

IDRISI : A COLLECTIVE GEOGRAPHIC ANALYSIS SYSTEM PROJECT

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ABSTRACT

IDRISI is a grid-based geographic analysis system, developed at Clark University, that is designed to provide the focus for a collective program of system development and exchange. The core consists of a set of independent program modules that act upon a simple and easily accessible data structure. Individual researchers can thus add new modules in any computer language so long as this simple data structure is maintained. In order to provide the greatest possible flexibility, both real and integer data types are supported, along with ASCII, binary, and run-length encoded data files. Similarly, continuous images such as remotely sensed data and digital elevation models are handled as readily as categorical map coverages. The core program set, written in PASCAL, provides a series of fundamental utilities for the entry, storage, management, display and analysis of raster images. In addition, a ring program set has been established to provide a group of analytical tools commonly associated with grid-based geographic information systems. Currently available in inexpensive development versions for CP/M, MS-DOS and VAX-VMS systems, it is hoped in the near future to establish an on-line bulletin board through which users can exchange experiences and new program modules.

INTRODUCTION

Over the past two decades geographic information systems technology has developed rapidly. However, access to that technology has not been as forthcoming. Software costs have tended to be high, hardware needs specialized, and individual program development difficult. In addition, problems requiring small-scale analysis are often overwhelmed by large-scale systems, and research-oriented projects commonly require analytical capabilities well beyond those of a "standard" configuration (eg. Olsson, 1985). In an attempt to address these problems, a geographic analysis system named IDRISI has been developed at Clark University over the past year. Presently available in development versions for VAX-VMS, MS/PC-DOS, and CP/M-80/86 operating systems, the system supports a wide range of readily available micro-computer systems.

DEVELOPMENT PHILOSOPHY

IDRISI can perhaps best be characterized as a research analysis system rather than a large-scale inventory tool. Consisting of a set of completely independent program modules, IDRISI was never designed to become a single comprehensive program. Rather, it was intended to establish an

environment for the creation and development of individual project-related modules by independent researchers on the basis of its simple and easily accessible data structure and core program set. By establishing a network whereby users can share experiences and program development, it is hoped that the system can then grow in organic response to the needs of the user community.

Given these general objectives, the development of IDRISI has been based on four primary principles :

1. the system should be available at low cost, using readily accessible technology;
2. data integrity should be maintained at all times;
3. data accessibility and system flexibility should have precedence in program design; and
4. the system should naturally accommodate the display and analysis of continuous images as readily as categorical map types.

The effects of these principles can be seen in all aspects of the system, ranging from data structure, to program logic, to image display.

DATA STRUCTURE

Perhaps the most fundamental consideration in the design of the system was data structure. IDRISI is a grid-based geographic analysis system, and thus processes information about image cells in a map-like matrix. However, unlike some systems which require that these data be stored as two-byte integers, IDRISI accommodates both integer and real data types. Furthermore, there is no limit to the size of the grid employed, and grid dimensions can be changed at any time by either windowing or concatenating new sections. Each coverage is stored as a separate file, with a single-field record for each cell. Both ASCII and binary storage structures are supported for these files, along with the ability to transform from one to the other when needed. In addition, run-length data compaction is supported as a storage structure for categorical (integer) coverages.

Given that the data files are not structured according to the particular characteristics of any project, each data file has an accompanying documentation file (automatically created) that records information about the data type as well as other features such as the number of rows and columns, title, legend (if any), ground resolution, and the like. In all operations, IDRISI programs use this information, along with normal mixed-arithmetic rules, for determining the data type and geographic structure of the result.

The primary motivating factors behind the choice of data structure were data integrity and data accessibility. There are many geographical operations that require the precision and range of real numbers. Given that the system was envisioned as a small-scale analysis system rather than a large-scale inventory tool, the extra storage requirements were

felt to be negligible compared to the enhanced flexibility and essential integrity that real numbers would afford.

In order to give maximum flexibility to the import, export and modification of data, it was felt imperative that the user have direct access to data files at all times. It was further considered that many users who might wish to create their own modules would be most comfortable programming with ASCII format files. It is for these reasons that the default data format supported is ASCII. While not the most efficient format, it combines the desirable qualities of simplicity and accessibility.

