

# KNOWLEDGE BASED IMAGE CLASSIFICATION IN A GIS

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### ABSTRACT

A geographic information system (GIS) equipped with both vector and raster data processing capabilities sets the stage for incorporating a-priori knowledge, in the form of segmentation by polygons and as lexical data, into the analysis of remotely sensed data. This paper discusses the design and implementation of this system and illustrates the analysis process on an example.

**KEY WORDS:** Knowledge base, Image analysis, Image classification, Segmentation, A-priori knowledge, GIS, Image statistics, Integrated System.

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### INTRODUCTION

Airborne and especially spaceborne imaging sensors collect a vast volume of data on the state of the earth's environment and its resources. These data are processed and analyzed in digital image analysis systems where the digital number of each pixel is examined individually and then assigned to a theme or class based on its compliance with values found in training samples of a particular class. This is the well known supervised classification. The decision is essentially made on the bases of the spectral response value represented by the digital number of a pixel. This per-pixel spectral classification is rather simple to implement in computers. It yields acceptable results when the classes in question have a unique spectral response pattern and the training areas are truly representative samples.

This technique is, however, very simplistic compared to the art of visual image interpretation. It is analogous to the case of covering a photograph with a blind, and then attempting to sort the thematic information by observing the grey levels or colours through a small slit which is sequentially scanned over the image. Human interpreters consider not only tone and colour, but also properties like texture, shape, size, pattern, site and association. An IF-THEN deductive reasoning process leads to the final answers. Numerous attempts have been made to incorporate some of the above elements into the digital image classification process, but only texture could be dealt with successfully. Even in this case, a so-called "texture image" is derived and used as a data layer in a per-pixel classification. Perhaps the heart of the problem is that all other elements express spatial relationships which cannot be modelled in a per-pixel observation.

Another shortcoming of current digital image classification procedures is that the image data is usually analyzed in isolation from other pertinent information. The data sets are, of course, often multi-layered, incorporating multi-spectral, multi-temporal and multi-level acquisitions. Non-image data such as topography, geophysics, geology may also be utilized as additional raster layers. Information such as property and land use boundaries, infrastructure, prior inventories and statistics are rarely utilized. As yet, such information could serve as a knowledge base on which to build subsequent analyses. Such information is, however, stored as cartographic and attribute data in geographic information systems (GIS), and the vector and alpha-numeric representation used is not compatible with the

raster organization of digital images. Therefore, a necessary prerequisite to knowledge based image analysis is to store and manipulate image, cartographic and attribute data in a single system.

### 2. THE HYBRID GIS

Researchers at the Department of Surveying Engineering, University of New Brunswick (UNB), among others, have realized the need for data integration and developed CARIS/RIX, a Raster Image Extension (RIX) to the Computer Aided Resource Information System (CARIS) [Derenyi and Pollock, 1990; Derenyi, 1991].

CARIS is a comprehensive GIS, developed and marketed by Universal Systems, Ltd. (USL) in Fredericton, N.B., Canada [Masry, 1982; USL, 1991]. It runs under both the UNIX and VMS operating systems and supports a wide range of input and output devices. The user interface is based on X-windows and MOTIF standards. Originally CARIS was built as a vector based system and was recently equipped with the capability of raster representation of geographic features and extended to accommodate the processing and analysis of digital images.

CARIS/RIX provides the means for digital map to image and image to map geometric correction and registration. It incorporates numerous image processing functions such as various contrast enhancement routines, arithmetic operations, thresholding, spatial filtering, principal component transformation and image processing in the frequency domain. Geographically registered images can be displayed as a backdrop to digital cartographic data. On-screen digitization in the raster image backdrop and interactive cartographic editing is possible. Provision is made for polygon based image statistics generation, which is a key element in knowledge based image classification and will be elaborated on in the next chapter.

