Integration of Remote Sensing in a Raster and Vector GIS Environment

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ABSTRACT

This article describes the way in which remote sensing and raster ad vector GIS modules are integrated in the Intergraph Modular GIS Environment (MGE) how they are used in complex 'real world' GIS workflows. To achieve the heavy duty interdisciplinary workflows that are common in GIS it is crucial to tune hardware and software and to tune software modules mutually. Because Intergraph designs it own hardware and software and the disciplines under the GIS umbrella cover the widest possible range, this tuning is achieved.

The article describes the special tools that permit efficient image processing, raster GIS operations and dynamic vector GIS operations. Examples of such tools the features of the Image Station 6187: the Tile Manager, the VI- 50 Image Computer and Edge II gaphic processor boards for image pocessing. Other examples are the GOAL overlay language for raster GIS operations and the dynamic aspects of the object-oriented Dynamic Analyst module.

Two examples serve to illustrate the integration of remote sensing in dynamic vector GIS and in raster GIS:

- A forest damage assessment based on existing WDB II vector-based infrastructural information and land use information from remotely sensed origin.

- The first phase of a multitemporal agro-ecological suitability assessment study on Africa using FAO ARTEMIS NDVI maps.

The rationale for remote sensing in a raster and vector GIS

A GIS database usually consists of a vector or topological database with more or less alpha-numeric linked to it. Such a structure is quite inflexible, once it has been designed and input at the expense of major efforts in manpower and quality control. A GIS generally serves as a tool for (adequate) planning and management of resources. Therefore it is vital to keep it up to date continuously.

The most common data source available for continuous updating is raster data. Such data is supplied by imaging satellites at working scales of 1:15,000, 1:50,000, 1:100,000, 1:250,000, 1:10,000,000, etc. and in time cycles varying from once per 26 days worldwide, to once per half hour worldwide. In the very large scales, aerial photogrpahs have become an accepted source of digital data.

For environemntal and land resources management, raster-satellite data is often the only source of information. In the Intergraph GIS concept as well embedded image processing module was therefore considered a vital part of an up-to-date system concept.

The Intergraph tuning of hardware and programming techniques permits the efficient processing of the massive flows of data that occur in the transformation of raster data to GIS information. Raster, topological and non-topological data structures can be used for manual interactive heads-up digitizing and automated information extraction, whatever method is most appropriate in a certain situation.

INTRODUCTION

The best method to illustrate the integration of remote sensing in the Intergraph GIS Environment is to dicuss a number of typical workflows. In this article we will describe the system environment, the core features of the remote sensing raster and vector GIS modules to permit efficient workflows and a number of typical workflows:

1) A physical planning exercise (forest damage assessment) using existing vector-based infrastructural data

and new environmental information from remote sensing sources.

2) Multitemporal agro-ecological suitability assessment using the FAO/UNESCO soil map, the FAO Agroecological Zone methodology and ARTEMIS-NDVI (Normalized Difference Vegetation Index) maps and CCM (cumulates cloud) maps from Africa.

1. THE SYSTEM ENVIRONMENT

All work described below is carried out an Intergraph 6240 workstations. The software used is modules from MGE (Modular GIS Environment) (Integraph 1990). Of the over 25 products available under the MGE umbrella, the following are used in the workflows described:

- MGE/SX:	The platform product
- MicroStation:	Intergraph's graphics CAD base product
- RIS:	(Relational Interface System) to interface between MGE and Relational databases
- Informix:	A relational database.
- ISI2:	Image Station Imager for Image processing
- MGGA:	(MGE grid Analyst) for Raster GIS operations
- MGE Dynamo:	MGE's Dynamic Topological Analysis Module.
- MGPM:	The Projection manager module
- DB Access:	General graphics and database interface

The Intergraph (system) environment is perhaps best charactierized by the degree of tuning that has been achieved between the hardware and the software and between the modules themselves.

