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APPLICATION OF INTERACTIVE SCENE ANALYSIS TECHNIQUES TO CARTOGRAPHY[1]

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Summary

One of the most time-consuming and labor-intensive steps in map production involves the delineation of cartographic and cultural features such as lakes, rivers, roads, and drainages in aerial photographs. These features are usually traced manually on a digitizing table in painstaking detail. This paper investigates an alternative approach, an interactive system that eliminates the need for detailed tracing. A human operator graphically designates a feature of interest by pointing at or crudely tracing it with a display cursor. Using this input as a guide, the system employs context-dependent, scene-analysis techniques to extract a detailed outline of the feature. The results are displayed so that errors can be corrected by further interaction, for example, by tracing small sections of the boundary in detail. This interactive approach appears applicable to many other problem domains involving large quantities of graphic or pictorial data, which are difficult to extract in digital form by either strictly manual or strictly automatic means.

Index Terms: Automated Cartography, Scene Analysis, Interactive Systems

Introduction

The production of maps from aerial photographic data is a process that, despite a large body of mechanical techniques, is primarily labor-intensive. One of the most time-consuming steps in this process is the delineation of topographic, cultural, and land-use features, such as lakes, rivers, roads, and drainages. Currently, a trained operator must manually trace the detailed boundaries of features, a lengthy process. Similar problems also occur in the process of digitizing maps for later updating.

In such a labor-intensive craft, it is reasonable to look toward computers as a possible means for eliminating much of the routine work. The idea of a fully automatic, aerial photograph-to-map computer system, while appealing, is not only unfeasible at present but is likely to remain so for the foreseeable future. A more promising approach would be to develop an interactive system whereby an operator could quickly indicate gross features and have the system fill in fine details. The system would relieve the operator of the need to attend continuously to many details and allow him, instead, to simply guide the processing. Any errors made by the system could then be corrected interactively. The feasibility of such an interactive approach has been successfully demonstrated at the Stanford Research Institute (SRI) using the Interactive Scene Interpretation System (ISIS).[1]

Example

The following scenario illustrates how a user and interactive system might work together on a typical cartographic task, extracting an outline of the large lake in Figure 1.* Human input will be shown by thick white lines and the computer's response by thin ones. In Figure 2, the user has designated an area of interest that is then displayed at a magnified scale. In Figure 3, a crude triangular region is drawn by the user to indicate roughly the center of the lake. The computer's initial guess, shown in Figure 4, contains both errors of omission (samples excluded along the periphery), and of commission (unwanted tail in lower left-hand corner). The operator crudely encircles the tail (Figure 5) and tells the computer to omit all points in the enclosed region. He also points at several omissions (the crosses in Figure 5). The computer responds with the boundary shown in Figure 6.

Method of Approach

The examples and counterexamples of lake were used to develop and debug interactively a computer procedure for distinguishing between pixels (picture elements) from the lake and those from the shore. The resulting procedure was then used by a conventional boundary-following algorithm to extract the lake outline.

This algorithm first detects the lake boundary by scanning outwards from the center of the designated triangle until the discrimination procedure classifies a pixel as "nonlake." It then follows the boundary in a counterclockwise direction. The next boundary point is determined by applying the discrimination procedure to the pixel immediately to the right of the present boundary element and then testing pixels in a counterclockwise arc about the present element until a "lake" classification is encountered.

The interesting part of this work concerns the methodology used to develop the discrimination procedure.

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[1] The research reported herein was supported by the National Aeronautics and Space Administration under Contract NASW-2086. Additional support was provided by the Advanced Research Projects Agency of the Department of Defense under Contract DAHC04-72-C-0008 with the U.S. Army Research Office.

* Figure 1 is an orthophoto of Fort Sill, Oklahoma, coarsely digitized at 256 x 256 resolution. A coarse digitization was used to speed processing for this example.

