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SYSTEMS

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Summary

The development of Geographic Information Systems (GIS) leads to integrated processing and storage of spatial data in raster and vector form. It is often desired that the raster data can be treated like the structured vector data.

An object oriented management method of raster data is presented. One or more images and individual raster objects can be managed simultaneously. The method is based on space clipping with quadtree structure and possesses a high flexibility. To some extent, it offers a possibility to fill the gap between raster and vector worlds.

The method is implemented on the Siemens Graphic Workstation 9732 (UNIX, C); first results will be presented.

1. Introduction

Most of the Geographic Information Systems (GIS) offered nowadays base on vector graphics processing. They can realize a series of functions and results with regard to theoretical considerations and practical requirements. Some important properties such as entity and attribute handling, organization of graphic primitives and objects with topological relationships, combined storage of graphic and logical informations, and so on, are fundamental facilities (M. Schilcher, 1985, J.A.R. Blais, 1987, D. Fritsch, 1987).

On the other hand, raster data representing digital images play more and more an important role in GIS. Therefore its integration into vector based GIS becomes an actual research and application theme (D.F. Marble/D.J. Peuquet, 1983, W. Göpfert, 1987), which may also be interpreted as an evolutionary process (M. Schilcher, 1987). This leads to so-called "hybrid" processing of graphics data (M. Schilcher et al., 1987) considering vector data, raster data and attributes (non-graphics) simultaneously (see Fig.1). At a primitive level, the user might be satisfied with a vector-raster overlay. But as far as some comfort is concerned one should merge vector data into raster data and vice versa using the profits of both structures. This paper is devoted to a special research topic in solving this task - the object oriented integration of raster data.

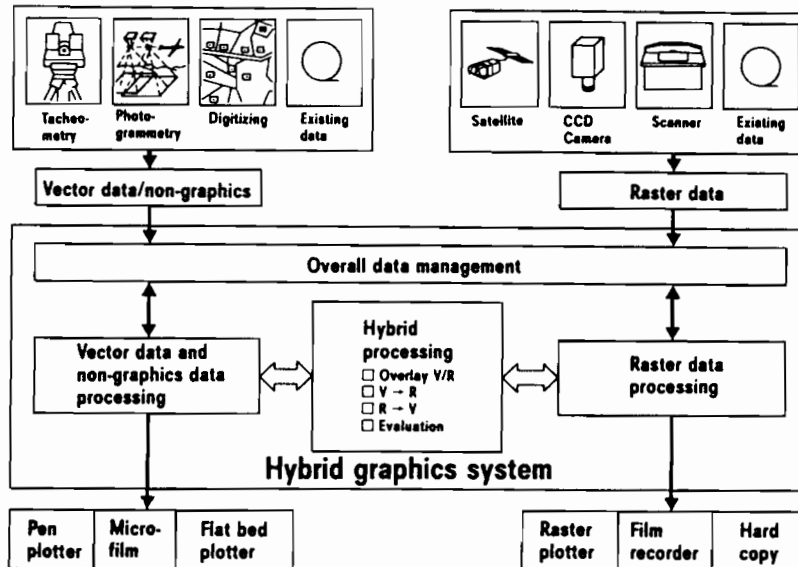


Fig.1: Hybrid graphics data processing

The idea behind the approach is to manage the raster data or their geometric properties objectwise. In the meantime modern hardware to display and process raster data has a high standard in quality and moreover, offers fundamental utilities. The combination of these possibilities with a suitable geometric and topological treatment of raster data gives excellent results as will be shown below.

## 2. Object Oriented Management of Raster Data

Object oriented management of geographical data is often applied to solve the data organization problem in GIS. This concept makes use of compact graphical or logical units of the data for the composition and processing by adequate algorithms.

In vector data processing this method is well developed and realized in information systems providing for data acquisition and editing only to highly complex data handling. But in raster graphics the logical consideration in relation to the image contents has not yet been considered in more detail. One reason may be the performance requirements due to great data volume. Thinking in recent hardware developments such as transputers and array processors this problem can be overcome, so that the potential of a logical treatment of raster data should be fully exhausted.