1.1 Hardware/software tuning

As intergraph designs and produces its own processors, hardware and software, an ideal, tuning can be achieved. General-purpose software that runs on general-purpose hardware has the advantage that the cost of hardware can be kept low. This is, provided a customer wants to use products from many different software developers. This advantage is, however, paid for in terms of overall system efficiency.

In general-purpose software and hardware configurations, large numbers of checks need to be performed that bear no relation with the actual (GIS) job, while on the other hand, specific advantages of the hardware and software can often not be fully exploited.

In the Intergraph environment, all factors can be kept under control to achieve the maximum overall systems efficiency. Problems that cannot be solved hardware wise, can often be overcome with a smart software design, while limitations of software design can often be overcome hardware wise.

The savings of efficient tuning can represent gains in time and storage requirements of hundreds of percents.

1.2 Tuning between different modules

It is well known that specialists working in the different disciplines in GIS (eg. photogrammetrists, cartographers, remote sensors, etc), tend to live in their own world, speak different languages and use different data formats. A choice of excellent discipline oriented systems is available for point solutions eg. for remote sensing, survey, map output etc. Unfortunately, most users follow a workflow that crosses the "territory" of a number of different disciplines. With the disadvantages of such an approach we are all familiar: the different point solutions are excellent for what they are meant to do, but during seemingly trivial steps a workflow gets hopefully frustrated or even totally blocked.

One of the advantages of the Intergraph system is, that in its modular form, it covers the widest range of different disciplines in the GIS industry. By having all modules under the same umbrella, a corporate policy can secure mutually transparent transitions in the different workflows.

2. CORE FEATURES OF AN INTEGRATED REMOTE SENSING AND RASTER/VECTOR GIS

Below we will deal with a number of the special features in the Intergraph GIS, that permit efficient image processing, raster and vector GIS workflows and smooth transition between them. Due to the space limitations, only a number of the most important tools can be dealt with here.

2.1 Special Remote Sensing Tools

Two of the key items in image processing are the management of memory and disk space with increasingly larger datasets. The Intergraph solution for **memory management** for bulky remote sensing jobs, is the **Tile manager**. In ISI2 (the image processing product) an image is organized in tiles of 128x128 pixels. The tile manager works virtually transparent for the operator. It tracks and organizes the use of the available memory according to the actions of the operator. If an image is greater than the memory available, the priorities indicated by the previous use of the image, guide the Tile-manager in decisions on the tiles to be kept in memory and those to be stored in a temporary file on disk. If the problems rise above its capacities, it intelligently gives up and asks the operator to take appropriate action.

The Tile-manager is designed to prevent the use of, for image processing extremely inefficient, UNIX swap space. Apart from the fact that the Tile Manager is 4-5 times faster than Unix swapping, the /usr/tmp is space than can be allocated or freed on a day by day basis, while the UNIX swap space allocation is a fixed part of the disk configuration, that needs to be appropriate for (seldom) used peak requirements.

The main virtue of the Tile Manager is, that it permits to work with almost indefinite file sizes. E.g. a Landsat Thematic Mapper image of 3x36 megabytes, can be elaborated in its full extent interactively, with 32 megabyte internal memory.

The more memory available, the faster the process, but it will always work.

2.2 Raster/Vector integration

A standard tool that even comes with a stand alone-image processing module is the Intergraph CAD package MicroStation. The more than thousand 2D+3D MicroStation vector manipulation tools, are thus available also in image processing workflows. The Intergraph Projection Manager module is an other standard tool. Users can work in an unprecedent accurate mapping environment of 64 bit precision (1 cm resolution for the total earth surface). With these vector based tools raster imagery can be registered with standard errors of less than 1/10th of a pixel.

2.3 Registration

One of the most time and disk space consuming tasks are registration and resampling. In Intergraph, raster to map registrations often do not need any resampling at all. Any first order operations can be carried out instantaneously and without resampling, thanks to the special structure of the header of each file.

