INTEGRATED GEOGRAPHIC INFORMATION SYSTEMS: FROM DATA INTEGRATION TO INTEGRATED ANALYSIS

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ABSTRACT

Geographic Information Systems (GIS) are more and more seen as an integral part of the modern information and communication society. Improved methods for data access and integration have accelerated this process. Scientific advances have also paved the way for GIS as a catalyst for a new evolving discipline *geoinformatics*. One of the problems in applying geospatial technology has been the currency, accuracy, accessibility and completeness of geoinformation (GI). Remotely sensed image data, especially from satellites, can be used to generate current, accurate and synoptic information about all parts of the earth as a basis for geoscientific analyses in GIS. Consequently, almost all major GIS software packages offer now at least the possibility to display and query digital images as part of their GIS database. With the advent of the new satellites of 1m resolution or even better we will see another push for the integration of remote sensing images into GIS.

However, the current status can still be described primarily as data exchange between a GIS and an image analysis system or an add-on of some image processing functionality to a separate GIS. Images are seen as another GIS layer, integration consists more or less of a georeferencing and overlay process. In this paper, we will address a concept for remote sensing as an integral part of a modern GIS which requires a system independent view of integrated GIS functionality.

1. INTRODUCTION

1.1 Geoinformatics - An Evolving Discipline

The emergence of geoinformatics as a new scientific discipline for the acquisition, storage, analysis and presentation of geospatial information has more or less been accepted by the scientific community. With its interdisciplinary roots, it bridges the gap between basic disciplines such as computer science or mathematics and the application oriented fields such as geosciences, planning or natural resources management. The *tool vs. science* debate that dominated the discussion during the early 90's has effectively been terminated by the factual developments. All elements that make up a scientific discipline exist: textbooks, university programs and degrees, scientific conferences and journals as well as university chairs and academic societies. As a dynamic and evolving discipline that is based on multiple developments it may be called geoinformatics, geomatics or geographical information science depending on its heritage and/or regional distinction.

Depending on its orientation and origin geoinformatics can have a core in geodesy, geography, landscape planning, or information management. This is reflected by its emphasis on the acquisition, modeling and storage of geodata, the analysis of geospatial information, the generation of digital spatial planning products, or the development of effective spatial database management systems and algorithms. The important factor is that geoinformatics must be more than a patchwork of more or less unconnected components. It has to offer an integrated approach to the acquisition, storage, modeling, analysis, and presentation of geo-processes (Ehlers et al., 1999). Within this process, geoinformatics has been integrated into the general information technology (IT) development. Geospatial information is now recognized at all decision levels as an extremely important information layer. A consequence of this importance can be seen in the R&D programs of the European Union (EU) which treat geospatial information as an integral part of the general information infrastructure (Brand, 1995; Burrough et al., 1997; Reginster, 1999).

1.2 GIS and Remote Sensing

The system for handling geospatial information, a GIS, is without any doubt the most important tool within geoinformatics. As such it is often confused with the scientific discipline itself which in return leads to misunderstandings in the *tool vs. science* discussion (see above). The development of designing and improving GIS is, however, a major catalyst for geoinformatics research and progress.

Remote sensing and its associated image analysis software are a major source of geospatial information acquisition and extraction. They are especially important for natural resource management and environmental applications and offer an operational and continuous source for synoptic, accurate, current and quantifiable information about the Earth surface. Remote sensing has emerged from a different origin than GIS. During the last ten years, however, we have seen a strong push towards a better integration or cooperation of remote sensing image processing and GIS technologies (see, for example, Ehlers, 1996; Gahegan and Flack, 1996).

2. INTEGRATION OF GIS AND REMOTE SENSING

2.1 Status of Integrated Systems

The advantages of the integration of GIS and remote sensing have been demonstrated in a large number of application oriented projects (see, for example, Star et al., 1997). However, the merging of remote sensing (and its associated image analysis) and GIS has often resulted in the creation of just another 'dumb' GIS layer with pictorial information. Integration is restricted to a mere georeferencing and image overlay (better: *underlay*). A complete analysis from a remotely sensed image to a geo-object can be performed only by manual interpretation. GIS and remote sensing information is usually processed independently from each other. The ideal goal should be that GIS objects can be extracted from a remote sensing image to update the GIS database. In return, GIS 'intelligence' (e.g. object and analysis models) should be used to automate this object extraction process (see figure 1). Although we have seen a number of advances in this process, we are still far away from total automation even for applications such as natural resource management (see, for example, Förstner and Plümer, 1997).

