KNOWLEDGE-BASED INTERPRETATION OF SCANNED LARGE-SCALE MAPS USING MULTI-LEVEL MODELLING

H. Mayer, C. Heipke, G. Maderlechner

D621: Competence Center GIS
Siemens Nixdorf Informationssysteme AG, Otto-Hahn-Ring 6, D-8000 Munich 83, Germany
Tel: +49-89-636 2166; Fax: +49-89-636 45202; E-mail: hm@ssym1.zfe.siemens.de

Chair for Photogrammetry and Remote Sensing
Technical University Munich, Arcisstr. 21, D-8000 Munich 2, Germany
Tel: +49-89-2105 2671; Fax: +49-89-2809573; E-mail: heipke@photo.verm.tu-muenchen.de

Corporate Research and Development
Siemens AG, Otto-Hahn-Ring 6, D-8000 Munich 83, Germany
Tel: +49-89-636 3389; Fax: +49-89-636 2393; E-mail: gm@bvax4.zfe.siemens.de

Commission III

ABSTRACT:

Present results of map interpretation systems still require significant manual interaction effort. This is mainly caused by a lack of high level knowledge in the systems. In this paper we introduce a multi-level model for a large-scale map as the key to improved and robust automatic map interpretation. The levels of the model are called semantic objects, graphics and text, image graph and image. Objects, operations to be performed on the objects and relations between the objects are presented for each level.
Mixed bottom-up and top-down reasoning is performed by instantiating the concepts of a semantic network built up from the semantic objects, the graphics and text and the image graph levels. The interpretation uses relations on attributed arcs and nodes as well as template matching on the image.
First results for the interpretation of a Bavarian cadastral map of scale 1 : 1000 are presented.

Key Words: automatic map interpretation, model based interpretation, semantic network, top-down and bottom-up processing

1. INTRODUCTION

For all kinds of spatial planning purposes large amounts of topographic and cadastral data are required. This information is more and more needed in digital form to build up geographical information systems (GIS). Compared to photogrammetry, surveying etc existing paper maps are the most inexpensive source of input data for the GIS. A GIS whose level of detail corresponds to large-scale maps (scales from 1 : 100 to 1 : 5000) is composed of attributed (ie meaningful) high quality vector data. Maps of this scale are usually plotted as black and white (ie binary) line drawing.
If a map of this kind is scanned, the result is a raster image. This is not the type of data needed for the vector GIS. Today the conversion of paper maps to GIS data is accomplished through manual digitisation of the maps. Another possibility is the interactive digitisation of the scanned image on the screen. This is known as "overlay technique" and has the advantage that the map and the digitised data are directly comparable. The drawback of both approaches is that they are very labour intensive and that the results depend on the skills of the operator.

Because there are a lot of maps to be digitised, the automatic conversion of the scanned maps to attributed vector data is a great challenge. The basic tasks are the extraction and the interpretation of the lines.

One possibility is to use techniques from pattern recognition and line drawing analysis. For maps of low complexity (eg cadastral maps of scale 1 : 500 or 1 : 1000, forest or water plates of a topographic map) commercial software packages are available which use these techniques (eg STRUVE from M.O.S.S., Germany, GEOREC from SysScan, Norway). They operate in batch mode accompanied by manual pre- and postprocessing. The amount of manual editing is closely related to the complexity and the quality of the maps. For instance for cadastral maps of scale 1 : 500 of very good quality for the GEOREC system time savings of 50 % compared to manual digitising were reported [Schmitz 1991]. However, these techniques fail, if more complex maps of lower quality are to be converted to GIS data.

In this paper we introduce a multi-level model for a large-scale map as the key to improved and robust automatic map interpretation. The levels of the model are called semantic objects, graphics and text, image graph and image. Objects, operations to be performed on the objects and relations between the objects are presented for each level. We first shortly review some work done in the knowledge based interpretation of maps. Then, we introduce our model for the interpretation of a large-scale map and its representation by a semantic network. The flow of the interpretation is explained next, followed by first results.