The objective is to construct the simplest procedure, using all available feature extraction operators, for distinguishing example points from counterexample points. Table 1 lists typical feature extraction operators, ordered by computational complexity. Details of these and other operators can be found in standard texts on scene analysis.[2,3] There is a hierarchy of graphic interaction (pointing) modes, as Table 2 indicates, by which the machine can be shown examples. From a single sample pixel, it is possible to construct a program that accepts contiguous pixels whose point attributes (i.e., brightness, hue, or elevation, if available) differ from the indicated pixel by less than a threshold. An implicit inference is being made here that the rest of the pixels on the feature resemble this single pixel. Given an example region, the thresholds can be widened to encompass the range of attributes measured on that region. Counterexamples can then be used to narrow these limits. In general, the more complete the example, the less iteration will be required to develop a good specification. If an example and counterexample cannot be distinguished on the basis of thresholded point attributes, averages or distributions of attribute value over local areas can be used. If this still is not sufficient, an attempt can be made to distinguish between the two on the basis of the size and shape of the regions delineated by outlining. The final procedure will be composed of conjunctions and disjunctions of these criteria.

Table 1

TYPICAL OPERATORS

- Point Operators (applied to individual pixels)
  - Brightness
  - Color (hue and saturation)
  - Elevation
- Local Area Operators (applied to sets of contiguous pixels in small circular or oblong areas)
  - Average of Attribute Values
  - Distribution of Attribute Values
  - Weighted Averages (templates)
- Region Operators (applied to clusters of contiguous pixels)
  - Texture Over Regions
  - Shape of Regions
  - Size of Regions

Table 2

GRAPHICAL INTERACTION (POINTING) MODES FOR DESIGNATING EXAMPLES AND COUNTEREXAMPLES

- Single Points
- Small Regions
  - Inside
  - Outside
- Crude Outline
  - Inscribed
  - Circumscribed
- Detailed Outline
  - Segments
  - Complete

Now, let us examine in detail the interactive process by which the lake-outlining procedure illustrated above was developed. The sampled, digitized image (Figure 1) was read into ISIS and displayed on a RAMTEK self-refreshing CRT. With the cursor, the user then created a small region in the interior of the lake and asked the system for a distribution of brightness values for pixels in this area. From these data he composed a one-line program that tested whether a pixel belonged to the lake based on thresholded brightness (the only available point attribute). The edge follower used the program to produce the outline shown in Figure 4.

The user next drew a crude boundary around the "bad" pixels in the tail and again requested a brightness distribution. A significant overlap with the previous distribution of example pixels was observed. Adequate discrimination was achieved empirically by increasing the operator size so that brightness of a point was computed as the average brightness over a circular area centered on the point. This crude spatial filtering acted to exclude dark areas of the image with insufficient width to qualify as lakes. Finally, the brightness threshold was widened to include the brightnesses of the missed points that the user had indicated with the cursor. Using the updated program, the edge follower was able to obtain an outline that tracked fairly accurately the actual lake.

The final procedure for distinguishing lake points from nonlake points is, in fact, a "model" for what pixels from a lake look like to the computer. The program was written on-line in an interactive language (LISP) and then debugged interactively as contingencies arose. Interactive refinement is a powerful concept for a scene-analysis programmer. It frees him from the necessity of formulating programs in a language that is understood by the machine but that is cumbersome for people. Instead, it allows direct communication with the program via a common language of images. Debugging is simplified in this system. Instead of predicting the problems that the system is likely to encounter, the program is executed on exemplary images and debugged when errors arise.

Further Examples

Automatic Extraction of Previously Learned Features

The procedure developed in tracing the first lake can serve as the initial basis for extracting other lakes in similar terrain. Even if the outline is not exact, it provides a good starting point for further interaction. Figure 7 shows a boundary extracted for the small lake using the same discrimination procedure developed for the large lake. In this example, the user manually designated a single pixel in the center of the second lake to initiate the boundary follower. Alternatively, an initial sample could have been acquired automatically, by scanning systematically through the image for a reasonably sized set of contiguous pixels satisfying the criteria for "lake." Note that any subsequent interaction required to refine a boundary could be used to further improve or generalize the original discrimination procedure.