3D manipulation

Draping imagery and orthophoto production are two functions where the disciplines of image processing, photogrammetry and terrain modelling meet and merge.

2.4 The Image Station 6187

Let me finish this introduction of special remote sensing tools with the latest development: the Image Station 6187.

In the Image Station 6187 (Intergraph, 1991; Hassani 1991) a great deal of development efforts have culminated. The following features are put to their maximum effectiveness:

1) The Tile Manager
2) The Edge II graphics processor board
3) The VI-50 300 MOPS (Million Operations Per Second) Image Computer (based on technology from VITec)
4) A stereo display using a special pair of liquid crystal glasses from Crystal Eyes.

With this functionality, the ImageStation 6187 has become the most powerful image processing and the first digital photogrammetric workstation in the GIS industry. Let me illustrate the work power with one (out of many possible) examples:

To achieve the accuracy required in photogrammetry, a standard aerial photograph needs to be scanned at least at a resolution of 7,5 micron. This produces datasets of about one gigabyte for a standard 24 x 24 cm aerial photograph. To work in stereo, at least two or three photos need to be available. The Tile manager makes it possible to manage such volumes of data from disk to memory and to freely roam through 2-3 gigabyte volumes with 32 - 256 megabyte of internal memory available. This I/O work is assisted by the double screen buffer (2x12 bit) which is one of the possible Edge II configurations and the VI50 processing power. The image computer in addition resamples the image 'on the fly' such that it looses its 'pixel' appearance.
Furthermore the Edge II display permits the interlaced display of two independent bands at 120 Hz. A special radiographic device connected to a pair of liquid crystal glasses that shutter at 120 cycles per second -odd and even- for the two eyes. This results in a most amazingly sharp 3D stereo image.
Finally a 3D cursor bar and a space ball complete the tools

to create 3D maps with photogrammetric accuracy by means of heads-up digitizing.

The development on the Image Station 6187 has only just started. One of the future options of the Image Station is the calculation of 3D models directly from the parallax differences in stereo image sets.

Special tools for efficient Raster GIS operations
The Intergraph raster GIS module MGGA (MGE Grid Analyst) acts as an integrator between almost all disciplines/modules of a GIS. It accepts and/or converts 8, 16 and 32 bit format terrain modelling and remote sensing data, raster maps and ascii and vector data. In raster form many operations that are diffcult to perform in a vector structure are surprisingly easy such as shortest path calculations, watershed related calculations, neighbourhood operations, conditional zoning, linear regressions, spread operations and overlay operations with 'if-then-else' and 'while' loops. (Compton, 1991, Intergraph, 1991b).

As a complement to image processing, it is especially important that MGGA presently permits to vectorize raster maps (such as classification maps) such, that the results are straightforwardly incorporated in the MGE dual database graphics RDBS structure.

Special tools to permit efficient vector GIS.
Distributes databases
A vector GIS is generally used to store and retrieve large volumes of accurate spatial data with varying density of information, linked to (large) alpha numeric data volumes. One of the first bottlenecks experienced in the operation of many vector GIS's, is that data can reside in different RDBS's and on different hardware platforms. To overcome this, Intergraph developed the RIS (Relational Interface System), which permits a transparent use of various RDBS's on a network.

Dynamic topology and attributes
For spatial analysis, a topological structure is required in vector GIS. One of the major bottlenecks in practical workflows where spatial analysis is used, is that any change in the basic map data generally requires a painstaking regeneration of the topology (that can last for hours or days depending of the size of the database involved).