2. FORMER WORK IN MAP INTERPRETATION

The basic operation for processing line drawings is line extraction from a raster image. Often this is done by thinning or by a distance or medial axis transformation of the binarised image [Smith 1987] followed by line tracking and line approximation. Another possibility for obtaining the lines is the extraction from grey-valued images [Joseph 1989]. It returns lines and line crossings. A first step in processing the lines (eg [Domogalla 1984]) is to attempt to reconstruct the elements of the graphics (eg points, straight and curved lines, circles, arrows, hatched and screened areas and other kinds of map symbols). It should be pointed out that in nearly all cases this reconstruction can only be partially successful, because of errors in the input data (in the map itself or introduced by scanning or preprocessing) and because of a lack of higher level knowledge.

After the partial reconstruction of the graphics the interpretation of objects of the domain (eg buildings, roads), denoted by the graphics is attempted using higher level knowledge. The work we will present in the following is ordered according to an increasing use of high level knowledge.

In the system CAROL [Illert 1991] designed for the interpretation of large-scale maps (eg German base map 1 : 5000) emphasis is laid on the improvement of different interpretation modules. The text and the symbols are recognised by classifying the contours expanded in a Fourier series. The system also recognises hatched areas and dashed lines and combines symbols into strings (eg digits to numbers). At last, strings and symbols are assigned to spatial features (lines, points).
MARIS [Suzuki and Yamada 1990] is a system for the interpretation of large-scale maps of Japan. At first, special algorithms for tracing closed polygons are utilised to find buildings. Afterwards, height contour lines and lines representing railways, roads and water areas are recognised.
T. Kilpeläinen [Kilpeläinen 1988] tries to recognise buildings in city maps. She only describes the buildings (local knowledge) on several levels of detail, using the programming language PROLOG. Although she does not model the surroundings and the relations among the buildings and the surroundings, she obtains high recognition rates.
Another direction is chosen by J.A. Mulder [Mulder 1988]. He investigates topographic objects and constraints between them. Then he analyses simple line drawings containing these topographic objects using a constraint satisfaction technique.
M. Ilg [Ilg 1990] uses domain dependent knowledge to analyse road maps, using bottom-up and top-down processing for hypothesis generation and missing parts prediction respectively. He uses the exo-skeleton (skeleton of the background of the image) to find parallel lines.
CIPLAN [Antoine 1991] is an experimental system to interpret French city maps. It uses a model containing "real entities" (eg buildings, roads), their graphical representations and the relations between them together with a procedural network for the extraction process.

3. MODEL FOR A LARGE-SCALE MAP AND ITS REPRESENTATION

In this chapter we present a model for large-scale maps. It is organised in four levels and described in the following for cadastral maps of scale 1 : 1000. In addition to three levels (semantic objects, image graph and image) that resemble the three levels from computer vision (high, mid and low level) we use the graphics and text level. It is an intermediate level between the image graph and the semantic objects level and takes into account that our input data is the result of classification and symbolisation by a human.
Each level consists of objects, operations to be performed on the objects and relations between the objects. In addition there are operations to be performed on and relations between objects in different levels.

For the representation of the model we use a semantic network. Our work was inspired by the ERNEST system [Niemann et al. 1990]. The nodes of the semantic network are called "concepts". If a concept is instantiated, the result is called an "instance" of that concept. In the semantic network we use two types of relations (arcs) that set up our network and connect the nodes: the "part" (inverse: part-of) relation and the "generalisation" (inverse: specialisation) relation. A concept built up from the part relation consists of other concepts, relations between these concepts and operations to be performed on these concepts. A concept built up from the specialisation relation consists of one other concept and specialisation conditions for this concept.
For the different levels examples of concepts that represent objects are given. The operations on and the relations between the concepts are explained for the levels (see chapter 3.1.) and between concepts in different levels (see chapter 3.2.).