### 2.1 Object Oriented Management of Raster Data by Means of Plane Clipping with Quadtree Structure

In order to specify the concept of a "raster object" we begin with a fundamental operation - plane clipping (decomposition) with quadtree structure. There are many references on quadtree structures coming from different point of views (J.P. Lauzon et al., 1985, P. Mazumdar, 1987, C.A. Shaffer/H. Samet, 1987). The method we are presenting optimizes the decomposition with regard to special hardware utilities,

offered by raster technologies.

Every plane structure (shadowed area in Fig.2a) can be represented by one and only one quadtree composed of real branches and dark nodes (Fig.2b). This means that every special quadtree defines a certain plane structure.

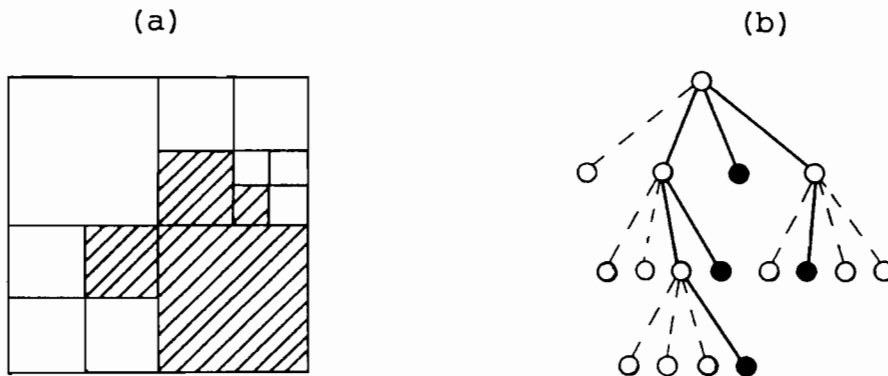


Fig.2: Plane structure and clipping with quadtree

In other words a plane structure can be clipped by a quadtree to some "basic elements" which correspond to the tree nodes. These basic elements can also be seen as "building stones" of a plane structure. The implementation of an effective algorithm to access and display the basic elements (supported by hardware utilities) provides for a mathematically evident and operational system processing the plane structure. Its resolution depends on the clipping level of the quadtree and must be finite because of realization reasons.

Let  $n$  be a defined plane square and  $N$  the set composed of all basic elements clipped by quadtrees of this square down to a certain level (resolution). Note that  $n$  is also element of  $N$  ( $n \in N$ ).

There is a natural relation on  $N$  due to the equivalence of every basic element and its four underlying basic elements, if a decomposition of e.g.  $k=2$  is used (Fig.3).

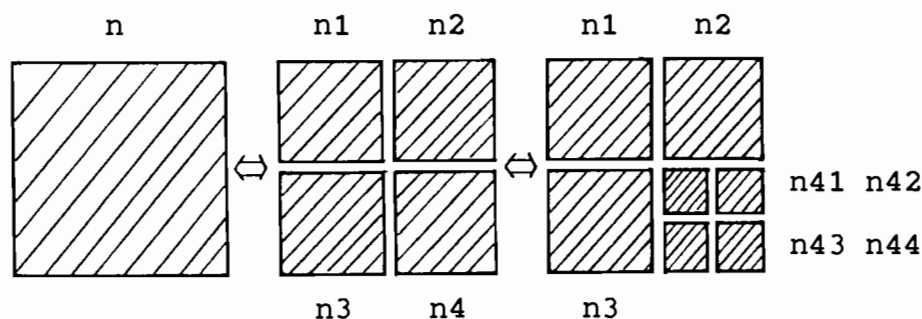


Fig.3: Basic element and its subdivision into four underlying basic elements

We denote this fact by the operations  $\cup$  (union),  $\cap$  (intersection) and  $\subset$  (inclusion) as follows:

$$\begin{aligned} n &= n_1 \cup n_2 \cup n_3 \cup n_4 \\ &= n_1 \cup n_2 \cup n_3 \cup (n_{41} \cup n_{42} \cup n_{43} \cup n_{44}) \end{aligned} \quad (1)$$

and

$$\begin{aligned} n_1, n_2, n_3, n_4 &\subset n \\ n_{41}, n_{42}, n_{43}, n_{44} &\subset n_4 \subset n \quad (\text{transitive}) \end{aligned} \quad (2)$$

as well as

$$\begin{aligned} n_1 \cup n &= n, \quad n_2 \cup n = n, \quad \dots \\ n_1 \cap n &= n_1, \quad n_2 \cap n = n_2, \quad \dots \end{aligned} \quad (3)$$

In general, for two intersecting basic elements  $m$  and  $n$  with  $m \subset n$  it holds

$$m \cup n = n \quad (4)$$

and

$$m \cap n = m \quad (5)$$

The operation  $\cap$  can be expanded to pairs of no intersecting basic elements  $m$  and  $n$  by setting

$$m \cap n = 0 \in N \quad (\text{empty}) \quad (6)$$

Now let  $P$  denote the collection of all possible plane structures composed of a no intersecting subset of  $N$ . Furthermore, every basic element in  $N$  is an element of  $P$ .  $N$  is in some sense the core set generating the set collection  $P$ .

By definition, every element  $p \in P$  composed of no intersecting basic elements  $n_1, n_2, \dots, n_k \in N$  represents a plane structure, what may geometrically be interpreted as a "raster object". It will be denoted by

$$p = n_1 \cup n_2 \cup \dots \cup n_k = \sum_{i=1}^k \cup n_i \quad (7)$$

On the set collection  $P$  the set operations  $\cup$  (union),  $\cap$  (intersection) and relation  $\subset$  (inclusion) can also be defined in consistency with (1)-(6). With

$$p = n_1 \cup n_2 \dots \cup n_k = \sum_{i=1}^k \cup n_i, \quad n_i \in N$$

and

$$q = m_1 \cup m_2 \dots \cup m_l = \sum_{j=1}^l \cup m_j, \quad m_j \in N \quad (8)$$

it follows

$$\begin{aligned} p \cup q &= n_1 \cup n_2 \cup \dots \cup n_k \cup m_1 \cup m_2 \dots \cup m_l \\ p \cap q &= (n_1 \cap m_1) \cup (n_1 \cap m_2) \cup \dots \cup (n_k \cap m_l) \end{aligned} \quad (9)$$

Furthermore, if

$$\begin{aligned} & p \cup q = q \quad \text{or} \quad p \cap q = p \\ \text{we say} & \quad p \subset q \quad (\text{p is included in q}). \end{aligned} \tag{10}$$

The union  $\cup$  and intersection  $\cap$  on  $P$  are solved by means of the same operations on  $N$ . While the operations on the set collection  $P$  have to be performed by special encoding methods and algorithms, the operations on the core set  $N$  can directly be supported by the hardware utilities.

It should be noted that the union  $p \cup q$  and intersection  $p \cap q$  are also elements (plane structure) of  $P$  (that is,  $p \cup q \in P$ ,  $p \cap q \in P$ ). Abstractly  $P$  with  $N$  builds a topological space.

To every raster object one can define various entity keys and attributes. We will see that some interesting results based on the geometric and topological properties of the set  $N$  and the set collection  $P$  occur as shown below.

i) For given  $p$  and  $q$  ( $p, q \in P$ ) of (8) with every  $n_i \in N$  there is a  $m_j \in N$  so that

$$n_i \subset m_j \quad (\text{that is } n_i \cup m_j = m_j \text{ and } n_i \cap m_j = n_i)$$

then the formulae (10) are valid. This means geometrically, the area  $p$  is a subarea of  $q$ .

Keeping this operation in mind it is easy to answer the query due to the topological relationships such, as if the area  $p$  is contained in the area  $q$  without an explicit storage of these relationships.

ii) If 
$$p \cap q = 0 \tag{11}$$

then the areas  $p$  and  $q$  have no intersection.