The ASCII format works quite well when the number of digits per cell are few (such as with LANDSAT imagery and most categorical maps). However, when real numbers are extensively used, serious storage problems can result. Version 1 of IDRISI simply allowed the conversion of ASCII to binary as a storage compaction technique. However, Version 2 (in progress as of Nov. 1986) incorporates binary as a fully supported data format. As with the data type, data format is recorded in the accompanying documentation file, and all operations in Version 2 preserve the prevailing data format. Thus, users can work consistently in one format or the other, without ever having to switch. However, the CONVERT facility will always allow a change from one to the other.

PROGRAM STRUCTURE

In keeping with the notion that IDRISI should be a program that grows organically in response to user needs, the decision was made that it should consist of a series of independent program modules rather than a single unified program. The effect of this is that new programs can be added that are entirely independent of other programs in the IDRISI set. Furthermore, the language in which these programs are written is irrelevant to system operation. New programs need only adhere to the simple structure of the data files. Furthermore, for programming simplicity, documentation files can be ignored. A module exists to create these files as a separate operation when needed. Individual users can thus add new capabilities in the programming language of their choice, without reference to other module operations or the housekeeping functions normally required for efficient operation.

In order to gain the widest possible circulation among currently available microcomputers, it was decided to create the core program modules in Turbo PASCAL. For larger-scale applications, a VAX PASCAL version has been written concurrently with the micro versions. However, some differences exist between these language implementations. Therefore, to facilitate this development, a series of generic routines (for the most part input/output) were written to give some commonality between the two versions of PASCAL. Each module thus has access to an internal subroutine library which executes version-specific commands. The program code in the modules themselves appears identical from version to version.

The experience with Turbo PASCAL has been excellent. The interactive nature of the editor and rapid compilation have greatly speeded program development. The resulting code has also been found to be compact and efficient. Although there are some shortcomings with respect to the size of data and code segments it can handle, this has not proved to be an issue in this project. We have therefore adopted Turbo PASCAL as the primary language for system development.

PROGRAM CAPABILITIES

IDRISI program modules fall into one of three groups:

1. core modules, providing fundamental utilities for the entry, storage, management, display and analysis of raster images;
2. ring modules, providing extensions commonly associated with a major analytical mode (such as GIS or Image Processing); and
3. peripheral modules associated with specific research projects.

IDRISI's core program modules (Table 1) provide the primary foundation upon which individual research modules can be built. As can be seen in Table 1, there is a strong emphasis upon data management, retrieval and display in this set, with the original design objectives playing a strong role in determining the particular mix of capabilities offered. For example, the data accessibility and system flexibility objective can be seen as a major influence in the design of the data management modules, while the desire to be able to analyze and display continuous images played a strong role in configuring the retrieval and display modules. Additionally, the core set includes some basic facilities for analysis that were considered to be fundamental to all related applications. These are the RECLASS, SCALAR and OVERLAY operations.

Initially, it was intended only to develop those modules envisioned for the core set. However, the decision to apply IDRISI to an ongoing GIS project for the Clark University Program for International Development, quickly precipitated the formulation and writing of a GIS ring (Table 2). The GIS ring includes analytical operations which are, for the most part, typical of grid-based geographic information systems. The capabilities chosen for the core and GIS ring, and their particular characteristics, evolved from a careful consideration of both theoretical classifications of GIS capabilities (eg. Berry, 1984; Dangermond, 1983; Dangermond and Freedman, 1984; Olsson, 1985; Tomlinson, 1976), and practical experience with the ODYSSEY (Morehouse and Broekhuysen, 1982), UDMS (HABITAT, 1985), and Map Analysis Package (Tomlin, 1980) systems. The Map Analysis Package was particularly influential in establishing this set, as can be seen in the group of image-wise operations such as DISTANCE, PATH, VIEWSHED and WATRSBED. Olsson's (1985) innovative study of desertification in the Sahel was also a strong influence, providing the impetus for including the INTERPOL and HINTRLND modules.