3.1. Levels of the model

The first level is called "semantic objects". It contains all the objects that are denoted by the map legend. For cadastral maps of scale 1 : 1000, there are three types of semantic objects (see Fig. 1): basic map objects, cadastral objects and topographic objects.
The basic map objects describe the map (the margin built up from the sheet designation, the edition note, the scale etc.), delimit the drawing plane (the framework and the neatline) and give information about the location of the map (the grid with grid coordinates and grid intersections). No operations exist but there are relations between the locations of the objects.
The cadastral objects (see Fig. 2) are the parcels, their corresponding numbers, the parcel areas, the boundary lines and the boundary stones. Only relations exist: the cadastral objects build up a layer that is exhaustively filled out by non overlapping (ie mutually exclusive) parcels. A parcel consists of a parcel area and a corresponding number. Parcel areas are surrounded by boundary lines. The boundary lines are related to the boundary stones: at every end of a boundary line a boundary stone is situated.
The basic types of topographic objects are: buildings, roads (also places), railways, forest, meadows, fields and waterbodies (see Fig. 3).
For the buildings, forests and roads part-of and specialisation relations of these objects are given. For the other objects the relations are not shown.

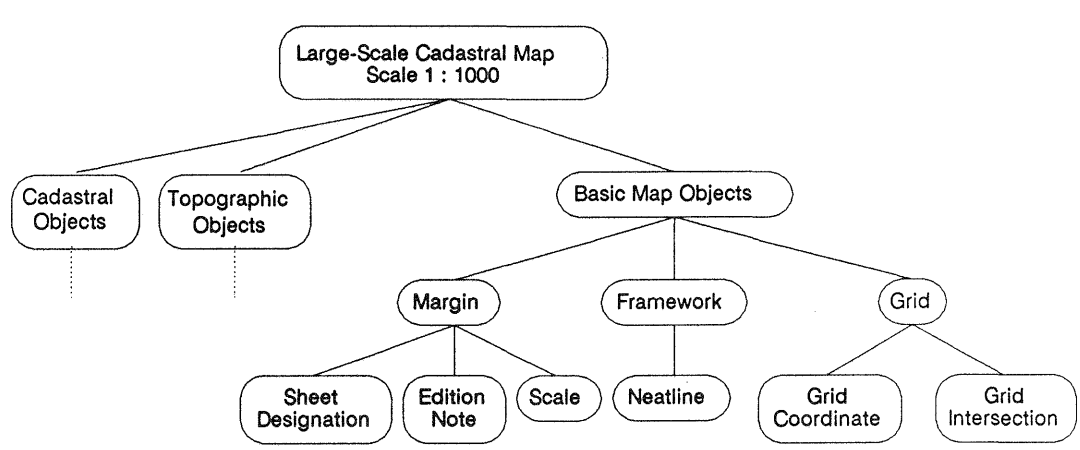

Fig. 1: Objects in a large-scale-map 1 : 1000
(the objects below are parts of the objects above)

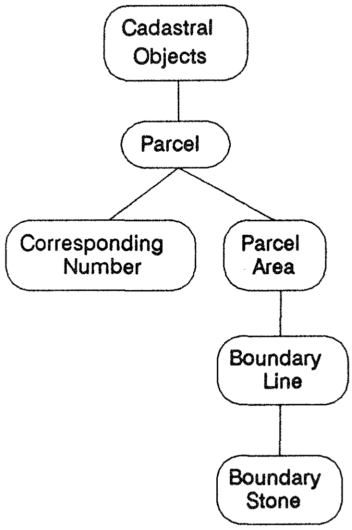

Fig. 2: The cadastral objects
(the objects below are parts of the objects above)

The roads as well as all other objects that can be considered as areas consist of an identifier and an area. All these areas are built up from the object general area. This object is surrounded by boundary lines and topographic lines (lines that separate different topographic objects).
An example for a concept of the semantic network is the parcel area (PA) consisting of the concept boundary line (BL). Another example is the concept general area (GA) consisting of BL and the concept topographic line (TL). The parts of PA and GA bound the area. The concept boundary stone (BS) is part of the concept BL. Two boundary stones are situated at the ends of the boundary line.