Linear Features

Linear features, such as rivers and roads, may also be outlined using similar interactively generated procedures. In Figure 8, the upper branch of the river connecting the two lakes is shown. Here the user pointed at a single river point just above the fork. Starting from this point and using a threshold based on its brightness, the boundary follower tracked the river until it intersected the road. The trainer next indicated additional starting points on each river branch below the road, and, using the same threshold, the river boundary was completed. The final river boundary is shown in Figure 9. These crude boundaries could be improved by applying a thinning algorithm.[5] Figures 10 and 11 show the final results of tracing the designated features and then projecting them back onto the original, high-resolution image.

Possible Extensions

Automatic Generation of Discrimination Procedures

The above examples required that the user supply discrimination procedures for distinguishing between the brightness distributions of designated regions. These procedures were interactively formulated using data provided by the system. An obvious next step would be to have these procedures formulated automatically by the system based on the user-designated examples and counterexamples. In this mode of operation, a user might crudely sketch a feature of interest. The system would use this to formulate a discrimination procedure and then attempt to trace a detailed boundary. Errors would be handled interactively, either by manually editing part of the boundary or by providing the system with additional examples and counterexamples with which to refine the discrimination procedure.

For simple discrimination procedures of the type described in this paper, automatic generation appears straightforward. Existing ISIS subroutines could be used, for example, to select the appropriate threshold and operator size for distinguishing the brightness distributions of example and counterexample points.[4] The same approach should be applicable with the other operators in Table 1 when additional discrimination is required.

Elevation Data

The availability of elevation data would make many of the tasks described above much simpler. The constant elevation of a lake, combined with local brightness values, would provide a powerful discriminating test. And, in many cases where the brightness contrast between two features is poor, a difference in slope or elevation may be sufficient to distinguish them. Similarly, features in mountainous terrain would prove more tractable with elevation data.

Digitization of Existing Maps

The same techniques used to trace features on aerial photos would also be useful for tracing features on existing maps to reduce them to digital form. In many cases, the processing should, in fact, be easier, because of the better contrast available in maps. These digitized maps could then be updated interactively using recent aerial photographs. Ultimately, information in existing digitized maps could be used in lieu of pointing to indicate preexistent features on the photograph. This would allow the program to use the digitized map to guide the subsequent analysis of the aerial photograph, in the same way as would a person.

Elimination of Map Editing

The process described should eliminate the need for an independent editing step after the map features have been extracted. The editing is an inherent part of the process of incremental refinement of the outline and, therefore, should not be normally needed as a post-processing step.

Conclusions

We believe that the examples described above demonstrate the technical feasibility of applying interactive, scene-analysis techniques to cartography. Whether or not the techniques developed will prove practical in actual cartographic use is, of course, a matter for further study. The simple feature extraction operators used (essentially a threshold applied to the average brightness computed over a bar-shaped operator) almost certainly will not suffice in more complex aerial scenes. Moreover, processing times may become a key factor at the image resolutions required for cartographic accuracy. An appealing aspect of the interactive approach is that, when necessary, the user can always revert to detailed manual tracing. Thus, the approach would be useful even if it applied in only some of the cases encountered in practice.

In the future, we plan to apply interactive techniques in a variety of other problem domains involving large volumes of graphic and pictorial data that are difficult to extract in digital form by either strictly manual or automatic means.

