THE INTEGRATION OF CARTOGRAPHIC DATA STORED IN RASTER AND VECTOR FORMATS

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ABSTRACT

The advantages and disadvantages of raster and vector formats for capture and storage of cartographic data are considered. The problems of converting from raster to vector format are reviewed and the desirable characteristics of a cartographic raster to vector conversion procedure are outlined. A possible strategy for construction of such a procedure is suggested based on AI techniques.

INTRODUCTION

For some considerable time now two distinct and fundamentally different technologies have been pursued for capturing cartographic data and making it available in machine readable form. Vector digitizing methods rely on encoding cartographic features such as strings of x/y coordinates on a sequential, feature by feature basis. They generate, subject to operator digitizing skills, compact and accurate representations of individual cartographic features in a manner which ensures that the relational structure of the feature-defining coordinates can easily be preserved. For this reason vector representations of cartographic features are widely used in many mapping applications and cartographic database systems. Unfortunately the price paid for preservation of relational structure and accuracy of feature definitions is high costs in both machine and operator time and increased complexity in data manipulation.

Raster digitizing on the other hand provides a much faster means of capturing cartographic data and has other significant advantages. In particular the grid format makes for straightforward manipulation of the data to the extent that many operations such as windowing, clipping, zoom and pan can be hardware based. Raster digitized data are easily integrated with data from other sources such as satellite imagery and the data records themselves can be stored in a straightforward way using direct access filestore. Despite these advantages raster formats have several major disadvantages. In particular the identification and manipulation of image features is extremely difficult because there is no inherent relational structure within the image pixels. Furthermore, for cartographic images raster storage is inefficient because usually only a very small proportion of the image pixels have non-zero values.

For these reasons it has long been clear that the ability to encode vector structured features into raster format and conversely the ability to extract vector coded features from raster imagery would be of tremendous value in any automated mapping system. Procedures for vector to raster (V/R) conversion are readily available (see Chapman, 1982) but the reverse operation, raster to vector encoding (R/V), is far less straightforward and "off the shelf" packages for R/V conversion are not commonly available.

Although a number of computer-based drafting packages have some degree of raster to vector conversion capability there appears to have been little thought given to the cartographic requirements of an effective R/V procedure. It will be the aim of the following discussion to explore some of these requirements and to comment on some existing research developments which may ultimatley enable them to be achieved.

A STATEMENT OF THE PROBLEM

A digital cartographic image is represented as a function of two variables (x,y) and is stored in the form of a two dimensional array. If $L_x = (1,2...N_x)$ and $L_y = (1,2...N_y)$ are the x and y spatial domains, then L_x and L_y is the set of square resolution cells and the digital image I is a function which assigns some grey level $G \in \{1,2...N_g\}$ to each cell; $I: L_x \times L_y \rightarrow G$. In the case of a multi spectral image $G_k \in \{1_k, 2_k...N_{kg}\}$ for K = 1 to N_k spectral classes.

Embodied within this image I is a set of visually identifiable features, $F \in \{1,2...N_f\}$. Each F spans cells of I in such a way that $F_1 \cup F_2 ... \cup F_n = I$. In a simple picture the set of cells associated with each feature F would be homogenous, contiguous, and the set of features F would be non-overlapping with a one to one correspondence between each feature and a classifiable object. For example:

F_1	(FIELD OF CORN)
F_2	(FALLOW FIELD)
F_3	(TRACK)
F_4	(WOOD)
.	.
.	.
.	.
F_n	(STREAM)

Table 1: Identifiable Cartographic Features

Furthermore, in order to exist as a discrete, identifiable element of F each f would be clearly differentiable from its neighbours on the basis of the structure exhibited by its spectral grey tones. Given this simple structure each feature within F is separated from its first order neighbours by a clearly identifiable edge which can be represented as a vector. The set of vectors partitioning all of the features constitutes a coherent network of nodes N and links L which could be searched to generate a data structure of the following type:

LINK	RIGHT FEATURE	LEFT FEATURE	START NODE	END NODE
L_1'	f_a'	f_k'	N_{k1},	N_p
L_2'	f_d'	f_z'	N_1,	N_t
	.			
	.			
	.			
L_n	f^*'	f_e'	N_f'	N_m

Table 2 Basic Cartographic Data Structure

It is the aim of effective R/V conversion procedures to generate the above data structure from digital imagery in such a way that associated data structures can be derived.