The second level is called "graphics and text". The objects in this level include graphics objects (eg points, straight and curved lines, circles, arrows, hatched and screened areas and other kinds of map symbols) as well as text objects (characters and digits). In this level mainly neighbourhood relations are used and operations analyse eg the thickness, position, size or the orientation of objects.
Some examples for concepts are point, circle_1.9mm, polygon, polygon_0.35mm, polygon_0.18mm and remaining object (RO). The remaining objects are candidates for text, numbers or symbols that at present we do not investigate any further. The concepts polygon_0.35mm and polygon_0.18mm are specialisations of the concept polygon (their thickness is known from the map legend). They are exhaustively and exclusively specialised according to their thickness. The concept point is used to preserve the information, which polygons are connected and which are not. The concept circle_1.9mm (line thickness is 0.18mm and radius is 1.9mm) preserves the topology of the polygons in the same way as the concept point but the junction of the polygons is marked with a symbol. The symbol consists of a circle bounding an area that conceals the junction and a part of the polygons.

The third level is called the "image graph". It consists of a number of separated attributed graphs, each corres-

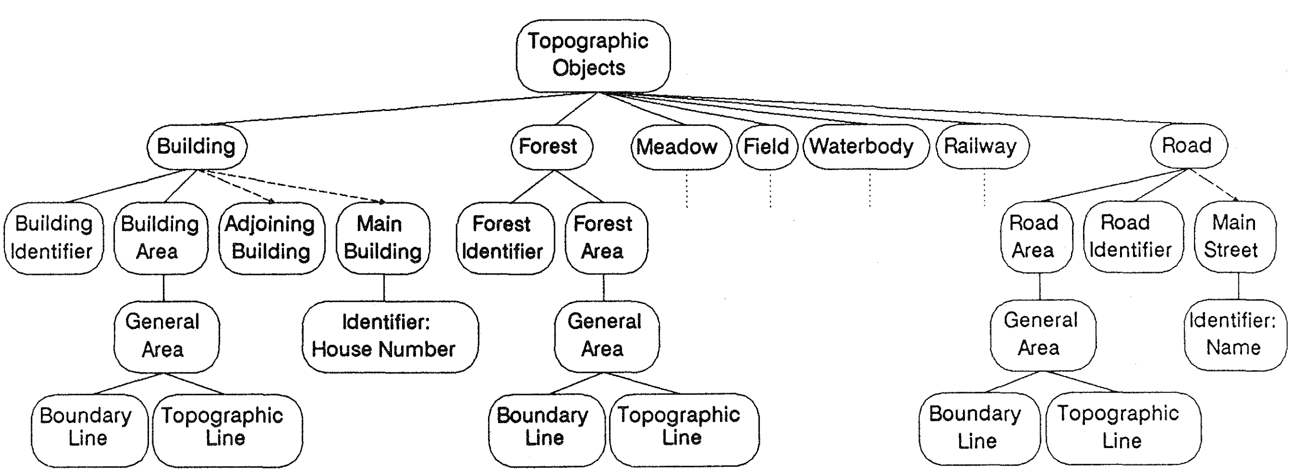

Fig. 3: The topographic objects
(lines: the objects below are parts of the objects above;
dashed lines: the object at the end of the arrow is a
specialization of the object at the beginning)

ponding to a connected component. The arcs of the graphs correspond to the lines and are attributed with the thickness of each line segment. The nodes correspond to the line crossings and are attributed with the coordinates and the thickness of the line crossing.
Examples for concepts are graph, node and arc as well as small graph and large graph. The nodes and arcs are parts of the graph. The small graph and the large graph are specialisations of the graph according to the specialisation condition that the area of the bounding rectangle of the graph as well as the ratio between this area and the sum of the length of the arcs are below or above the corresponding thresholds.