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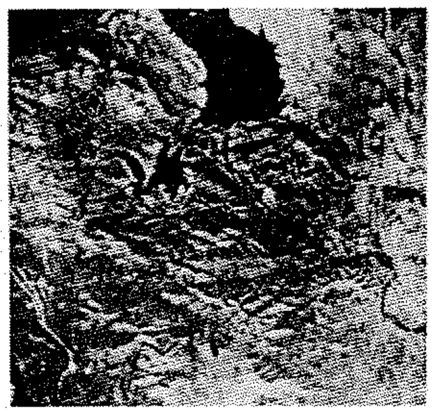

FIGURE 1 DIGITIZED AERIAL VIEW OF FORT SILL, OKLAHOMA (8 BITS AT 256 x 256 RESOLUTION)

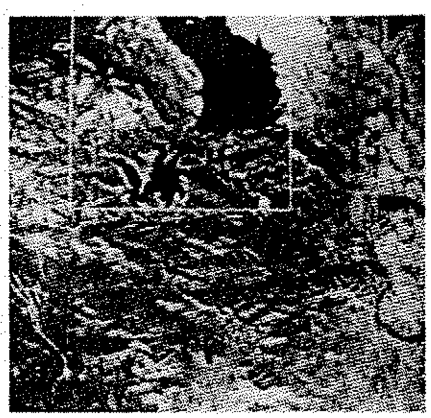

FIGURE 2 WINDOWING TO OBTAIN MAGNIFIED DISPLAY OF WORK AREA

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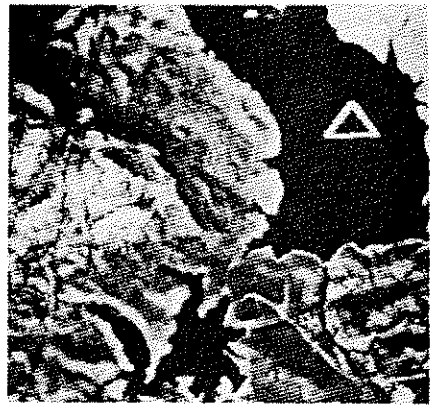

FIGURE 3 USER MANUALLY DESIGNATES A FEW IMAGE POINTS CONTAINED IN LARGE LAKE

FIGURE 4 INITIAL BOUNDARY WITH DEFECTS

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FIGURE 5 USER INDICATES ERRORS

FIGURE 6 FINAL BOUNDARY OF LARGE LAKE AFTER UPDATING MODEL

FIGURE 7 FINAL BOUNDARY OF SMALL LAKE

FIGURE 8 OUTLINE OF RIVER AFTER DESIGNATING ONE POINT IN THE UPPER BRANCH

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FIGURE 9 OUTLINE OF RIVER AFTER DESIGNATING AN ADDITIONAL POINT IN EACH LOWER BRANCH

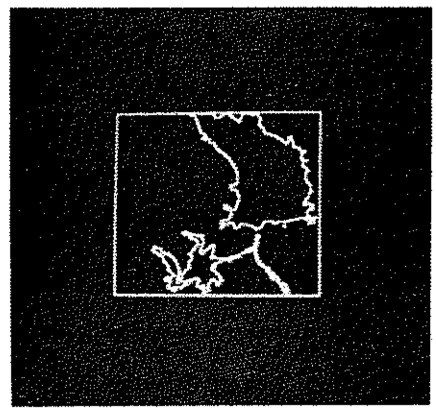

FIGURE 10 COMPLETED MAP OF MAJOR WATERWAYS WITHIN WINDOW

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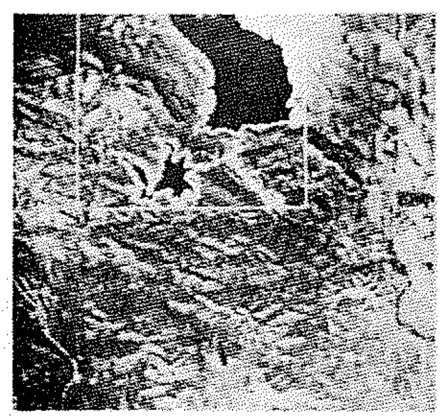

FIGURE 11 COMPLETED MAP SUPERIMPOSED ON ORIGINAL IMAGE

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