From the TIGRIS research program the Dynamo (Dynamic Analyst) concept has been developed to overcome this (Herring 1989). Dynamo is a truly object-oriented GIS in which object intelligence permits to maintain topological relationships "dynamically". As object technology is less suitable to maintain large corporate databases, there is a transparent transition of data to and from the MGE dual database in Dynamo. Not only topological relationships are maintained dynamically, also attributes of spatial features can be manipulated dynamically because they can be functions that can call other object-oriented functions. The first workflow discussed below, is one that steps through the Image Processing, raster GIS and object-oriented vector GIS disciplines. Landuse data obtained in the image processing module, will be integrated - with the raster GIS module - into an existing dual database structure and from there moved to the object environment for dynamic analysis to study alternative physical planning models or environemntal alternatives.

After this introduction to the most relevant system features of MGE and to the relationships between image processing raster and vector GIS, let us now look at the real workflows.

3. WORKFLOW ONE: PHYSICAL PLANNING

The first workflow is a typical example of a physical planning exercise in which we use both an existing vector based infrastructural database and we need to obtain up-to-date environmental information from satellite data. The objective of this workflow is to create a topological structure of vector based highways and landuse information on The Netherlands and to perform various dynamic model analyses on forest damage.
Data used is the World Databank II (WDB II) data set on Europe, digitized from maps at a scale of approximately 1:1,000,000 (NTIS, 1990) and brought in Lambert Conic Conformal projection. This data set consists of land/water, national, subnational boundaries and rivers and major roads.

A NOAA AVHRR[1] mosaic of imagery at one km resolution composed of band 1,2,3 of The Netherlands is our source for environmental (landuse) information.
The first step of the workflow is to register a subset of the NOAA image to the vector data. As we register image data to a vector map, we do not need to resample the image but just warp the image to the vector data by writing the coordinates in the transformation matrix of the file header. In the Intergraph environment this is an istantaneous

1 NOAA = National Oceanographical and Atmospheric Administration (of the USA).
AVHRR = Advanced Very High Resolution Radiometer.

operation that requires minimal disk space (as no new file is produced) and minimal time delay for the operator.
The forest information needs to be obtained via a supervised classification. As this is one of the most calculation-intensive operation in image processing, optimization of the efficiency of this operation is important. A computer, however, is fast, but not inherently intelligent. It will devote as much time to classify the North Sea pixels into the 25 landuse classes as it will to the Dutch territory and so it will to the parts of the Belgium, France and Germany that fall outside the area of interest but inside the -square-image.

Masks are a vital tool to both increase the efficiency of any classification operation and to bring human intelligence in the process.
The creation of masks is facilitated by the use of the CAD editing commands of MicroStation on which the Image Processing solution is built. Piece-wise density slicing permits to create a land-water-separation-mask. The "fetching" of the national (vector) boundary permits us to separate out land area belonging and not belonging to The Netherlands. The logical combination of the land/water masks and the 'inside/outside -The Netherlands- mask' produces the mask we need.
The use of the mask speeds up the classification process with a factor of 5, as The Netherlands occupy only 18% of the image. Masks (eg. derived from soil or geological maps) can also be used for classification operations by ecological zone. This permits to spatially separate out zones where classes occur that cannot be spectrally separated.

A classification result is hardly ever ideal. A 90-95% or higher accuracy is rarely achieved. The iteration process of a classification operation is more often ended due to physical exhaustation of the operator or to depletion of the funds, than by reaching the required accuracy aimed at. Near the 80-90 per cent accuracy limit, improvements in one corner of the image tend to go at the expense of accuracy elsewhere.
With a CAD system at hand, it is not nocessary to force the system to achieve the last 15-10 percent of accuracy in automated way. They computer is good in bulk operations. It is often more worthwhile to spend two days in systematic editing of this bulk result, than 1 day of performing fruitless iterations (because the two days of editing will still be necessary afterwards).
The following post classification tools are available:
- Majority filtering, with different thresholds for 'noise' classes to be removed.
- Line preserving edge filtering, which is a majority filter that preservs linear features.
- Conditional filtering of noise per class, during the vectorization operations.
- CAD commands for manual editing of classes by pixel, block or polygon and 'painting'.