The fourth level is called "image". It is the result of scanning the map and binarisation. This level consists of the two dimensional matrix of binary pixel values (raster image). The existing neighbourhood relations between the pixels are not used in our model. Operations on the image are image processing routines. They always produce raster images as output.

3.2. Relations and operations between the levels

There are four different types of relations and operations between levels.

The first type connects the semantic objects level with the graphics and text level. It consists of the relations between the graphics and text objects on the one hand and the semantic objects on the other hand as given by the map legend. No operations are used.
An example is the relation given by the map legend that boundary lines correspond to polygon_0.35mm, that topographic lines correspond to polygon_0.18mm and that boundary stones are symbolised by circle_1.9mm.

The second type connects the graphics and text level with the image graph level. A relation between the size of a graph in the image graph and the type of objects (graphics or text) is used. Operations perform the transition from arcs and nodes to graphics objects.
The concept polygon for example is a specialisation of a concept arc that belongs to a large graph. The concept RO consists of all nodes and arcs that belong to a small graph.

The third type connects the graphics and text level directly with the image level. Only operations are used. They extract symbols, characters and digits from the binary image. In chapter 4.2. an example is given for the extraction of the concept circle_1.9mm by means of template matching.

The fourth type connects the image graph level with the image level. Only one operation is used. It consists of line extraction from the image followed by a graph building process. An example of the application of this operation for the creation of instances of the concepts node and arc is given in chapter 5.

4. FLOW OF THE INTERPRETATION

The goal of our first test was to find the parcel areas, the general areas and the remaining objects in a Bavarian cadastral map of scale 1 : 1000. Therefore the flow of interpretation is only described for this example. The interpretation is restricted to parcel areas, because the corresponding numbers that are also parts of the parcels are not yet recognised.

To achieve the goal we have to instantiate the concepts PA, GA and RO. For reasons of simplicity we make no difference between the concepts BS, TL and their symbolisation (circle_1.9mm, polygon_0.18mm). The concept BL consists of the parts polygon_0.35mm and BS. In the following the instantiation of the concepts is shown. The instances created from the concepts are the interpretation of the scene.

4.1. Bottom-up instantiation of the concepts

The instantiation of some of the concepts from the graphics and text level is a simple bottom-up process. The given instances of the nodes and arcs are analysed according to the type of the graph they belong to (large/small graph).
If a concept arc belongs to a large graph, then an instance of the concept polygon is created. The thickness of the polygon is calculated as a mean of the thicknesses of the line segments of the arc.
If concepts arc and node belong to one small graph, then an instance of the concept RO is created. All the related nodes and arcs are parts of the concept RO.

The condition for the instantiation of the concept PA is that there exist instances of the concepts BL and BS. The concept BL consists of the concepts polygon_0.35mm and BS. The concept polygon_0.35mm can be instantiated by analysing the thickness of the instances of the concept polygon. If the thickness of a polygon is beyond a threshold the concept polygon_0.35mm is instantiated. If it is below this threshold the concept TL is instantiated.

The bottom-up instantiation of the concept BS is complicated. The concept BS consists of arcs (the small circles in Fig. 6). Hence one possibility to find instances of the concept BS is to search for arcs that resemble circles. However, due to distortions in the input image and because of errors introduced by scanning or line extraction the arcs are deformed and can be broken up. For this reason we decided to use template matching in the image to find the BS.

4.2. Top-down instantiation of the concept boundary stone

Top-down instantiation is a way to gain evidence for the existence of the BS. An instance of a concept polygon_0.35mm initialises the instantiation of a concept BL. By means of the neighbourhood relation instances of the concept BS are found, if they already exist. If they do not exist, instances of the concept arcs that could be parts of the BS are searched for. If they are found these instances are transferred to the concept BS for instantiation via top-down processing.

