DESIGN AND IMPLEMENTATION OF A GIS BASED DIGITAL IMAGE PROCESSING SYSTEM

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ABSTRACT

An increasing demand for digital images as an input to geographic information systems (GIS) creates a need for a data processing environment which incorporates the main functionality of stand-allown image processing systems while maintaining the full capabilities of a GIS. This paper presents the design and implementation of the Computer Aided Resource Information System Raster Image Extension (CARIS/RIX) which is such an environment. The main purpose of CARIS/RIX is to facilitate the extraction of information from digital images while displayed in registration with digital maps. Certain image processing and analysis functions have been developed which are specific to this new environment and a number of conventional image processing operations have been included. A user server interface facilitates future extensions of this facility.

KEY WORDS: Hybrid GIS, Data integration, Image processing, Image display, Integrated System, CARIS.

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1. INTRODUCTION

There is a rapidly increasing demand among users of geographic information systems (GISs) for the use of digital images as a source of data. This demand can best be served by a fully integrated GIS and image processing system (IPS). Accordingly, in the early part of 1989, researchers at the Department of Surveying Engineering, University of New Brunswick (UNB) began to develop a series of image analysis software modules that could access the spatial and attribute information stored in a GIS. The project resulted in a series of software packages which support the commonly used image processing and analysis functions and operate on a raster data structure which is compatible with the existing data structure of the GIS. The result is CARIS/RIX the Computer Aided Resource Information System (CARIS) Raster Image Extension (RIX).

2. CARIS SOFTWARE OVERVIEW

CARIS is a comprehensive, vector based, GIS developed and marketed by Universal Systems Ltd. (USL) in Fredericton, N.B., Canada [Masry, 1982]. It runs under both the UNIX and VMS operating systems and supports a variety of input and output devices. The user interface is based on X-windows and MOTIF standards. It consists of three comprehensive software packages as illustrated in Figure 1 [USL, 1991]. Each package contains a set of software modules which perform specific functions.

The **Cartographic Processing Package** is the entry level package. It supports the collection and editing of cartographic data and the creation of high quality cartographic output products. Central to this package is the Primary Graphics software module, which comprises an interactive graphics editor, CARED, and supports commands to capture, modify, maintain, and display cartographic data.

The **Topology Creation Package** provides the creation and maintenance of topology and attribute information, which may be attached to the graphical data. It also supports the formation and maintenance of polygon and network topology.

The **Database Analysis Package** is the top level package, which serves proximity analyses, database inquiries, and report generation from a CARIS database consisting of graphic and attribute files. CARMAN, the CARis MANager, is used for querying the graphic database and spawning queries to the attribute database. Links between graphics and attributes are established by an alphanumeric key.

In addition, the Specialized Support Application Package serves a number of optional operations. A development library is also provided.

3. IMAGE DATA ORGANIZATION

3.1 The Raster Data Structure

During run-time, the pertinent raster data is stored in a system of tilemaps [Reedijk, 1990]. A tilemap is an array based representation of a 512 by 512 pixel portion of the raster extent. By dividing the raster into several manageable pieces, an efficient processing mechanism is achieved without demanding a great deal of storage space. In fact, this scheme allows the interactive processing of the raster data in random access memory (RAM). For a permanent representation of raster data, a storage format is used.

The maintenance and handling of the tilemaps is the responsibility of the tilemap manager. Many tilemaps may reside in memory during run-time and the tilemap manager swaps the tilemaps as required. Associated with each tilemap is its geographic position within the raster extent, the size of the pixels in ground units, and the number of bits assigned per pixel. These values constitute the so-called raster definition file.

A raster image is viewed as consisting of one or more layers with each layer consisting of one or more regions as shown in Figure 2 [Derenyi and Pollock, 1990a; 1990b]. In a region, all pixels must be rectangular and must correspond to the same raster definition. This means that they are arranged according to a uniform rectangular grid, they have the same ground unit dimensions, and their values are stored using a uniform number of bits. The extent of the region and the ground location of each of its pixels is defined to an acceptable accuracy, or can be derived from information stored in association with the region.

An example of a **region** is a single channel of a full Landsat Thematic Mapper (TM) scene. Each pixel covers a nominal 30 metre by 30 metre area on the ground and is stored in 8

bits per pixel. The region is rectangular with an extent of approximately 6100 by 5300 pixels per scene. If the scene has been geometrically corrected and geocoded, the map coordinates of each pixel can be determined by its position in the raster.