Unfortunately digital, cartographic images rarely have this very simple structure and derivation of the information in Table 2 is not straightforward. Complications arise primarily because

(1) Members of the feature set F are rarely non-overlapping. This destroys any possibility of a one to one correspondence between features and objects as in Table 1. In turn this leads to extreme difficulty in arriving at the data structure defined in Table 2.

(2) Members of the feature set F are often not clearly differentiable from their first order neighbours on the basis of their grey level characteristics alone. This leads to missing or incomplete links in the network of edges again hindering construction of the required data structure.

(3) Individual features within the set F rarely display homogeneity in terms of their grey-level structure. This hinders definition of the links set L by introducing spurious links, yielding incorrect locations of true links and generating noise in the identification of edges.

The extent to which these problems afflict any particular raster image depends largely on the source of the data and its method of collection. In the context of R/V conversion several cases are of interest as follows:

(1) Scan digitized cartographic documents
(2) Scan digitized aerial photography
(3) Remotely sensed scenes from aerial or satellite platforms.

Generally type (1) poses the least problems as far as vectorisation is concerned because during the cartographic design and construction phase of the document's generation features will have been organised in a clear and concise way. Nevertheless major problems exist, especially for example, where text overlays individual features. Cases (2) and (3) are of great interest because the ability to derive structured, vector data direct from aerial photography and satellite imagery would, in many cases, enable rapid, low cost mapping from these sources by removing laborious vector digitizing work from the map production process.

Unfortunatley it is these types of imagery which pose the most formidable problems for vectorization. In addition to the difficulties already described image noise arising from atmospheric distortions, cloud and sensor sensitivity/calibration are all of significance. Furthermore the images will almost always have geometric distortions which must be corrected if useful cartographic data is to be generated on a convenient referencing system.

THE CARTOGRAPHIC REQUIREMENTS OF AN EFFECTIVE R/V CONVERSION PROCEDURE

Whether the source of data is raster digitized maps or remotely sensed imagery it is possible to identify at least some of the basic cartographic requirements of an effective R/V conversion procedure. The first requirement is to be able to generate the data structure in Table 2 to some specified degree of accuracy. From this basic vector data it is then necessary to be able to generate other data structures which are commonly used in handling digital map data.

Traditionally cartographic features can be classified as zones, networks, points and text. Data structures for handling each of these categories are well known (Baxter, 1976) and are shown for the first three of these data types by Figure 1. In order to generate the zone and network models for raster imagery it is necessary to identify a topologically correct set of links and nodes. Given these data it is possible using algorithms devised by the author to generate the zone and path definitions shown in Figure 1 automatically.

Point feature data requires far more straightforward data structures for effective computational manipulation (Figure 1) but still gives rise to problems. In particular, individual features require identification which, in the context of remotely sensed imagey,