The concept BS is now tried to be instantiated with one of these arcs as spatial reference. A compound operation is used for the instantiation. A binary template of the circle symbolising the BS is matched in a specified area with the binary image. If the score of this matching lies beyond a threshold, points on the centre line of the template are matched into the image graph and the arcs found are marked as parts of the BS. Other meanings of these arcs are deleted. Furthermore, the topology of the lines ending in the BS is changed so that the lines intersect in the centre of the BS.
The determination of the arcs is carried out to integrate the knowledge gained by the matching into the instances of our semantic network to keep it consistent.

After the BS are found they are integrated as parts in the instance of the concept BL from which the top-down processing was initialised.

Because all the necessary parts are now available the concepts PA and GA can be instantiated. The parts of the concepts are found by an operation that calculates the neighbouring parts to a given part. Thus, the parts of the concept are found incrementally. If no more parts are found, it is checked if the related area is closed and if this is the case, the concept PA or GA is instantiated.

5. IMPLEMENTATION AND RESULTS

We use a small part of the map (512 pixels x 512 pixels scanned with 400 dpi; see Fig. 4) to test the interpretation capability of our implementation.
The map is scanned and binarised. The result is a raster image in level 4.
In this level disturbances and the screen symbolising the buildings are removed from the image which results in the cleaned image (see Fig. 5). This cleaning operation is based on the area of the connected components in the image. The remaining information will be used later for the recognition of buildings.
On the cleaned image a topology preserving thinning operation and a distance transformation are performed. The lines are tracked, and a graph building process and a line approximation are performed [Maderlechner and Jeppson 1988]. The results are graphs in the image graph (see Fig. 6). For every graph also the sum of the length of all arcs and the area of the bounding rectangle are computed. According to these values the graphs are specialised into small graphs and large graphs.

The instantiation is carried out according to chapter 4. Fig. 7 shows the result for the instantiation of the polygon_0.35mm. Obviously most of the labelling was correct, but two short lines of the boundary stone in the lower left were classified as polygon_0.35mm.
In Fig. 8 the six instances of the parcel areas can be seen. The boundary stones have all been found and the polygons that were wrongly classified as polygon_0.35mm (see above) have been recognised by matching the centre line of the boundary stone into the image graph and then deleted.
Fig. 9 shows the general areas. They partially correspond to the parcel areas. These areas are marked with the same numbers as in Fig. 8. The areas that are split by the topographic lines are marked by characters. Obviously all the areas that can be seen in Fig. 4 have been found. However, some of the general areas still have to be

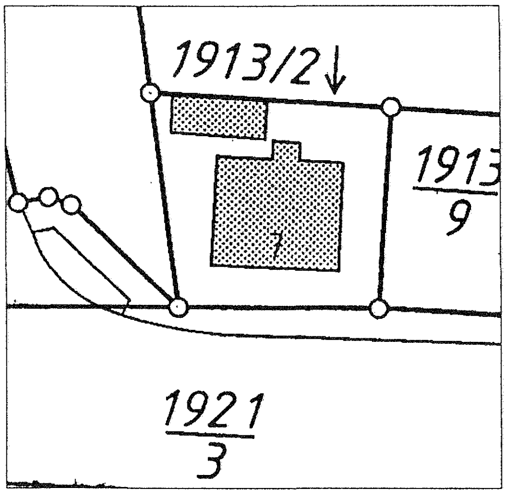

Fig. 4: Part of a scanned and binarised cadastral map of scale 1 : 1000

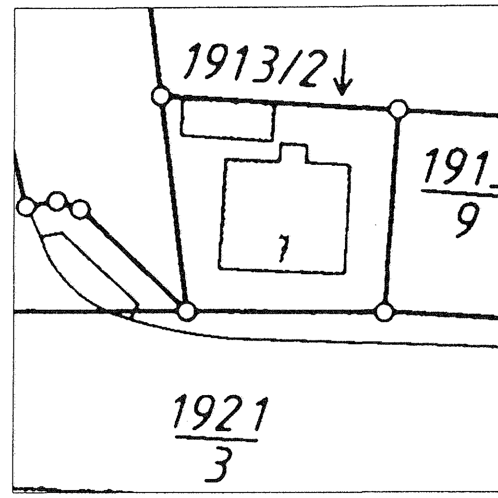

Fig. 5: Result after elimination of disturbances and the screen symbolising the buildings.