Although the IDRISI system was primarily envisioned as a geographic information system, the need to include facilities for treating continuous data, along with a desire to provide fundamental capabilities for incorporating remotely sensed data, naturally led to a consideration of image processing operations. Although the Image Processing ring has not yet been comprehensively addressed, a number of modules have been created in conjunction with projects using remotely sensed images (Table 3). In addition, it should be noted that the core program set allows a wide range of image processing operations to be undertaken. Indeed, on the understanding that a common conceptual and procedural basis links all raster operations, all IDRISI operations are considered to act on images.

Perhaps the most basic facility that reflects this character is the IMAGE program which accommodates the display of continuous images. In order to provide an inexpensive system with reasonably high resolution, a half-tone technique was created using groups of adjacent pins on readily-available dot-matrix printers (Figure 1). The drivers vary from one printer to the next, but typically involve a 6 by 3 group of pins (overlapping by 50% in the x direction) to produce a square pixel of about a millimeter in width. An 8.5 by 11 inch page can thus usually accommodate a 256 by 192 image window. The 6 by 3 pin configuration easily accommodates 32 grey levels -- a resolution quite adequate for many purposes. In order to prepare images for display, the program module HISTO produces image histograms while STRETCH can be used to undertake a linear contrast stretch and output a new image with a range from 0 to 31. For very small image windows, the program module EXPAND can be used to enlarge the display window.

Among the core analytical operations, OVERLAY also reflects this image processing character. The OVERLAY module was designed to encompass all operations that produce a new image from more than one original. These include the ability to add, subtract, multiply, divide, minimize, maximize, cover and exponentiate on a pixel-wise basis, with boolean operations being achieved with binary images. Since the divide operation accommodates the ratio operation commonly used in many natural resources applications of remotely sensed images, a "normalized ratio" was also included. Here, the difference between two images is divided by their sum -- an operation commonly used in the derivation of vegetation indices using the red and near-infrared bands of multi-spectral imagery.

The FILTER operation was originally included as a neighborhood characterization process, similar to the SCAN operator in the Map Analysis Package GIS. However, given this evolving image processing character, the facility was extended to allow the convolution of any user-defined 3 x 3 filter over the input image. In addition, options include pre-defined mean, median, mode, edge-enhancement, low-pass and high-pass filters.

As can be seen from these examples, the IDRISI system is intended as a general purpose raster processing system. As

mentioned, no work has been specifically directed towards the development of an Image Processing ring. However, rudimentary image analysis can be achieved with the core set. For example, a parallelepiped supervised classification can be achieved by using the STRETCH, IMAGE and WINDOW operations to first view the image and extract training areas. The HISTO module can then be used to examine spectral response patterns (the SCATTER module has since been added to aid this process), with the RECLASS module being used to extract the class range within each band as a binary image. The multiply option of the OVERLAY module can then be used to combine the results from each band, and thereby derive the final classification.

PROCESSING LOGIC

Given the fact that the system is designed to run on a variety of microcomputers of varying capability, all IDRISI modules use as little random-access memory as possible. This is not simply a concession to current microcomputer technology (which is changing rapidly). It is implicit in the design philosophy that the size of image that can be handled should be constrained as little as possible by memory availability. Therefore it was considered that memory is better employed on processing-buffers than image storage.

IDRISI operations fall into one of three categories: pixel-wise, region-wise or image-wise. Pixel-wise operations, such as those involved with almost all of the core modules, require storage for only one data value at a time. Region-wise operations such as the convolution operator in FILTER, or the neighborhood functions in SURFACE and AUTOCORR temporarily store a moving group of scanlines at a time. Memory requirements are thus kept to a small multiple of the number of image columns. At present, the microcomputer versions of these modules are restricted to images of 2000 columns or less, but an unlimited number of rows. This could be increased considerably with a large-memory model version of PASCAL (anticipated with the next release of Turbo PASCAL). However, images of such a magnitude would clearly approach the manageable limits of most current microcomputer systems. For wider images, either the image can be TRANSPOSED or the WINDOW module can be used to extract sub-images for processing.