It can easily be verified that the necessary and sufficient condition for (11) amounts to no intersection of a pair  $n_i$  and  $m_j$  in (8).

iii) If the following decomposition is valid

$$\begin{aligned} & p = p_1 \cup p_2 \cup \dots \cup p_n, \quad p_i \in P \\ \text{and} & \quad p_i \cap p_j = 0, \quad i \neq j \end{aligned} \tag{12}$$

then  $p_1, p_2, \dots, p_n$  build a complete (topological) decomposition of  $p$ .

This special case is very important because in a GIS an administrative management (e.g., a land built up by its states, or land use assessment) corresponds always to a complete decomposition (Fig.4).

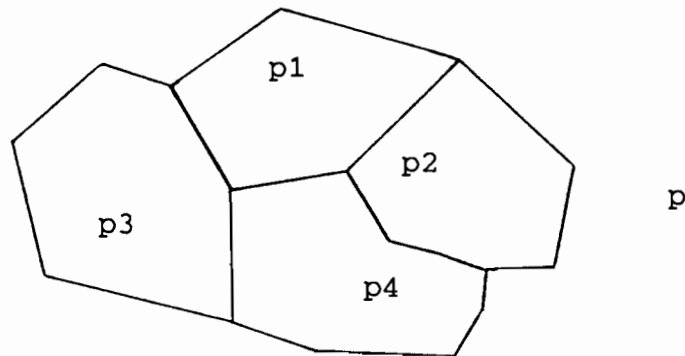


Fig.4: Complete decomposition of an area

- iv) Heredity of attributes and logical consistencies can be done as follows: the common attributes associated to every subarea  $p_1, p_2, \dots, p_n$  can be evaluated to the complete area  $p$  (e.g. the sum or the average of the contents of certain attributes). But in turn, the attributes of  $p$  can be hereditary applied to specify the properties of subareas.

This occurs when the results from the union and intersection are compared with each other. We can also associate some preconditions to the evaluation algorithms, so that an algorithm is carried out, if the preconditions are accomplished (knowledge based actions). For example, if and only if the condition (12) is satisfied, an evaluation "population of  $p$  by the sum of individual populations of  $p_1, p_2, \dots, p_n$ " is allowed.

The classical approach of area organization is based on vector processing of the area boundaries. In this procedure the points and lines representing the area are stored and may be vectorial displayed, sometimes with the support of fill-in functions. The method presented above processes not the boundaries, but the basic elements of the area (plane); it stores and processes "quasi-vectorial" and "quasi-rasterwise" with regard to hybrid graphics. There are situations in practical applications, where the graphic contents can be processed neither in pure vector form, nor they have to be processed in pure raster form because of the huge amount of storage space (e.g. scanned maps). First experience has shown, that our approach is very efficient; its importance is mainly directed to the management facilities of plane objects, which can influence the design of GIS allowing for hybrid graphics processing.

A further interesting property will also be exhibited: the method produces a so-called "boundary effect" to be used for vectorization. The quadtree structure provides for smaller basic elements at the boundary of the area, whereas larger basic elements are concentrated in the middle domain. Therefore the object oriented management of raster data can also result into vectorization, if line following and approximation functionals are used in a postprocessing step.



### 3. Example

A first application of the method presented above gives optimism to concentrate further research on clipping procedures. An aerial photograph of the city of Rosenheim/Bavaria (about 40 km eastern of Munich) has been scanned; the excerpt we are dealing with (see Fig.5a) amounts to 1 (MByte) storage space. The manual classification results into 11 classes to be managed as objects in our procedure (see Fig.5b).