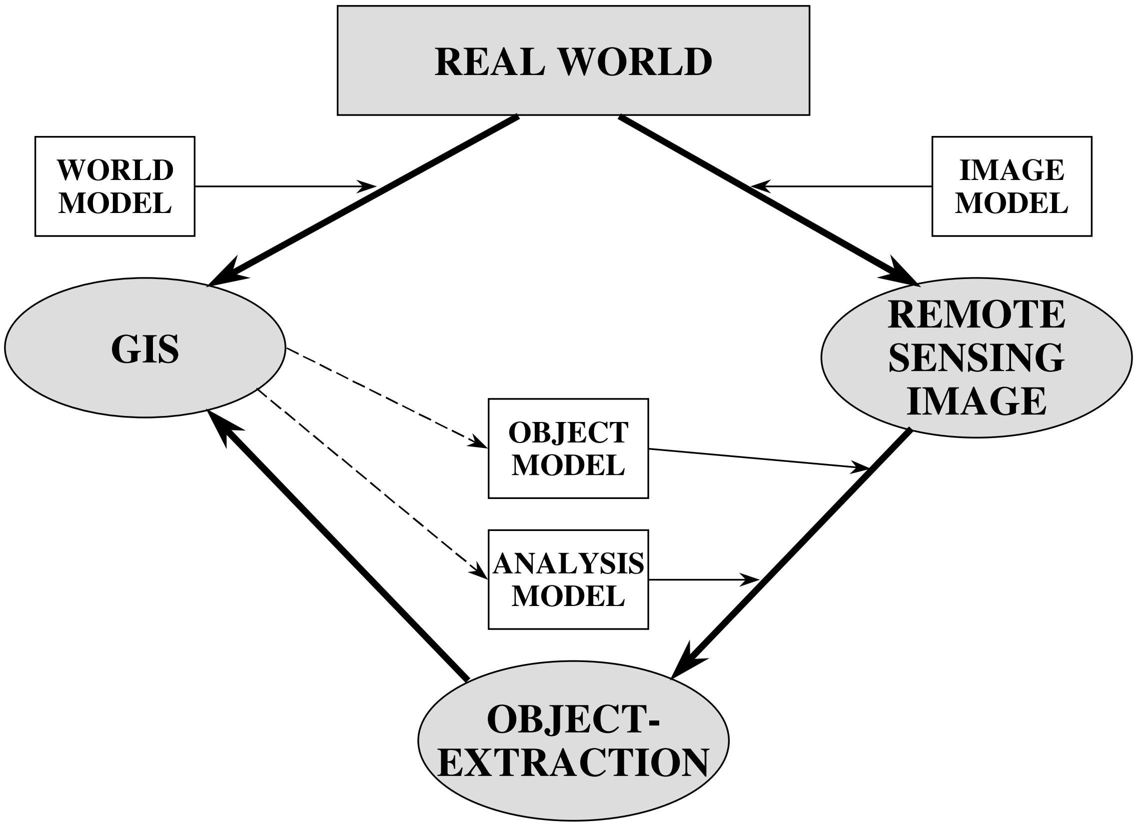

Figure 1. Concept for Automatic Extraction of GIS Objects from Remote Sensing Imagery

Ehlers et al. presented as early as 1989 a concept for a totally integrated system for remote sensing and GIS. They differentiated between three integration levels: (a) two separate systems with a data interface; (b) two principally separate systems with a common user interface; and (c) a totally integrated system (Ehlers et al., 1989).