A more challenging group of operations are those that require random access to the entire image. These include the image-wise operations of DISTANCE, PATH, VIEWSHED, WATRSBED and HINTRLND. An obvious alternative to core-resident random-access memory is the use of either floppy or hard disk-based random access files. Since disk space is a relatively cheap commodity, this is clearly a viable alternative for microcomputer-based systems. However, the mechanical operations required by this process can significantly reduce processing speed. Algorithms therefore have to be chosen with care. The DISTANCE module, for example, which calculates the proximity of each pixel to the nearest of a set of target cells, uses an "advancing-front" technique to alleviate this problem. In two passes, one through the sequential

data file, and a second backwards through a random-access intermediate file created during the initial pass, the program computes the distance from every cell to the nearest non-zero cell in the target image. The process is very much like moving a directional processing "squeegee" down, and then back up the image. The random-access disk file is thus used only once --to move back up the image.

As a result of these considerations, IDRISI is clearly disk-intensive. However, by increasing the size of the buffers associated with text (ASCII) files, and using high-speed block transfers to processing arrays for binary files, efficient operation can still be achieved.

PRESENT STATUS and FUTURE DEVELOPMENT

At present, IDRISI is available in development versions for most CP/M, MS/PC-DOS, and VAX-VMS systems. It is intended that the pricing of the system should always reflect no more than the costs of maintenance and distribution. Furthermore, it is our hope that the system will provide a focus for independent and collective program development. To this end, we plan to establish an on-line bulletin-board system through which users can exchange software and experiences. Through this medium, users will be able to access news about the system, immediate software updates, and advice on system use from both fellow users and system developers. Those that develop their own modules can upload them in order that they may be shared by the user community. User uploads will then be reviewed and, if necessary, modified for inclusion in the standard IDRISI set.

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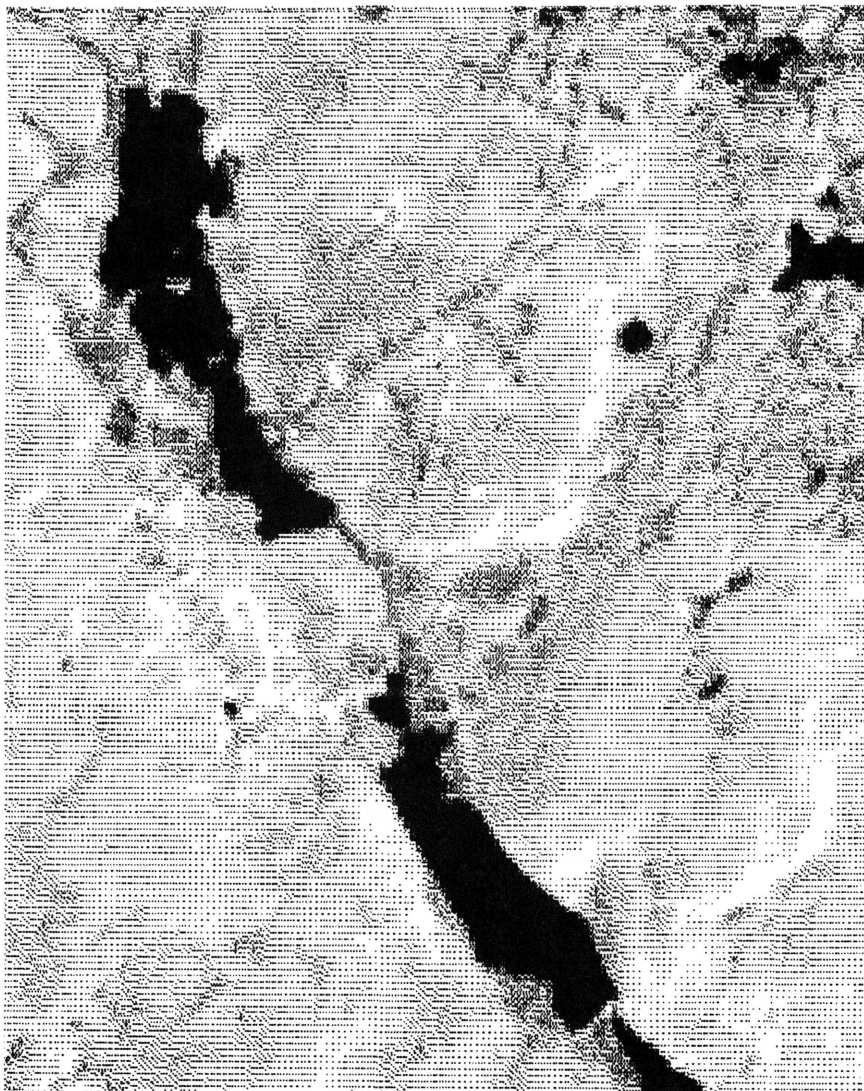


Figure 1 : An example of output from the IMAGE program module. The scene is a portion of a Thematic Mapper Band 4 (infrared) image, near Worcester Massachusetts.