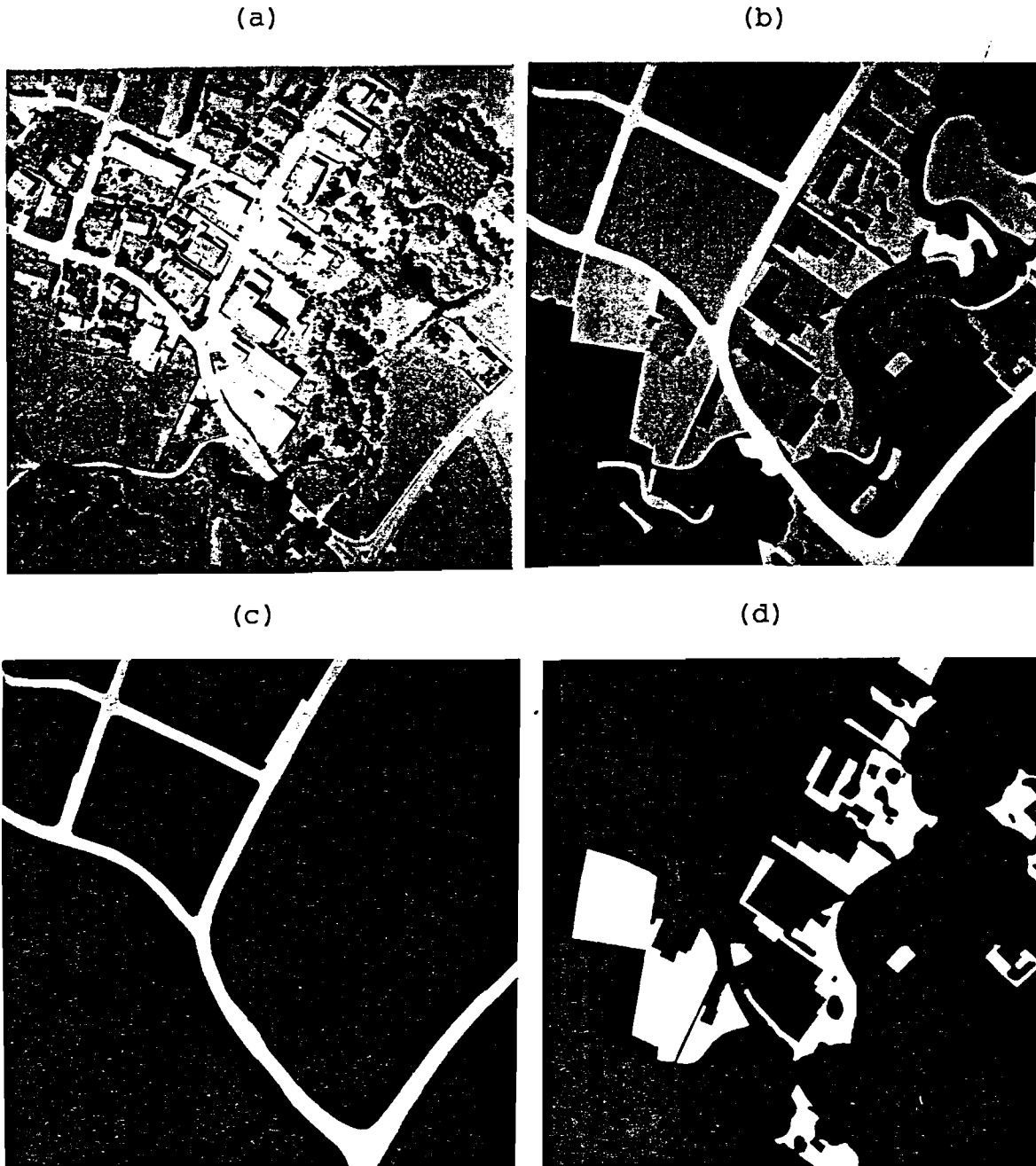


Fig.5: Raster oriented management of an aerial photograph

A reorganization of Fig.5b by means of object oriented management with quadtree structure reduces the storage space to about 150 (KBytes), which gives nearly a factor of 7. It

is now easy to process, query and display a certain object (class) such as streets (Fig.5c) or green zones (Fig.5d). The "boundary effect" within object oriented management is demonstrated by Fig.6a and 6b; the clipping of pixels representing an object (area) within the quadtree structure reduces the pixel size from large to small. At the final level the edges of the objects are obtained.