Once the post classification options are exhausted, we have the choise to either move the data to our raster GIS or to move the data to our vector GIS. In this example we move to our vector GIS, and more in detail to Dynamo.
There are two ways to move classification results to the vector world:
1 - If we have our World Data Bank data already in topological form, we can vectorize all raster polygons in a bulk operation. The graphics file produced as such can subsequently be bulk loaded in the same object space by using graphics level and colour characteristics as a key. Default and individual attributes can be designed in the data model for each class (eg. name, area, dominant crop/tree species, etc.)
2 - If we have the WDB II data in the dual graphics/RDBS MGE environment, we can download the classification results in the same environemnt, by vectorizing them class in MGGA. The transition from the MGE environment to Dynamo is achieved with one command that uses so-called "list files" (pointer sets of graphics, centroid elements and related database information). A library of list files can in one command be hauled over into the object environemnt. The dictionary (database schema) is automatically generated in this process. In Dynamo this dictionary can, on the fly, be updated. The downloading of simulation and analysis results into the central database (or for reporting) follows the inverse road. From a collection of result sets (the name of pointer sets in the Dynamo environment), the MGE dual database is automatically updated, both graphically and in the alphanumeric database.
Once we have all necessary data in Dynamo in dynamic topological form, we can manipulate them at will. In our case the forest features and major road network in The Netherlands are the most important features. In Dynamo we extensively use result sets and query sets. The first one is a pointer set to a collection of features that can be based on spatial and/or attribute data. A query set is the standard SQL statement that is generated for the operator by the system in a menu driven operation. The operator can stepwise build up his simulations and analyses and check them by highlighting or colour filling the result sets. Once verified, he can concatenate the query sets, to run increasingly complex models.

From results sets and/or query sets, new features can be generated e.g. zones (in forest areas within a certain distance to major roads) by merging neighbouring features or by synthesizing new features bases on modelling results.

All new features are instantaneously integrated topologically, with the existing data. In this way a large number of models can be run immediately under various assumptions of political or economical restrictions and without interruptions.

The final result of the analysis could be a number of maps of forest under potential threat of (e.g.) lead deposition and acidification under various conditions and a report specifying the total area and the names of the forest, the forest types involved and the depreciation of the information (if such information were available in the database). These results can be written to the MGE database and to new tables or in the RDBS.

4. WORKFLOW TWO: AGRO-ECOLOGICAL SUITABILITY ASSESSMENT

The second workflow deals with an agro-ecological suitability assessment on the continent of Africa, using NOAA* AVHRR* NDVI (Normalized Difference vegetation Index) maps produced by NOAA itself (on a weekly basis from the whole world) and monthly NDVI maps of Africa produced by the FAO (Food and Agricultural Organization of the United Nations) ARTEMIS system. ARTEMIS stands for Africa Real Time Environmental Monitoring using Imaging Satellites. It is an operational system to create satellite maps on Africa for drought early warning purposes (Harten, 1991). In this workflow the strength of a combination of remote sensing and raster GIS tools is illustrated.

Where the conditions for vegetation growth are suitable, the conditions for agricultural crops can be assumed suitable also. Vegetation and this vegetation index maps can be considered as in indicator for the length and the spatial distribution of the agricultural growing seasons. The objective of the project/workflow reported here, is to assess the usefulness of NDVI maps to determine the agricultural length of the growing season.

4.1 Background

Before describing the actual workflow, it is quite relevant to discuss the context. The work carried out at Intergraph is building on:
- work that has been going on for at least 10 years by the group of Tucker at NASA's Goddard Space Flight Centre (Tucker, 1983, Townsend, 1984),
- on the vision of the FAO Remote Sensing Centre (Hielkema, 1980) and
- on the work of the ARTEMIS team of NLR (the Dutch National Aerospace Laboratory) (NLR, 1986).