TABLE 1 : IDRISI PROGRAM MODULES IN THE CORE SET

A. Data Entry Modules

INITIAL	Initializes a new image with a constant value.
UPDATE	Keyboard entry / update of image data.
POINTRAS	Point-to-Raster conversion.
LINERAS	Line-to-Raster conversion.
POLYRAS	Polygon-to-Raster conversion
INTERPOL	Interpolates a surface from point data using either a weighted distance or potential surface model.

B. Data Storage Modules

CONVERT	Converts data files from ASCII to binary or vice versa.
PACK	Converts integer data to run-length encoded storage format.
UNPACK	Converts run-length encoded data to sequential format

C. Data Management Modules

DOCUMENT	Creates a documentation file for a new imported image file, or revises the document file of an existing image file.
CONCAT	Concatenates two images to produce a larger image.
TRANSPOS	Transposes the rows and columns of an image.
WINDOW	Extracts a rectangular subimage.
QUERY	Extracts pixels designated by an independent mask into a sequential file for subsequent statistical analysis.
EXPAND	Enlargens an image by pixel duplication.
CONTRACT	Reduces an image by pixel aggregation or thinning.

D. Data Retrieval and Display Modules

IMAGE	Produces a grey-scale image (up to 32 levels) using a half-tone procedure on dot-matrix printers.
DISPLAY	A "universal" display routine using ASCII characters. Large images can be displayed as a series of sub-images. Legends are produced using the image documentation file, and area statistics are given for each category.
VIEW	Allows direct examination of any portion of an image. Output precision is user-specified.
HISTO	Produces histograms of image file values. In addition to the graphic output, a numeric output includes proportional and cumulative frequencies along with simple statistics.
STRETCH	Produces a linear contrast stretch in preparation for image display using the IMAGE module.

E. Analytical Modules

OVERLAY	Undertakes pixel-wise addition, subtraction, multiplication, division, and exponentiation of paired images. Maximum, minimum, "normalized ratio" (eg. vegetation index), and "cover" (logical OR) are also supported. Other boolean operations such as logical AND, XOR, EQV, NOT and IMP are supported through various binary image overlay combinations.
SCALAR	Adds, subtracts, multiplies, divides, and exponentiates pixels by a constant value.
RECLASS	Reclassifies pixels by equal intervals or user-defined schemes.

TABLE 2 : IDRISI PROGRAM MODULES IN THE GIS RING SET

SURFACE	Produces slope gradient and aspect images from a surface.
AREA	Creates a new image by giving each output pixel the value of the area of the class to which the input pixel belonged.
PERIMETR	Creates a new image by giving each output pixel the value of the perimeter of the class to which the input pixel belonged.
GROUP	Classifies pixels according to contiguous groups.
DISTANCE	Calculates the distance (proximity) of each pixel to the nearest of a set of target pixels. Distances can be weighted by an auxillary friction (eg. cost) surface.
PATH	Finds the shortest path between two points, with the origin specified on a target image, and the destination specified as the lowest point on a surface image (eg. cost).
VIEWSHED	Creates an image of all points visible from a target over a given surface.
WATRSHED	Creates an image of all points uphill of a target.
HINTRLND	Determines the supply area dominated by point demand centers.
AUTOCORR	Computes Moran's "I" autocorrelation statistic for an image.

TABLE 3 : IDRISI PROGRAM MODULES IN THE IMAGE PROCESSING RING SET *

*	This set has not yet been comprehensively planned. Modules listed only include those existing as of November, 1986.
FILTER	Convolve an image with a digital filter. Mean, median, mode, edge-enhancement, low-pass, high-pass and user-defined filters are accommodated.
SCATTER	Produces a two-band scatter plot.
RADIANCE	Converts LANDSAT MSS and Thematic Mapper DN values to spectral radiances.