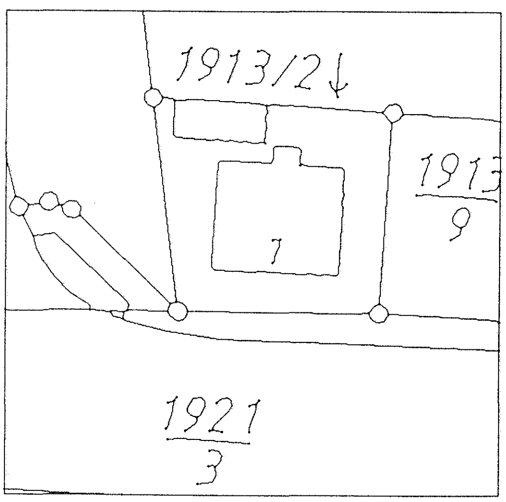

Fig. 6: Image graph consisting of attributed arcs and nodes constructed by thinning of the cleaned image, line tracking and a graph-building process

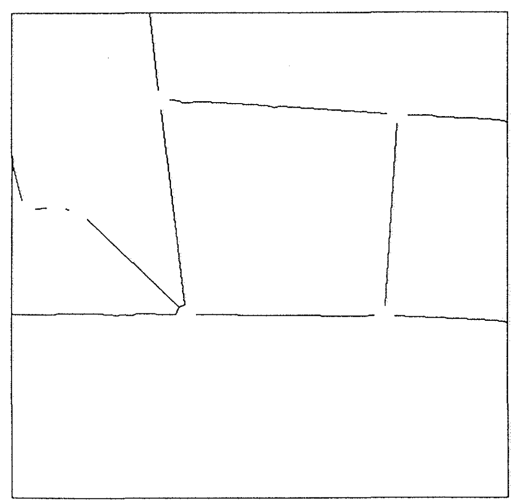

Fig. 7: Polygon_0.35mm (thick lines of the line drawing) used to guide the search of the boundary stones

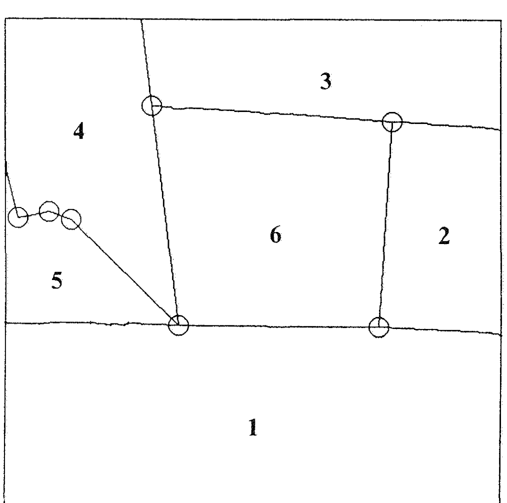

Fig. 8: Six parcel areas

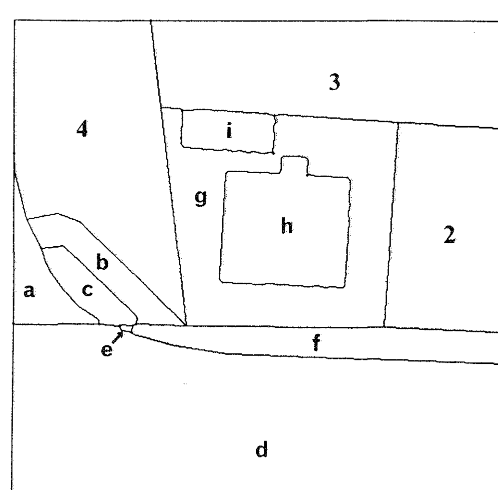

Fig. 9: Twelve general areas

merged to obtain meaningful areas (eg road areas). The merging can be constrained by relations of the topographic objects (eg roads build up a network) that are denoted by the areas.

