

SEMANTIC INTERPRETATION OF REMOTE SENSING DATA

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ABSTRACT

The interpretation of remote sensing data is a complex task because of the high variability of the image material under investigation. At the Institute of Communication Theory and Signal Processing procedures for maximizing the degree of automation of the interpretation of remote sensing data are developed. In this paper the system GEOAIDA is presented, which allows an intelligent, concise and flexible control of a scene interpretation by utilizing a semantic scene description. The system produces a hierarchic, pictorial description of the results as well as the structural context of the identified objects including the associated attributes. The output of GEOAIDA can be used for update of geographic information systems and for map generation.

1 INTRODUCTION

Based on good experience with the system AIDA (Tönjes *et al.*, 1999) (Tönjes, 1999) (Growe, 2001) developed at the Institute of Communication Theory and Signal Processing, the system GEOAIDA was developed to put the experimental oriented system AIDA into practice. Parts of this contribution were submitted for a special issue of the ISPRS Journal of Photogrammetry and Remote Sensing, planned to appear in April 2003. The basic approach to integrate additional knowledge in terms of a semantic network into the analysis is adopted.

Originated in all examined problems the conception of GEOAIDA (Bückner *et al.*, 2000) is focused on the interpretation of remote sensing data. Hereby an exclusive hierarchical description of the problem in a semantic network arose. Furthermore the possibility to add holistic operators is integrated. In AIDA only the leaf nodes of the used semantic network contain image processing operators to extract objects of the image data. The following grouping of the objects implied the problem, that the combinational diversity was often very high, because all objects extracted from the image had to be taken into account at the same time.

The so-called holistic operators can reduce the problem of the combinational diversity, by interpreting one image holistically. Holistic image processing operators can be connected to all nodes of the semantic network. The task of holistic operators is to divide a region into sub-regions and to reduce the possible alternative interpretations if applicable. The structural interpretation of the sub-regions follows and can verify or disprove the holistic results.

The aims of the system GEOAIDA are:

- Generation of a structural description of a given scene.
- Generation of hierarchical thematic maps.
- Multi-sensor analysis.

- Flexible integration of any image processing operator to the system.
- Treatment of alternative hypothesis.
- Inclusion of object relations to the analysis.
- Introduction of previous knowledge, e.g. knowledge of geographic information systems.
- The system offers a clear sequential control.
- Continuous geo-references of all objects.
- Clear and flexible structuring of the problem description.
- Parallelizing of all processes to accelerate the analysis.
- Easy to learn and expand by use of XML-interfaces.

The basis for interpretation of remote sensing data are results generated with image processing operators. In this context, image processing operators are all operators, that generate a labeled result image of a given image under use of a function. Each label has a special meaning. Such image processing operators are denoted classifying operators. They can fulfill simple threshold operations, texture based or model based methods and build the basis for an interpretation.

The different results of such operators are structured in GEOAIDA for optimal use. The problem, that different image processing operators can generate different information of the same region in the image, or that image processing operators generate wrong part interpretations is solved by use of addition knowledge, e.g. neighborhood relations. This additional knowledge is formulated in the nodes of the semantic network. Here, part-of relations or neighborhood relations of objects are specified.

Examples for typical input data of the system are shown in figure 1. The figure shows a region, recorded with three different sensors. The upper part is an example taken from an image recorded with a sensor in visual range, the middle



Figure 1: Multi-sensor Input Data (VIS, IR, Laser-scan) - TopoSys

part is recorded with an infrared sensor and the lower part of the image are height data, generated of laser-scan data.

Interpretation of remote sensing data means to transform input data into a structural and figurative description of the input data, which represents the result of the analysis (see on right side in figure 2). The structural description generated from the generic semantic network has the same structure as the semantic network. This form of result description makes it possible to access information of the object type, the geo-coordinates and all other attributes calculated during the analysis. The result and all intermediate results are stored in XML-descriptions and can be used for other examinations.

The figurative results are thematic scene maps (see figure 2) existing for all abstraction levels. The results can be iterative visualized for the existing abstraction levels. The detail level of the structural presentment corresponds with the figurative presentment. The selection of an object in the figurative representation focuses the corresponding object in the structural representation, so the attributes of the object are directly available.