The author, now working with Intergraph, was involved in this work, both at the FAO Remote Sensing Centre and in the NLR ARTEMIS team. The objective of the work of NASA, FAO and NLR was to make the daily worldwide coverage of the 4 km resolution GAC (Global Area Coverage; Kidwell, 1983) data of the NOAA AVHRR sensor available to create year-round, cloudfree maps that permit the assessment of ecological conditions worldwide.

The method was developed by NASA (Tucker et all 1985). The usefulness of this method for global early warning of crop failures was seen by FAO (Harten, 1991) and the Dutch Government supplied the funds, that permitted FAO and NLR to build the ARTEMIS system.
Since 1989, ARTEMIS produces 7.5 km resolution NDVI maps of Africa every 10 days and monthly. It also produces so-called Cumulatitive Cloud Maps (CCM's) on the same region, from 24 hourly Meteosat thermal infrared images per day (Ingen-Schenau et al, 1986). The CCM's supply an independent indication of the rainfall intensity, which is most of the warmer regions of the world determines the ecological cycles (Kassam 1980 in FAO 1980). A system build on data from two operational sensors also ensures continuity, when one of the two would fail.

4.2 Source data

FAO was so kind to supply an 18 month NDVI and CCM data set from September 1989 to December 1990. From a public domain data set a full year cycle of weekly worldwide NOAA ADVI maps became available as well as an FAO Soil map in GRASS format. These data formed the starting point of the investigation to test the combined image processing and MGGA raster GIS tools.

4.3 AEZ Methodology

The methodology used to test the MGGA raster GIS tools is developed by the FAO Agro-Ecological Zones (AEZ) team (FAO, 1978, 1980). The author had the opportunity to work with this team in Mozambique (Kassam at al, 1982; Van der Laan 1982) and at FAO in Rome in 1984-1985. The AEZ methodology is based on the assessment of reductions of the genetically optimal production of major crops under several levels of technology (high, medium and low), climatic zones (tropical lowlands and high lands, temperate, etc) (Shah, 1980 in FAO 1980).
The two main ecological conditions that limit growth are

soil type and the length of the growing season. In the AEZ methodology, te growing season is 'climatologically' defined based on the interaction of rainfall and evapotranspiration, while taking a certain soil buffer capacity into consideration. The method is suitable for long term national and continental wide assessments. This approach particularly suffers from the lack of spatial detail in climatic data. Reliable long term climatic data records are only available from a limited number of meteorological stations, that do not cover all relevant ecological zones (Van der Laan 1986).

4.4 Remote sensing preprocessing

Producing NDVI maps is one of the best examples of the operational creation of information from remote sensing data. The ARTEMIS system is one out of the few totally dedicated remote sensing systems in operation. The degree of data reduction that is performed in the remote sensing part of the workflow is dazzing. The AVHRR sensor basically records 1 km resolution imagery in strips of 3000 km wide. It records Africa in 4-5 orbits daily, in 5 bands of 10 bit data, stored in 16 bit words. This corresponds to an initial data volume (on Africa) or 540 gigabyte per year. For global storage this data is, on board, reduced to 4 km resolution (Kidwell 1983). ARTEMIS finally condenses this to 36 2.6 megabyte 10 daily NDVI maps and 12 monthly NDVI maps per year. Over the whole process this represents a data reduction rate of 17,000 times!

4.5 Objective of study

Monthly NDVI maps generally have a higher degree of cloud freeness than 10 daily maps, but a monthly map, unfortunately is too long to permit effective agro-ecological assessment. A significant crop-yield affecting drought period, can be 'averaged out' in a monthly period.

A single year of NDVI data is not sufficient to test the AEZ method that is based on the use of long term climatic records. On the other hand the creation of NDVI maps in itself or the visual analysis of them cannot be the full motivation of the ARTEMIS project. Digital analysis tools need to become available to properly assess the application potential of this spatially and temporally continuous source of ecological information.
The work described below, must be seen as one of the steps to assess the value of the ARTEMIS data and to develop the methods and tools to put this 'raw' information to more efficient use.