6. OUTLOOK

A model and its representation for the interpretation of large-scale maps and first results for the interpretation of a cadastral map were presented.

One of our major goals is the determination of the topographic objects. Support can be gained from the following principles that describe relations between topographic objects. Together with the topographic objects these principles can also be used for the analysis of aerial images.

The first principle is based on a relation between the type of basic objects that can be regarded as areas and their functionality: Basic objects that together build up a "mosaic of areas" (eg building, meadow, field) and basic objects that build up one or more "networks of long areas" (eg road, railway, waterbody). Based on this distinction relations exist between the objects building up the network of long areas on the one hand and the types of networks (eg rivers naturally build tree-like networks, roads build networks with a hierarchy according to the road types) and the types of the crossings (eg rivers cross railways and roads only by overpasses or underpasses) on the other hand.

The second principle is that there exist relations between parts of the network of long areas and some kinds of objects (eg parking spaces are connected with the road network).

The third principle deals with objects in the network of long areas. These objects are often accompanied by different parallel objects (eg traffic lanes and pavement track).

The fourth principle is concerned with objects from the image mosaic. Their forms are related to their type (areas like buildings have well defined forms). The orientation of an object is related to the orientation of other objects (eg a house is often oriented parallel to a road).

The fifth principle is a physical exclusion relation of some kinds of objects on some objects that can be regarded as areas (eg a pylon is not allowed to be placed on a highway).

7. REFERENCES

Antoine, D. (1991): CIPLAN: A Model-Based System with Original Features for Understanding French Plats. Proc., ICDAR '91, First Intern. Conf. on Document Analysis and Recognition, Saint Malo, pp. 647-655.

Domogalla, U. (1984): Ein Expertensystem für die automatische Erfassung von technischer Graphik. Proc. DAGM/OEAGM, pp. 297-303.

Ilg, M. (1990): Knowledge-Based Interpretation of Road Maps. Proc. 4th Int'l Symposium on Spatial Data Handling, Zürich, pp. 25-34.

Illert, A. (1991): Automatic Digitization of Large Scale Maps. 1991 ACSM-ASPRS, Vol. 6, Auto Carto 10, Baltimore, pp.113-122.

Joseph, S.H. (1989): Processing of Engineering Line Drawings for Automatic Input to CAD. Pattern Recognition, Vol. 22, No. 1, pp. 1-11.

Kilpeläinen, T. (1988): Automatic Objects Recognition in Line Maps. Int. Arch Photogr. RS, Part B10/IV, pp. 327-336.

Maderlechner, G. Jeppson, O. (1988): Representation, Classification and Modelling of Graphs for Efficient Pattern Recognition in Line Images. 9'th Int. Conf. on Pattern Recognition, Rome, pp. 678-680.

Mulder, J.A. (1988): Discrimination Vision. CVGIP 43, pp. 313-336.

Niemann, H., Sagerer, G.F., Schröder, S., Kummert, F. (1990): ERNEST: A Semantic Network System for Pattern Understanding. IEEE T-PAMI, Vol. 12, No. 9, pp. 883-905.

Schmitz, W. (1991): Automation der Katasterkarten mittels Scanner und Mustererkennung. In: Geo-Informatik, Schilcher (ed.), Siemens, pp. 181-186.

Smith , R.W. (1987): Computer Processing of Line Images: A Survey. Pattern Recognition, Vol. 20, No. 1, pp. 7-15.

Suzuki, S., Yamada, T. (1990): MARIS: Map Recognition Input System. Pattern Recognition, Vol 23, No. 8, pp 919-933.