### 3. KNOWLEDGE BASED IMAGE ANALYSIS

#### 3.1 The Concept

Knowledge based image analysis is viewed by the authors as the incorporation of non-spectral information into the process. On an elementary level, the inclusion of non-image raster data layers in the per-pixel classification could be

interpreted as a knowledge based technique. In a stricter sense, however, information pertaining to the spatial and temporal characteristics, inter-connections and relationships of classes constitutes a real knowledge base. Such information allows the introduction of a-priori constraints and expectations and deductive reasoning into the analysis.

Information which resides in a GIS can be incorporated either before classification for stratification, during classification for classification modification or after classification for post-classification editing. In stratification, cartographic data can be used to divide the scene into segments based on known administrative, property and land use boundaries, so that these sub-areas may be processed separately [Hutchison, 1982]. Polygon based spectral signature generation as samples for the classification is also possible. Classifier modification involves assigning a priori probabilities to the classifier, based on GIS stored information [Strahler, 1980]. Another approach is to perform per-polygon instead of per-pixel classification and use "IF-THEN" rule tables to reach a final decision based on a priori expectations and on the inputs from programs which model changes as a function of time. During postclassification sorting, GIS stored knowledge can help to resolve omissions and commissions [Hutchison, 1982].

### 3.2 Raster Image Statistics Generation

CARIS/RIX has the capability of obtaining raster image statistics for existing polygons, supported by the vector polygon to raster object conversion software developed previously by Reedijk, [1990]. This software interactively creates raster representation of one or more map objects. The map objects may be explicit nodes, lines, or polygons. A region of a specified radius referenced to the map object may be included in the raster object (i.e., this is a region specified by an "inclusion radius.") The map objects may be selected by pointing or windowing on the screen, or through a database query that refers to their lexical attributes. Map objects may also be defined by drawing a polygon with the cursor in the raster image backdrop. Boolean operations can be performed on raster objects. For example, a polygon and its perimeter can be separately rasterized, and then the latter subtracted from the former to obtain a rasterized representation of the interior of the polygon that excludes a margin around its edge. Raster objects can be saved on disk in an object-based representation that is analogous to that used for vector-based data storage in CARIS.

The fundamental problem of polygon to raster conversion is to determine which pixels lie within the bounds of the vector polygons. A simple but computationally expensive solution would involve the testing of each pixel to see if it lies within the polygon. A better approach is to use a polygon scan conversion technique.

An extensively used algorithm to solve this problem is described by Foley and Van Dam [1984]. This method was slightly modified to resolve certain ambiguities. The basic algorithm is as follows: At each edge of the polygon, the points where it intersects the centres or each scan line are determined. This list of intersections is then sorted, first in y, then in x direction. Each pair of intersection points in this sorted list corresponds to the end points of a swath of pixels within the polygon. Several ambiguities in the Foley and Van Dam approach were resolved in the final implementation. This ultimately led to a solution where every pixel was assigned to one and only one polygon.

Once the raster objects are defined and the image layers selected, the analyst can obtain the following image statistics for the corresponding map (vector) object:

- mean vector and standard deviation,
- variance-covariance matrix,
- lower and upper value limits in each data layer, and

- the number of pixels in each map object or groups of map objects. The statistics can be generated for single map objects or for a group of objects belonging to the same class. All image statistics are stored in the database as attributes of the map object. The frequency histogram of each layer can also be displayed.

The training statistics support the minimum distance to means, parallelepiped, and Gaussian maximum likelihood classification decision rules. A trial classification and a full classification option are available.

The trial classification option operates only on the raster objects selected as sites for the training statistics generation. The output is a confusion matrix and a theme assignment for each class, as well as for the unclassified and multiclassified pixels. The full classification option operates on the entire data file stored on disk. It creates theme files and pixel counts for each theme as the output.