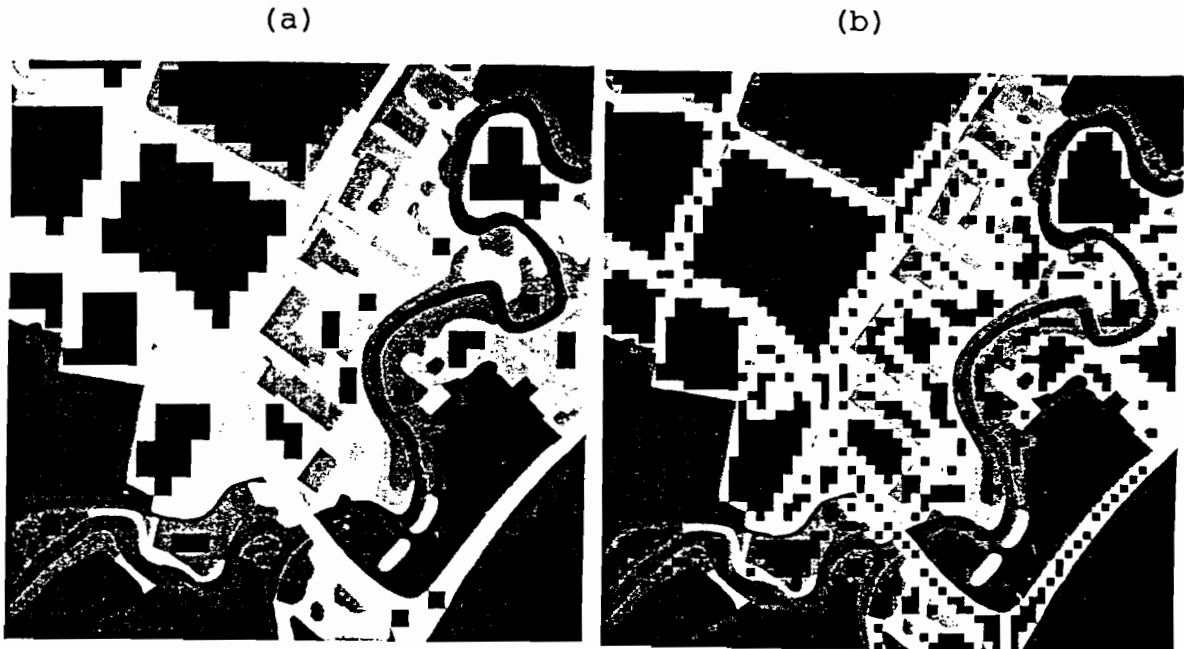


Fig.6 Approaching boundaries of objects by clipping pixels from large to small

A comparison between operators for edge detection (differentiators of 3\*3 such as Sobel, analytical) and our approach gives clear advantages for the benefit of clipping, because it is very, very fast with narrow bands representing the edges. This is also important for line following and vectorization: the smaller the edges the faster and more robust the vectorization process can be performed.

#### 4. Conclusions

The method of object oriented management of raster data is very promising: first of all it reduces the storage space considerably; secondly it allows for individual handling of objects adequate to recent object oriented programming procedures. It is efficient to create a skeleton by a complete decomposition of the original image. Every plane structure in this decomposition (raster object) is decomposed to some basic elements; its processing can be supported by hardware functions leading to fast response times. For the point of view of information science the basic elements (quadtree nodes) are fundamental because they cannot be again decomposed.

In comparison with conventional methods (representation of plane structures by boundary points and lines) this method is

very direct. Based on the object oriented data structure it allows for various queries in relation to geometric and topological informations. Some entity relationships corresponding to the plane structures become evident.

The data volume is larger than a pure vector processing, but the advantages predominate. Last not least the raster to vector conversion can be supported by this approach.

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