An example of a **layer** is a collection of several regions, where each region belongs to the same channel of a different TM scene, and where each TM scene covers a different area of the ground. In effect, this layer would be a single-channel mosaic of TM scenes. An example of an **image** is a collection of such layers, where each layer belongs to a different TM channel.

The image described above could be extended to include an additional layer consisting of, for example, regions derived from SPOT panchromatic data. Note that the raster definitions of the SPOT-derived regions would not be the same as those of the TM-derived regions (the SPOT-derived regions would have 10 metre by 10 metre pixels and their grids might not correspond to a regular subdivision of any of the TM-derived region grids).

The layer of SPOT-derived regions might be extended to include regions consisting of digitized panchromatic aerial photographs where each pixel has a ground dimension of say 1 metre by 1 metre. Regions that belong to the same layer do not have to conform to the same raster definition any more than do regions that belong to different layers. Thus a layer might be composed of data from a variety of sources in order to assemble the most complete ground coverage possible for an area of interest.

Regions may belong to more than one layer of the same image or even to layers belonging to different images. In any case, only one copy of a region is physically stored. Thus, images and layers are constructs that allow different relationships between regions to be defined.

The descriptive data for regions and layers are stored in tabular form in ASCII files, and the actual image pixel values are stored in separate binary files as unstructured stings of bytes. The region table includes all data needed to impart a structure to the stored image pixel values, as well as the parameters of each regions' raster definition. This implementation allows all of the descriptive data to be read and modified using a text editor.

3.2 Image Display Function

In the current implementation, the raster image display function resides in the Cartographic Processing Package. Either a monochromatic or a colour composite display can be created by specifying a single or three image layers. An image layer specified may conceptually be composed of one or many regions, each of which is a physically separate collection of data. The display system is programmed to unify separate regions into a single layer when the display is created.

For any given map display on a window-based display system, the drawing surface (or canvas) represents a certain geographic extent, depending on the scale at which the data is drawn on the screen and the geographic location that the data represents. Furthermore, each pixel in the canvas represents a certain geographic area and location. Thus, the canvas may be thought of as having a raster definition for which the pixel size, raster dimension, and location parameters are set by the display scale and location. When displaying raster-imagery as a backdrop to a digital map, CARIS obtains the canvas raster definition parameters as set by the map display and automatically resamples (by nearest neighbour) the image-region data to that raster definition when transferring the data from disk to RAM (Figure 3). Because of this resampling, the dimensions of the canvas

only influence the spatial resolution of the raster image display, and not the extent of an image-region that can be displayed at any one time. Also, for each image-region in the display, only the part that intersects the geographic extent of the display is read from disk. When reading a layer that is composed of multiple overlapping regions from disk, CARIS selects one region to be visible in the overlap area. The image display is controlled by the following commands: select layer(s), raster image draw, raster image on, raster image off and dim intensity.

4. CARIS RASTER IMAGE EXTENSION

Digital image processing and analysis operations were incorporated at three locations in the CARIS software as shown in Figure 3 [Derenyi, 1991].

4.1 Primary Graphics Raster Image Extension

This enhancement to the Primary Graphics module CARED allows the display of geographically registered images as a backdrop to digital cartographic data. Digitization in the raster image backdrop and interactive cartographic editing can be performed. The full pre-existing functionality of CARED is preserved, so that operators who are already familiar with the system, do not have to relearn any aspects of its operation to use the extension.

A number of real-time image enhancement routines were also implemented in CARED to facilitate the interpretability of images. These include contrast enhancement by histogram equalization, piecewise linear stretch, neighbourhood averaging, bi-directional gradient, and by user specified histogram. Pseudo-colour enhancement and transformation from red/green/blue to intensity/hue/saturation colour space are also available.

4.2 Database Analysis Raster Image Extension

This extension is attached to CARMAN. It facilitates the use of geographically registered image data as a source of information in interactive spatial analysis. Current implementation includes the generation of polygon based image statistics, supervised image classification, statistical evaluation of classification results and colour coded display of the classes. The image statistics provided are the mean vector, the variance covariance matrix, and the lower and upper limits of radiance values in each data layer. The statistics are generated for predefined areas represented by zones. A zone is a raster object generated in CARMAN or defined by boundaries stored in a polygon file.

4.3 CARIS Raster Image System (CRIS)

The operations described in the previous two subsections are executed in RAM, while a digital map and image appear in registration on the monitor. They are intended for applications which require visual interaction by the operator. Many image processing operations are, however, performed on images alone without using any companion cartographic data and without the need for interactive viewing. These are preprocessing tasks which prepare large data sets for the subsequent cartographic mapping and database analyses. Therefore, these operations can conveniently be executed on disk in batch mode and the results transferred to CARED or CARMAN for interactive manipulation. The new software module CRIS serves this need.

