts process camera and contact frames can produce excellent results, but the process cannot be controlled and modified as well as it can by using computer processed data and electronic imaging equipment (Kidwell, 1983). That control is essential to a key aspect of experimentation: the ability to repeat work, so that specific variables responsible for a result can be identified.

Computers are used to merge culture (human-relevant labels and symbols) from existing maps with more current imagery, despite the fact that the superimposed data are not of the same time period as the underlying image. By using this technique, users in areas of rapid change and development can be offered more timely products (Zang, 1989).

Map Design Considerations

The use of aerial and satellite imagery for GIS mapping makes possible exceptional accuracy, if anomalies characteristic of data collection (e.g., problems due to orbital mechanics) are corrected. However, labelling is difficult with such maps because of their continuous range of texture, colour and value.

Labels on image maps not only destroy data, but also are difficult to read in some traditional typefaces. The use of halos (white outline) for type (a feature of many traditional maps), of typefaces with variable-width strokes, and of colours used in grouping or classifying features are especially difficult with experimental image maps. Width-of-stroke problems are especially acute in use of a cursive languages such as Arabic.

Most black imagery and multicolour maps require the use of drop-outs or halos for line and lettering data because of dark areas in the imagery. Either solid black or full-reverse white must be used for names. Tests have shown that reverse lettering is much more legible than full-black type.

User Responses to Experimental Maps

In the past, users complained about the lack of lettering on image maps. (Map designers have resisted using the normal amount of labelling on image maps because type overlays destroy imagery.) Users have indicated that place names, elevation and watershed data are desirable. Many feel that photoimagery requires the overprint of additional cartographic data for effective use, though only selected data are needed. The data most desired by users seem to be political boundaries, index contours and public land survey notation, with a strong interest in selected data for street names/route numbers, drainage names and place names.

Anecdotal user response data are available from experimental maps generated for overseas clients. Much of the experimental activity at USGS has taken place under contract from other governments, which not only provide funding but also make it possible for staff to disregard traditional USGS map design criteria in development and production. However, such international efforts encounter cultural differences in map feature perception.

For example, East Africans interpreted the use of red to depict vegetation in TM imagery as clay, and green as vegetation (instead of permeable soil). The Sudanese wanted many place names on their maps, but could not provide ground control for the features, due to the high cost of control surveying.

Experimental maps are not of acceptable quality to much of the cartographic community, due to resolution and reproduction problems. They are valuable nevertheless to resource exploration firms, governments of developing countries, and the military. In many cases, satellite imagery provides reasonably accurate representations of areas either not previously mapped or mapped with very little detail.

Implications

It is apparent from this review of experimental mapping at USGS that the interpolation of missing data, the introduction of distortions via filtering (such as contrast enhancement), and the unavoidable misrepresentation of data must be taken in account when remote sensing technology is pushed to its limit.

It's clear also that users of satellite-based GIS data should verify critical locations using GPS rather than relying on orbital imaging. Further, attention must be paid to threshold standards for the amount of missing data that can be allowed, depending upon application. Obviously, the technology is capable of creating data to fill gaps, but GIS users must be aware that imagery contains what in the software industry is known as "vapourware". Finally, users should be aware of the strengths and weaknesses of display inherent in the various wavelength imaging systems, and realise distortions of data that may result from misapplication of imaging technology.

Experimentation with exotic image interpretation and display technology may suggest that as automated image interpretation systems come online, the traditional visual basis for GIS not only can but should be replaced by other information modelling techniques. However, given the millennia of map-based geographical information representation, any move toward other models will involve the substantial re-orientation and re-training of users of GIS data.

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