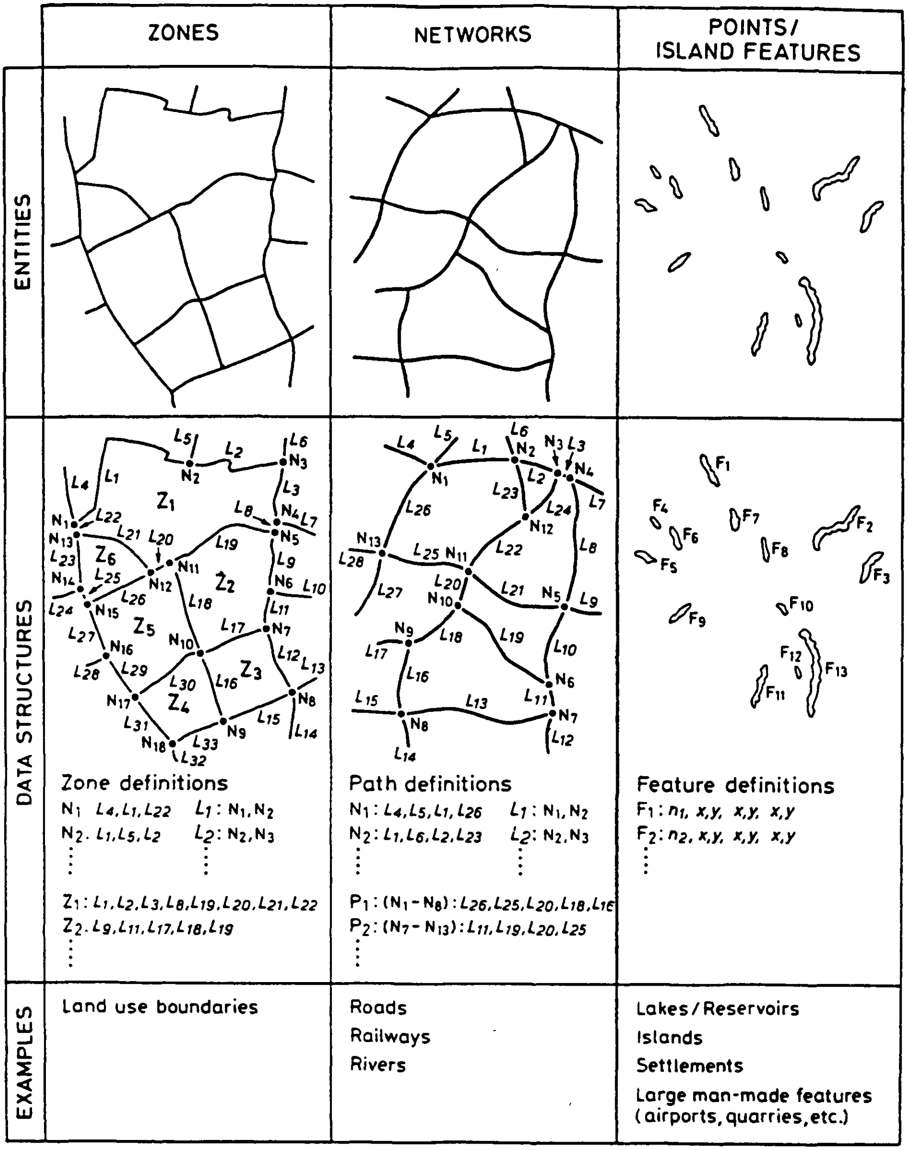

Figure 1: Basic data structures for cartographic information.

presents major problems of classification if fully automated methods are to be used. Furthermore, even simple differentation of point feature boundaries from zone and network boundaries is not straightforward in most types of cartographic image.

ARTIFICIAL INTELLIGENCE TECHNIQUES AND MAPPING FROM RASTER IMAGES

The difficulties in generating vector data structures from remotely sensed raster images which have been discussed so far are compounded by one overriding factor which arises from within the mapping process itself. Landscape features in an image are rarely translated direct to a finished cartographic product. Invariably they are examined visually by the cartographer and translated into some form of cartographic symbolism. Very frequently this translation involves extensive and highly subjective data interpretation and generalisation. As a consequence it is impossible in most circumstances to extract a map directly from a remotely sensed image because the image does not contain all of the information required to define the map.

It is this subjectivity in cartographic representation of real world information that complicates R/V conversion for cartographic applications. What is actually required is a procedure which identifies relevant vectors from the original image. These must then be examined in such a way that cartographic features relevant to the particular mapping application can be indentified and subsequently symbolised for map production. The processing of features in this way places the problems of R/V conversion fairly and squarely in the field of machine artificial intelligence. Similar types of problem are relatively commonplace in the fields of robotics.