Most of today's GIS offer hybrid processing; i.e. the analysis of raster and vector data. They also have image display capabilities or image analysis add-ons which offer some *level (b)* functionality (Bill, 1999). However, geospatial information is usually processed in either raster or vector form and has to be converted into the desired processing or output format. A truly integrated processing option (without prior conversion) does not exist. This is also valid for integrated remote sensing/GIS analyses. The requirements for totally integrated systems are usually defined on an *ad hoc* basis which is driven by project demands or the data sources to be incorporated (Ehlers et al., 1994; Johnston et al., 1997). What is needed is an analysis of the necessary processing components of such an integrated system. The *data integration* approach has to be replaced by an *analysis integration* approach. This implies that we need a taxonomy of system independent analysis functions.

2.2 Taxonomy of GIS Operators

If one looks into the functionality of current GIS it is immediately evident that GIS operations are usually based on the underlying system and its associated data structure. A general description of GIS functions could offer a system independent view. They are, however, predominantly concerned with *low level* functions (see, for example, Laurini and Thompson, 1992; Worboys, 1995). A GIS user, on the other hand, wants to perform a spatial analysis or a comparison of two possible locations for a specific development. He is normally faced with a system that offers a huge number of functions which are system and data structure dependent and have to be put together in a specified order to perform the desired analysis. A system independent taxonomy of *high level* GIS operations that are independent of the system and the data structure is still lacking. A notable exception is the Cartographic Modeling (*Map Algebra*) approach of Tomlin (1990). However, it is still restricted to raster based systems.

Tomlin structures his Cartographic Modeling functions into four classes with about 40 subfunctions. These functions are sufficient to perform almost every possible high level GIS analysis. The strength of his approach is the mathematical rigidity which is incorporated in a computer programming type GIS language. Structuring the Map Algebra commands in a procedure allows the composition of very complex GIS analyses. Basic Function Classes of Tomlin's Map Algebra are:

- LocalFunctions (e.g. point operations, overlay, recoding)
- FocalFunctions (e.g. neighborhood operations, buffering, distance calculation)
- ZonalFunctions (e.g. attribute operations, intersections)
- IncrementalFunctions (e.g. nearest neighbor, connectivity, slope, aspect)

Although these functions are system independent and form the basis of many GRID packages in current GIS software they are still data structure dependent, i.e. designed for raster GIS. A step further towards a universal GIS language is the approach of Albrecht (1996). Twenty data structure and system independent high level GIS functions are grouped into 6 classes (figure 2). A graphical user interface based on a flowchart principle allows the user to interact through a *Virtual GIS* (VGIS) case tool with the underlying proprietary GIS (Albrecht and Ehlers, 1994). The user is therefore not concerned with data structures, algorithms or conversion programs. Using a mouse he can create a flow chart for his specific GIS analyses based on the available operators and connectors (figure 3). The result is a flow chart which is composed of a number of GIS and database operations.

2.3 Taxonomy of Image Analysis Operators in Remote Sensing

Digital image processing started in the early 70's and is viewed as a young but established discipline. It was influenced by its one-dimensional counterpart, signal processing, by photography and optics, and by the scientific and technological developments in electrical engineering and computer science. Again, its interdisciplinary heritage is clearly visible in the very different descriptions of image processing functionality which can be seen in standard textbooks such as Pratt (1991) or Sonka et al. (1993).

Even in a well-defined application area like remote sensing, we experience very diverse approaches toward image analysis taxonomies. Table 1 presents the image processing functionalities as described in two standard textbooks for remote sensing (Jensen, 1986; Richards, 1986).