Currently available raster image processing functions are: various contrast enhancement routines, including direct histogram specification; spatial filtering, including a number of post-processing options; arithmetic operations performed on any number of layers in the raster image file; application of a user-defined threshold to the raster image; principal component transformation and image processing in the

frequency domain through the application of Fourier transforms. The supervised classification routine can also be run in batch model.

The rectification and orthoimage program is developed for the geometric correction and registration of raster images. Ground control points can be selected in a raster image and a digital map which are simultaneously displayed in separate windows. The evaluation of the selected points based on statistical testing is possible. The affine, polynomial, projective and spline transformations are provided for the geometric registration. Resampling can be performed by the nearest neighbour algorithm or by the bilinear and bicubic interpolations. Analytical photogrammetric operation, based on the collinearity equation, are available to deal with digitized frame camera photographs. Digital orthoimages and mosaics can also be generated if a digital elevation model (DEM) is at hand.

The Vector Orientation program is used to transform an existing map file from the ground coordinate system into a specified image coordinate system and to perform the inverse transformation. It can be performed in either two- or three-dimensional space. Correction can be applied for relief displacement if a DEM exists.

Vector transformation has significant advantages where a map and an image must be in registration for the purpose of analysis and information extraction but a permanent georeferenced image is not required. The map file is temporarily registered to the image and then the new information which has been derived and vectorized is transferred back to the correct coordinate system. This approach avoids the need for the computationally demanding resampling and eliminates the risk of introducing undesirable effects on the radiometric characteristics of the image data, which may occur during resampling.

5. FUTURE DEVLEOPMENTS

An integrated GIS/IPS prototype facility is now in place, which provides interested users with a wide variety of digital image manipulation functions. There are, however, certain bottlenecks which make the operation of the system somewhat awkward. For example, the raster image display and interactive image processing functions are rigidly embedded in the Primary Graphics module and it is difficult to utilize it elsewhere. On the other hand, the interface of CRIS with the three main line CARIS packages is too loose and not user friendly.

Future plans call for the development of a CARIS Shell which will be responsible for acquiring commands from the user and passing them on to the relevant task. The existing CARIS data structure which is needed by almost all tasks will be placed in a Shell. All raster image extension (RIX) operations will be bundled into a stand alone task and placed into the Shell so that it can be invoked by either CARED or CARMEN.

The CRIS batch operations will be handled through the new CRIS Server which will facilitate the off-line transfer of image data to and from the mainstream CARIS and the various image processing programs. This arrangement will encourage the expansion of the program library through third party software development without having to be concerned with the CARIS data structure. The new configuration is shown in Figure 5.

6. CONCLUSIONS

CARIS/RIX provides GIS users with a tool for the exploitation of digital images as a data source. It supports on-line image analysis and information extraction in a merged raster-image/vector-graphics display and

incorporates all the commonly used off-line image processing functions. This hybrid environment created for integrated processing of spatial information is, no doubt, a valuable asset in change detection map revision and resource mapping. The stage is also set for the development of a knowledge-based image analysis strategy by taking advantage of the information stored in the GIS.

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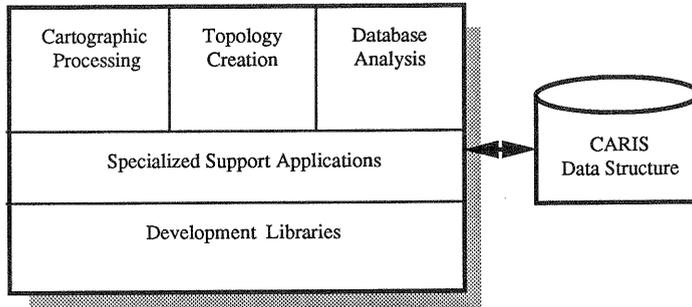USL (1991). *CARIS Products Description*. Universal Systems Ltd., Fredericton, N.B., Canada, May.
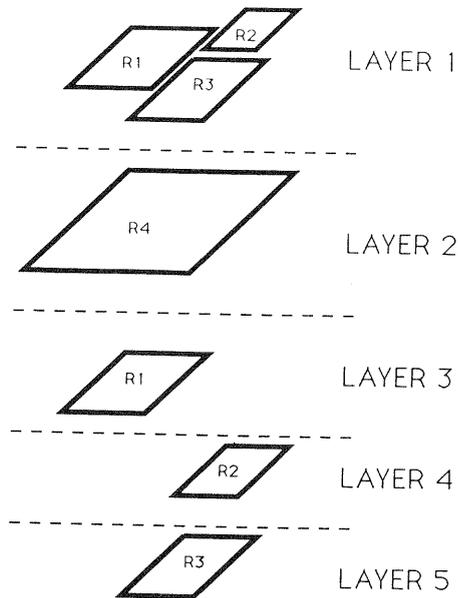
Cartographic Processing	Topology Creation	Database Analysis
Specialized Support Applications		
Development Libraries		