4.6 The actual workflow

The **first step** in the actual workflow performed on the Intergraph system was to bring all information to a common format and projection:

- 36 16 bit ARTEMIS NDVI and Cumulative Cloud maps of Africa in Hammer-Aitof projection at 8 km resolution (1280x1024 grid cells) (Ingen-Schenau, 1986)
- A dataset consisting of world maps in an unknown mercator-like projection in GRASS format with a varying resolution:
- 53 8 and 16 bit weekly NOAA NDVI maps (2500 x 94 grid cells), (Ambrosiack, 1984).
- one bit FAO/UNESCO soil map (30,000 x 15,000 grid cells)
- one 8 bit Vegetation map (360 x 720 grid cells)
- one 8 bit Cultivation Intensity map (4320 x 2160 grid cells)

The thematic maps were transferred to 8 bit and in ARTEMIS and NOAA NDVI map projections.

The **second step** was, taking into consideration the AEZ-suitability rules for soils, to reclassify the 'raw' soil map classes to different suitability maps per crop per level of technology (Sys. 1980 in FAO 1980). These maps will be used in the final agricultural suitability assessment.

The **third step** was to become familiar with the multitemporal behaviour of the NDVI and the cumulated cloud data.
The most obvious approach for this is to link the temporal behaviour of grid cells to the corresponding measurements of meteorological station at the position. A shell script was written that permits, for a single grid cell and a position with a variable radius, to obtain its temporal behaviour in the form of a multitemporal histogram. So far no meteorological data could be made available to test the remote sensing data against. Another approach to familiarize with the multitemporal behaviour of NDVI maps is provided by unsupervised clustering methods.
In image processing, unsupervised methods are used to find groups of image cells that have the same spectral behaviour.
Usually such methods are applied to determine 'natural' land cover clusters type in e.g. single date Landsat imagery. In the Intergraph system, dozens of files (presently over 40) can be analysed together in such procedures. From the two methods available (k-means and iso-data clustering; Tou, 1988) the iso- data method was found to be most suitable to determine the 'natural' ecological zones based on their multitemporal behaviour. A large number of clustering operations was run, with varying

numbers (50-200) and methods (random and operator defined) of input seeds and parameters. It was fascinating to see the correlations and the differences between the 'school-book' ecological zones and the results of this approach.
Some preliminary conclusions from this clustering approach are:

- In the area directly south of the Sahara and north of the Congo, the ecology seems to be predominantly determined by climatic influences. Only rarely variations were found in the ecological zones that do not fit the predominant climatic zones.
- The 'standard' ecological division of desert, sahel, savanna, humid and tropical zones has not been reproduced sofar, in spite of systematic attempts to achieve this. From the Sahara to the tropical zone, generally 7-9 zones with a different multitemporal behaviour were discriminated.
- In East and Southern Africa, the ecological pattern seems highly geologically determined.
- Not only in their relation with climatic and geological patterns, the northern and east/southern parts vegetation development with the cumulated cloud map patterns (rainfall), while in East (Southern Africa this correlation is much less obvious. The reason for this is quite possibly the different nature of the vegetation cover. Whereas in the northern region annual vegetation dominates which immediately responds to moisture supply and depletion, the dominant vegetation in East/Southern Africa is of perennial nature. Perennial vegetation roots much deeper and can thus tap moisture from deeper sources than direct rainfall. Well known to be negative correlated to rainfall is the 'miombo' savanna type (Brachystegia species) that is widely distributed in Eastern Africa and that produces leaves some weeks before the rains start. (Drummond et al. 1977)

Once stable ecological zone patterns have been detected, the common characteristics of their multitemporal behaviour are a good starting point to determine the parameters and a decision tree for agro-ecological suitability assessment.