Image statistics generation within pre-defined or user defined polygons has distinct advantages over the customary training statistics generation performed in image analysis systems. The statistics obtained can be stored as an attribute of individual polygons. It can aid qualitative decision making and can facilitate change detection without performing the classification of multitemporal data sets. Polygons can be located by codes, whereby potential difficulties and errors in the identification of training areas are eliminated. Operating within a GIS provides the means for developing per-polygon and contextual classification schemes and for including textual attributes in the analysis. Pre-classification segmentation and masking can be based on administrative or property boundaries and land use information residing in the map file. The combined vector-raster approach also facilitates the utilization of image data in corridor analysis.

### 3.3 Example

The knowledge based image analysis scheme is illustrated by a simple agricultural crop classification project. The Department of Agriculture and various marketing boards need annual forecasts on the yield of crop production and also wish to monitor changes in agricultural land use. Spaceborne images, such as LANDSAT-TM or SPOT data, are an excellent source of information for this purpose. A typical procedure for the execution of this project, in a stand allows image analysis, is as follows:

Near the time of the satellite's overpass, several fields are selected for each crop to be inventoried to serve as training fields during the analysis. The selection is made by site visits to assure total reliability. These fields are marked on maps or aerial photographs. After the satellite data has been acquired, these fields are visually identified in the image display on the screen of the analysis system and manually delineated with the cursor and stored in a training area file. The image statistics of each crop is then generated and used as an input to a per-pixel supervised classifier. Post classification edit is then performed to remove "stray" pixels and fill small unclassified gaps within the fields. Finally the total area covered by each crop in the region is determined by pixel count. It is also common to improve the area estimate by regression analysis. Permanent visual records may be produced in a suitable dot matrix plotter.

The knowledge based analysis approach to the same project would be implemented as follows: It is presupposed that a digital map base is available covering the region of interest. Administrative, property and farm filed boundaries are acquired in digital form and added to the digital map file in the GIS. An identification code is assigned to each field in the polygon attribute file. Training samples are collected by site visits in the usual manner but are stored by field identification codes in the data base. A list of crops

commonly grown in the region are compiled. Farmers are interviewed to learn about their crop rotation and planting practices and about their habits to subdivide fields from one season to the other. The area of each field is computed using the coordinates of the boundaries.

At the start of the image analysis, the map and the image are geometrically registered. The agricultural region is separated from other land use by segmentation with the help of the digital map base. Other stratification can also be performed based on information stored in the GIS. The location of the training fields is recalled from the database and the spectral response statistics of each crop is generated. A per-field (polygon) classification is performed. Spectral response statistics are generated field-by-field and are compared, through an "IF-THEN" rule table, with the statistics of the training samples. This table contains the expected occurrence of a crop in a particular field as function of geographic location, ownership, soil type, topography, crop rotation system, etc. If a match is found with a crop on the list within a preset tolerance then the appropriate crop code is assigned to this field in the database. In fields, which exhibit bi-modal or multi-modal spectral distribution an edge detection routine is invoked to determine the new crop boundaries.

In this approach, crop area estimates are based on the pre-computed areas of individual farm fields which is superior to the pixel count used in the previous method. Besides an aggregated figure for the whole agricultural region, area statistics can easily be generated for any geographic unit. Crop rotation information and land use change statistics can also be obtained through the database analysis module, if crop inventory from previous years is available.

#### 4. CONCLUSIONS

The example presented in the previous section clearly illustrates the superiority of the knowledge based analysis approach to the conventional per-pixel classification. Although the formal requires more elaborate preparation, more accurate results are expected which can be stored directly in a GIS. Further analysis may be undertaken to generate information which is unobtainable or difficult to obtain from the conventional hard copy outputs. For reoccurring projects, the initial investment in setting up the digital database and knowledge base is well justified.

The kind of knowledge based image analysis which was illustrated by the example is, however, only possible if image, cartographic and attribute data are merged within the same GIS and all the necessary tools are provided for their integrated processing and analysis. Research and development efforts at U.N.B. have brought this goal to realization.

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