2 SYSTEM DESCRIPTION

In addition to the input data additional knowledge in terms of a semantic network is provided to the system (see figure 2). This semantic network, exemplarily shown in figure 3 contains nodes and edges, whereat nodes represent the objects and edges represent the relations between the objects. Nodes of the semantic network are denoted concepts. During the analysis, the generic semantic network generates an associated network of instances, denoted instance network. In the concept nodes the data necessary for the analysis and an image processing operator are stored.

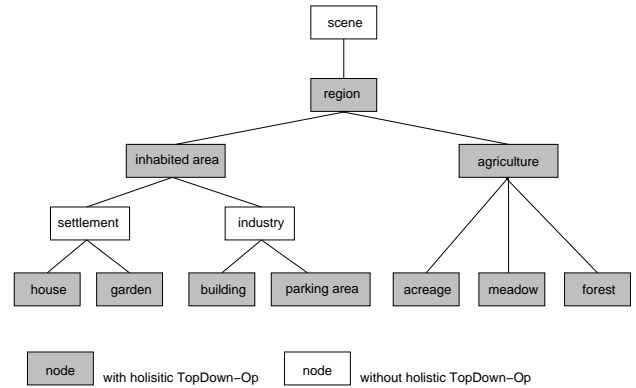


Figure 3: Example for a Semantic Net

The stored data is e.g. the minimal and maximal number of instances, that is necessary to build a higher instance. The instance *settlement* must contain at least two component parts of type *house*.

The semantics of the nodes of GEOAIDA is not exact determined, as in other semantic networks (Tönjes *et al.*, 1999), but can be particularized in the bottom-up-operators.

The result of the interpretation is shown schematically on the right side of figure 2 and contains a structural description of the result and a presentment of thematic maps.

2.1 Analysis

The middle part of figure 2 shows the analysis structure, which can be distinguished in two analysis steps, the bottom-up-step and the top-down-step. The top-down-analysis is model based and generates a network of hypothesis based on the semantic network. The grouping of hypothesis and the associated verification or falsification of the hypothesis is task of the data driven bottom-up-analysis. Result of the bottom-up-analysis is the instance network shown in figure2.

2.1.1 Top-down-operator The top-down-operator has the task to separate a region into subregions and to build hypothesis for the expected objects. The task is realized recursive from the upper nodes in the semantic network to the lower nodes. For this purpose any segmentation operator can be integrated, which creates hypothesis for the subregions. The advantage of holistic operators are e.g. splitting a region into subregions by means of a consistency measurement. E.g., the contemplation of texture allows only a few possible hypothesis for the investigated region, other possible hypothesis contained in the semantic network are not possible.

For all generated subregions geo-references exist, so the global reference is always given. The use of holistic operators enables a limitation of possible hypothesis, whereby the complexity of the analysis and the calculation time is reduced. Holistic operators can reduce the class affiliation of a region, without knowledge of the exact component parts of the region. During the top-down-analysis the

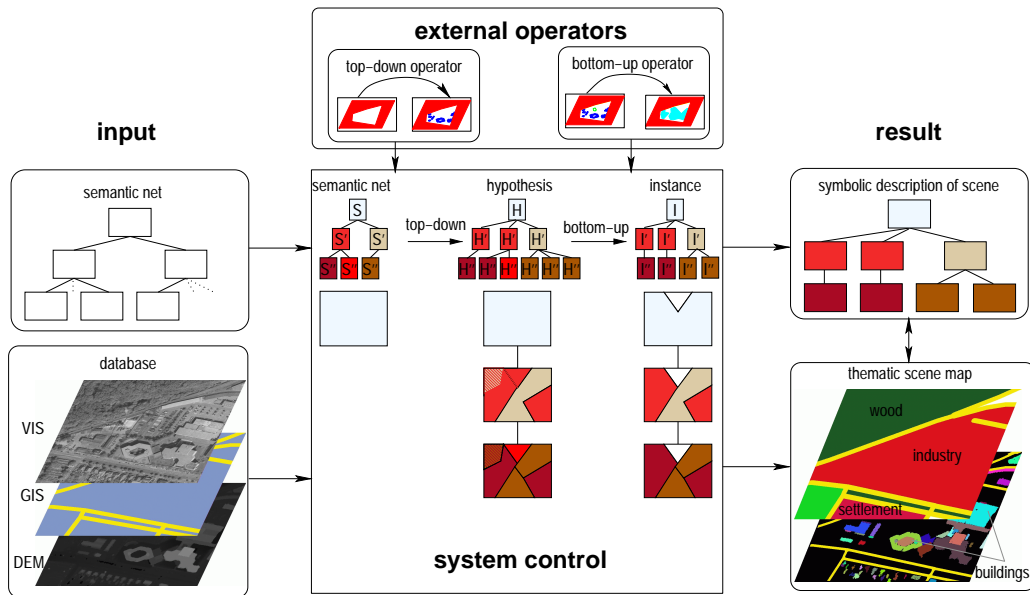


Figure 2: Components of GEOAIDA

restrictions of the concepts are checked and hypothesis, which are not conform are deleted.