4.7 The evaluation model

The rules to be used for the agro-ecological suitability assessment are derived from the AEZ methodology (Kassam 1980, in FAO 1980). To determine the parameters and rules to translate NDVI values into suitable length of growing season information, an interative approach has been adopted.

In the first phase of the project the rules to be applied are:

1) The start of the growing season is marked by a significant and permanent increase in the NDVI. What is a significant increase is, depends on the ecological zone.

2) As long as the NDVI values incraease or remain at the same level, the growing season is assumed to continue. Several growing seasons are possible per grid cell per year. Per growing season, three maps will be generated that indicate:

- the starting date
- the length of the season (in weeks, months or 10-daily periods)
- the average value of the NDVI values over the growing season

3) Once the NDVI trend in time significantly decreases, the growing season is assumed to end and the ripening starts

4) The main usefulness of the NDVI maps is to spatially detect interruptions of the growing season, that indicate crop damage. The length of the growing season and the soil characteristics can be evaluated crop by crop, taking into account a map of the crops grown and the dominant level of technology per region. To determine, however, which degree of reduction in the NDVI corresponds to a significant drought condition and which to the predominance of clouds is still a parameter to be determined.
   Weekly NDVI maps, produced by NOAA itself, suffered so severely from this problem, that they were found to be virtually not useful for automated evaluation.
   As the ARTEMIS system also turns out the CCM's, at the same resolution and interval of the NDVI maps, a possible interruption of the growing season, as shown by the NDVI data can be tested against the CCM's. In case of low cloud figures, the growing season can be considered interrupted. In case of high cloud figures, the growing season can be considered to continue until the first higher or equal NDVI value.

5) The positional accuracy of NDVI maps derived from the automatic registration of the daily overpasses for the three to ten months that a growing season lasts, cannot be assumed ideal. Thus the evaluation of a single grid cell data array cannot be used as a reliable input data for modelling. On the other hand, to average out too many grid cells (of 64 square kilometre each) tends to throw too many different ecological zones on

one heap. It was empirically found, that a radiance of one grid cell distance around a mid pixel was the best compromise.

6) If the above rules do not apply, the system will evaluate the situation as 'contradictory' and will mark it for further study.
   In MGGA the tools are available to evaluate complex scenario's as described above. At the moment of writing, no conclusive results are available. We are in the process to adjust parameters and to discover special circumstances that require different treatements.

CONCLUSIONS

In the Intergraph Modular GIS Environment (MGE), image processing is considered an essential function. It is well integrated with vector GIS and raster GIS modules. As Intergraph produces its own hardware and software a number of major advantages in can be achieved in GIS workflows:

- In contrast to system philosophies based on general purposes hardware and software solutions, an ideal tuning can be achieved where all system performance can be dedicated to solving the generally demanding GIS tasks.
- Intergraph, in a modular form, covers the widest ranges of disciplines in the GIS industry. This ensures mutually transparent transitions in GIS workflows that always tend to cross discipline boundaries.

The main tools that ensure efficient image processing, raster GIS and dynamic vector GIS workflows and mutual integration are discussed. For image processing is discussed the Tile manager for memory management, raster/vector integration, and special tools for instant registration and 3D manipulations. In the Image Station 6187, meant for heavy duty image processing and the first operational system for digital photogrammetry, the latest software and hardware developments culminate.

The MGGA raster GIS module acts as an integrator between all GIS modules. Its most powerful feature is a special GIS Analysis and Overlay Language (GOAL).

The Dynamic Analyst module: Dynamo is derived from the TIGRIS research program. In Dynamo both topology is maintained dynamically and attributes can be maintained and manipulated dynamically as well. As an illustration of the integration between image processing and raster and vector GIS two workflows are elaborated: one physical planning workflow where remote sensing information is integrated in the forest damage assessment simulation in Dynamo and one where multitemporal remote sensing informatiom is modelled in the raster GIS environment for agricultural suitability assessments.

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