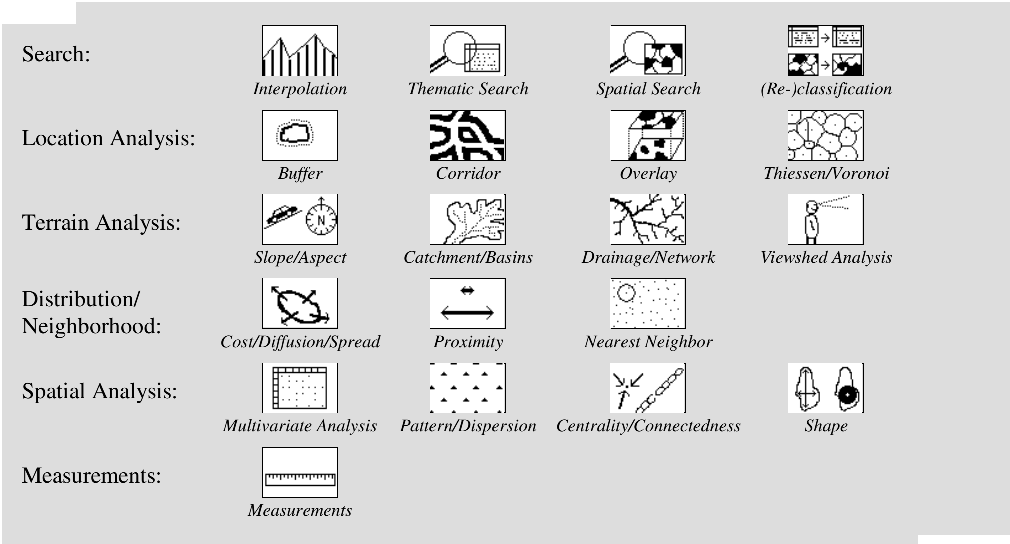

Figure 2. Universal GIS Functions (after Albrecht, 1996)

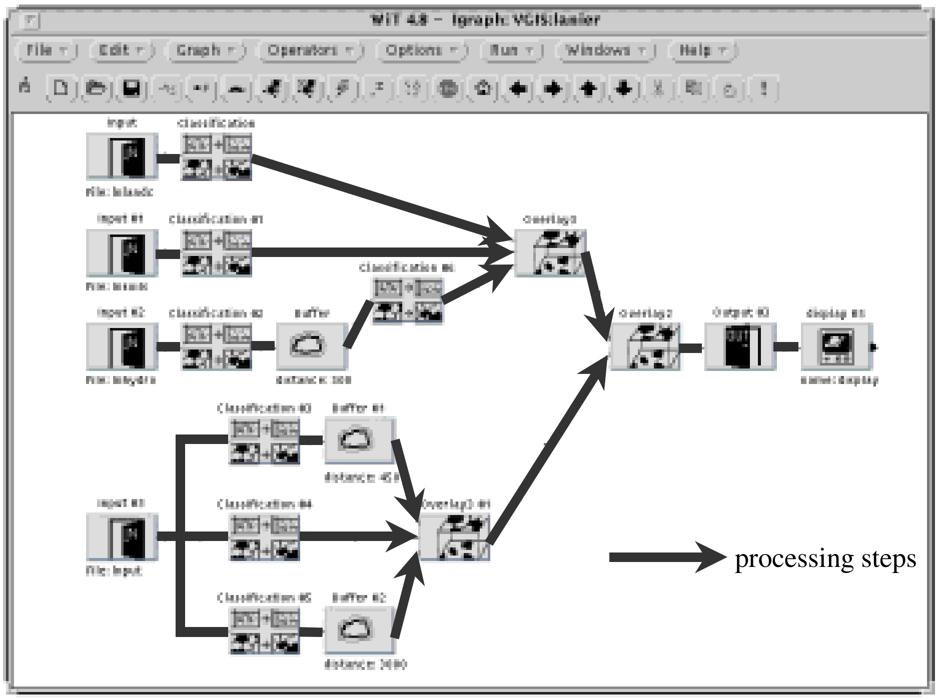

Figure 3. Graphical User Interface for VGIS. The Example shows the Processing Steps to Determine the Best Suitable Location for a Chemical Plant