These points are borne out by examination of Figures 2a and 2b. The Red, Green and Blue bands of a thematic mapper image covering the North Norfolk Coast of the UK are presented. Edges have been extracted for each band using the gradient operater proposed by Kelly (1971);

$$1\ \mathrm{GRAD}\ (I_{ji})1 = (I_{i+1,j+1} - I_{ij})^2 + (I_{i+1,j} - I_{i,j+1})^2 \qquad (1)$$

The resulting image for each band has been thresholded, the logical .OR. of the three data sets computed to give an edge map and the edge map has been superimposed on the original image.

Visual inspection of the result shows that even using this extremely crude method of constructing edges a large amount of cartographic information is readily available including field boundaries, coastlines, built up areas and many water features. Unfortunately going from the surprisingly successful edge line images to the data structures described above is fraught with problems to which straightforward solutions have yet to be found. The close up of a small village (figure 2b) underlines the generalisation problem in

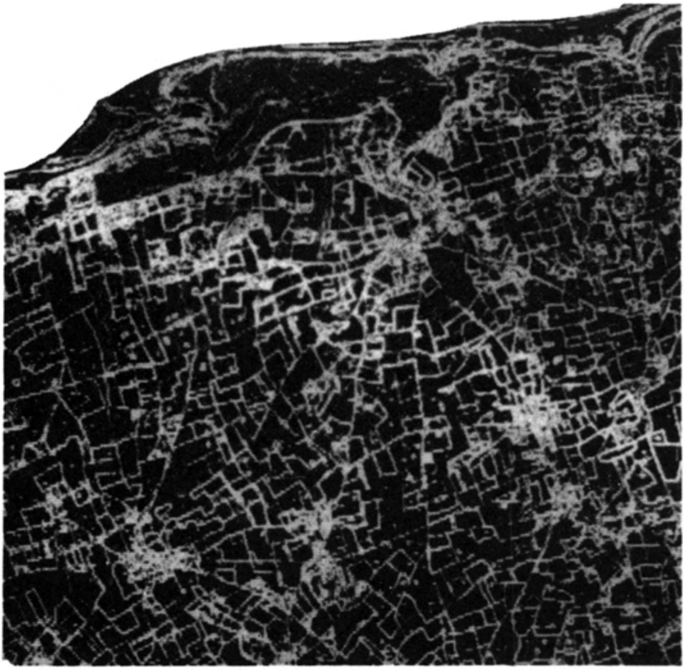

Figure 2a: TM data for North Norfolk Coast with overlayed edges

Figure 2b: Detail from above showing need for generalisation in urban areas

particular with an obvious requirement for some form of generalization required to denote the urban area.

The edge detector used here and other, more sensitive methods (Peli and Malah, 1982; Berzins, 1984; Suk and Hong, 1984) generate lines which appear visually correct but suffer from errors of placement, continuity and line width. Detection and correction of these problems is not straightforward. Pavlidis (1982) presents algorithms for line thinning but these are dependent on effective thresholding procedures for the original line generation and considerable latitude for error arises here despite recent improvements in thresholding techniques (White and Rohrer, 1983).

Despite the difficulties use of these edge data sets in conjunction with the original image data almost certainly provides a basis for vectorisation of the imagery. Early experimentation suggests that it is possible to characterise most significant cartographic features in images of this type on the basis of spectral signature, texture, shape/topology and edge characteristics/neighbour relations. Figure 3 shows that this last characteristic of image features may be a particularly useful addition to the spectral data commonly used in multi-spectral image classification (see Dutra et al, 1984) The diagram shows that variation in edge profiles between different feature types (row to row) is invariably greater than variation within line feature types (column to column).

The approach invovles constructing a database of feature 'templates' which can be used as a basis for searching the image itself and identifying features of each class. Relevant search methods are discussed by Kaufmann (1984), Matsuyama et al (1984) and You et al (1984). Having identified an individual feature it is extracted from the image and vectorized locally using the template as a model.

One major advantage of the template approach is that features are coded automatically in the vectorization procedure and the vectorised cartographic data can be output in a layered form.