CARIS
Data Structure

Figure 1. CARIS Software Overview

R2
R1
R3
LAYER 1

R4
LAYER 2

R1
LAYER 3

R2
LAYER 4

R3
LAYER 5

FIG. 2. A schematic example of a raster image in CARIS composed of four regions (R1-R4) and five layers.
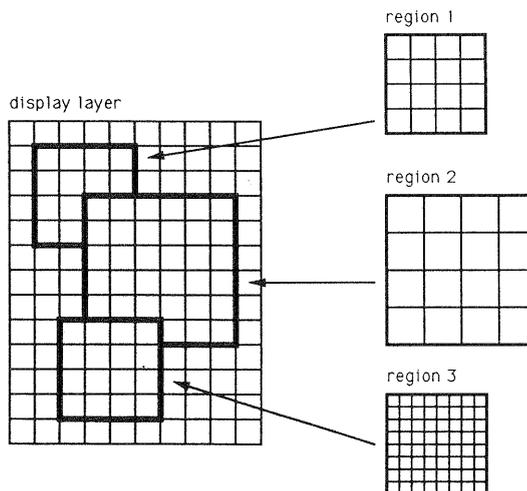
region 1

display layer

region 2

region 3

FIG. 3. Regions comprising a single layer are dynamically resampled to a uniform raster definition when displayed.

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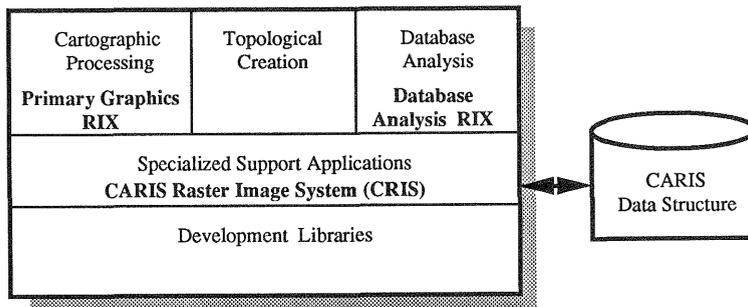| Cartographic Processing	Topological Creation	Database Analysis
Primary Graphics RIX		**Database Analysis RIX**
Specialized Support Applications **CARIS Raster Image System (CRIS)**		
Development Libraries		

CARIS Data Structure

Figure 4. CARIS Raster Image Extension

Cartographic Processing	Topological Creation	Database Analysis
Primary Graphics RIX		**Database Analysis RIX**
Specialized Support Applications **CARIS Raster Image System (CRIS)**		
Development Libraries		

CARIS Data Structure

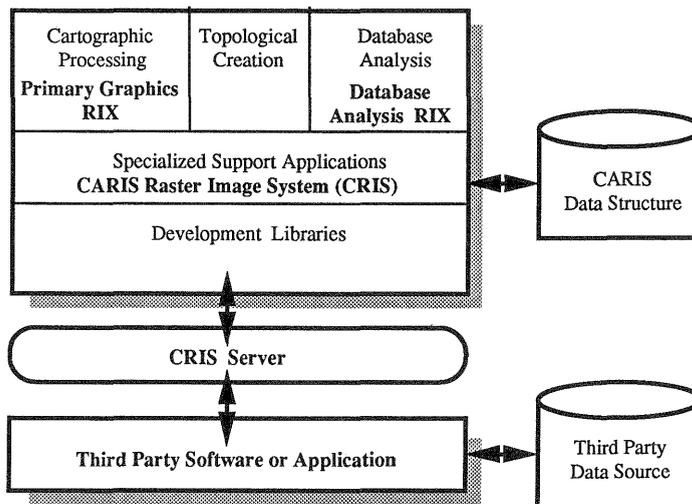**CRIS Server**

Third Party Software or Application

Third Party Data Source

Figure 5. New CARIS/RIX Configuration