<u>3a: Classification of Image Analysis Functions for Remote Sensing after Jensen (1986)</u>
Data Acquisition: Densitometer; Remotely Sensed Data in Digital Format; Digital Image Data Formats
Statistics Extraction: Univariate and Multivariate Statistics; Histogram Analysis
Display: B/W Hard Copy; Video Image Display; Transforming Video Display to Hardcopy
Preprocessing: Radiometric Correction; Geometric Correction
Enhancement: Magnification and Reduction; Transsects; Contrast Enhancement; Rationing; Spatial Filtering; Edge Enhancement; Special Transformations
Thematic Information Extraction: Supervised Classification; Unsupervised Classification; Incorporating Ancillary and Contextual Information in the Classification Process; Classification Accuracy Assessment
Change Detection: Nature of Change Detection; Change Detection Algorithms
<u>3b: Classification of Image Analysis Functions for Remote Sensing after Richards (1986)</u>
Data Acquisition in Remote Sensing: Spectral and Sensing Characteristics; Weather Satellites; Earth Resources Satellite Sensors; Aircraft Scanners; Radar Systems
Error Correction and Registration: Radiometric Distortions and Correction; Geometric Distortion and Correction; Image Registration
Radiometric Enhancement Techniques: Point Operations; Contrast Modifications; Histogram Equalization; Histogram Matching; Density Slicing
Multispectral Transformations: Principal Component Transformation; Tasseled Cap Transformation; Image Arithmetic, Band Ratios and Vegetation Indices
Fourier Transformation: Fourier Series; Fourier Transform; Convolution; Discrete Fourier Transform
Supervised Classification Techniques: Maximum Likelihood Classification; Minimum Distance Classification; Parallelepiped Classification; Mahalanobis Classifier; Table Look Up Classification; Context Classification
Unsupervised Classification Techniques: Similarity Metrices and Clustering Criteria; Iterative Optimization Clustering Algorithm; Single Pass Clustering; Agglomerative Hierarchical Clustering; Clustering by Histogram Peak Selection
Feature Reduction Techniques
Image Classification Methodologies: Supervised Classification; Unsupervised Classification; Hybrid Classification; Assessment of Classification Accuracy

Table 1. Classification of Image Analysis Functions for Remote Sensing

It is evident that the authors did not want to present a systematic taxonomy of image analysis functions. Nevertheless, Jensen's textbooks mixes hardware, sensors, systems and operations whereas Richard's approach does not present a rational structure when it deal with classification procedures (table 1). This is not meant as a criticism because both are excellent text books for remote sensing. Yet the inconsistency when dealing with image analysis taxonomies is an impediment for the development of a stronger theoretical background for the design and implementation of integrated

GIS. Without such a theoretical basis, however, the only way to a GIS/remote sensing integration seems to be a project driven *ad hoc* approach with limited usefulness and applicability.

3. AN INTEGRATED TAXONOMY

To set up a taxonomy of data structure and system independent GIS/image analysis functions one has to start either from the remote sensing or the GIS side. As the twenty universal operators from the Virtual GIS are currently the only taxonomy that meets the requirements stated above we will use them as starting point for an iterative approach (see figure 2). Based on typical remote sensing analyses, we selected four groups with 17 image processing functions to be added to the 20 universal GIS operators (table 2). The derivation of these functions is a first step and is based on an in-depth analysis of remote sensing and GIS literature and intensive project experiences (Ehlers and Schiewe, 1999; Ehlers, 2000).

Preprocessing: (a) Parametric Radiometric Sensor Corrections; (b) Parametric Geometric Sensor and Platform Corrections
Geometric Registration: (c) Deterministic Techniques; (d) Statistical Techniques (Interpolation); (e) Automated Techniques (Matching); (f) Error Assessment
3D Image Analysis: (g) Ortho Image Generation; (h) DEM Extraction
Atmospheric Corrections: (i) Deterministic Approaches; (j) Histogram Based Manipulations (Point Operations); (k) Filtering; (l) Image Enhancement
Feature/Object Extraction Techniques: (m) Unsupervised Techniques; (n) Supervised Techniques; (o) Hybrid Techniques; (p) Model-Based Techniques; (q) Error Assessment

Table 2. Universal Image Processing Functions for Integrated GIS

It has to be noted, however, that the operators presented in figure 2 and table 2 are not sufficient to define and describe the complete functionality of integrated GIS. Still required is a thorough analysis of hybrid processing capabilities, i.e. functions that allow a joint analysis of remote sensing and GIS information. It has to be investigated how polymorphism techniques can be used to extend the capacities of the VGIS universal functions of figure 2. The operator *Overlay*, for example, should be able to process image-image, GIS-image, and GIS-GIS overlays without a different name for every function option. First results can be found in Jung et al. (1997; 1998). Additional functions have to be developed, on the other hand, that extend the capabilities of integrated GIS beyond the sum of the single components. 3D urban information systems created from GIS and remote sensing can be seen as an example for these extensions.

Again, project driven singular solutions are still standard in the GIS community. Without a theoretical basis, however, their effects will not be of a lasting nature.

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