CONCLUSIONS

A number of basic cartographic requirements have been considered for an effective R/V conversion procedure. Early experimentation with a number of techniques drawn from the AI literature suggests that an effective R/V conversion procedure for cartographic applications may result from image searches using feature templates derived from the original image data. Despite this major problems remain to be solved. In particular, a method of handling the necessary cartographic generalisation required for effective mapping must be developed and efficient computational methods must be developed to enable the procedure to become operational with reasonable execution times.

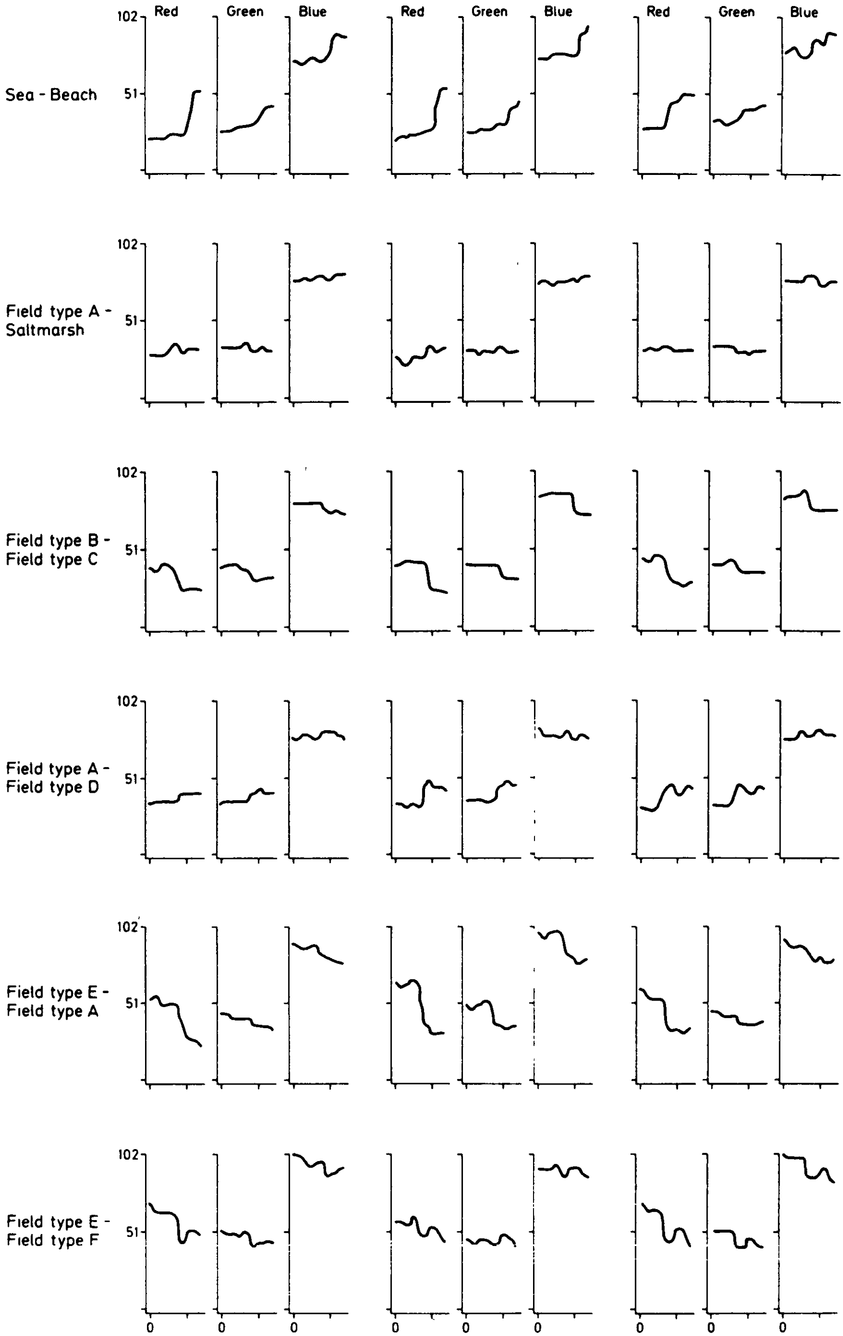

Figure 3: Across edge profiles for different feature types.

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