The depicted process chain is shown in figure 2. On the left side in figure 2 the input data is shown, consisting of an image database and a semantic network. In the middle part of figure 2 the scene interpretation is illustrated: The top-down-step generates a hypothesis network, shown in the middle, the bottom-up-step generates an instance network (see on right side). Under the three different networks the corresponding regions in the image are illustrated in three different levels of detail. On the right side in figure 2 the result of the scene interpretation is illustrated.

2.1.2 Bottom-up-operator The bottom-up-operator has the following tasks:

- Extraction of object attributes and measurement of single objects.
- Grouping of objects with guidelines of the user.
- Adaption of the label images to the new obtained interpretation.
- Measurement of the new group, generated by the bottom-up-step.

If the top-down-analysis reaches the leaf nodes, the analysis turns from model based interpretation to data based interpretation (bottom-up). The bottom-up-operators can also be extern programs, designed by the user of GEOAIDA. The user can also specify his special tasks in a functional description language. This sequence is shown in the right part of the scene interpretation in figure 2 corresponding to the top-down analysis. The top-down-path can generate different hypothesis for one region. The bottom-up-step has to decide for an explicit interpretation

for a region (see figure 2). The uncolored areas illustrate not classified regions, GEOAIDA can make use of a rejection class. Same colors in the structural illustration and in the figurative map denote the same object class.

3 EXAMPLES

Because it is not possible to explain the whole analysis of a project, some significant steps of the analysis are exemplarily demonstrated. The first example shows, how a region can be classified by means of the extracted objects. In the following the necessity of a quality factor for concurrent interpretation possibilities and the splitting of a region in different classes is illustrated. For the initial segmentation of the complete scene streets are used for the region borders. The streets can be taken from GIS or can be automatically extracted (Aviad *et al.*, 1988) (Barzohar *et al.*, 1993) (Bückner, 1998) (Baumgartner *et al.*, 1999) from the image data. In figure 4 a part of the complete scene is pictured. Figure 5 shows all objects detected during the scene analysis of one region. In figure 5.a the first step, the initial segmentation of the scene is shown, the streets are marked with black lines. For the central region the hypothesis *inhabited area* (compare figure 3) is examined. In figure 5.b the visual aerial image is shown. The extracted objects, like houses, are shown in the following figure 5.c without image data, each object type has its own label. The houses in figure 5.c are extracted with use of height data by an building extraction operator.

The initial hypothesis for the region *inhabited area* can be validated based on the existing component parts like the extracted houses. The interpretation result of the examined region framed by streets is the class *settlement* illustrated in figure 5.d. The classification result of the region was made with a quality factor, that is calculated of the component parts included in the region in the following way:



Figure 4: Part of the Complete Scene

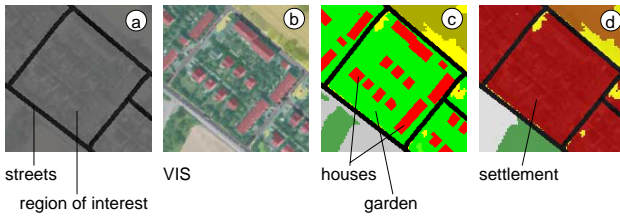


Figure 5: Example 1

The objects extracted as houses have a high quality factor, because the area of these objects lies between $60m^2$ and $500m^2$ and the orthogonality of the house corners is fulfilled. For the other existing class *garden* the expected area has realistic values. The ratio of the area filled with houses and the *garden* area is used for the interpretation of the examined region, also the quality values of the objects itself.

The second example is more complex, it describes the separation of a region into several classes with use of the quality values for the concurrent interpretations during the analysis. In figure 6 a part of the lower left side of figure 4 is shown separated by streets, which was extracted by application of a road detection operator.

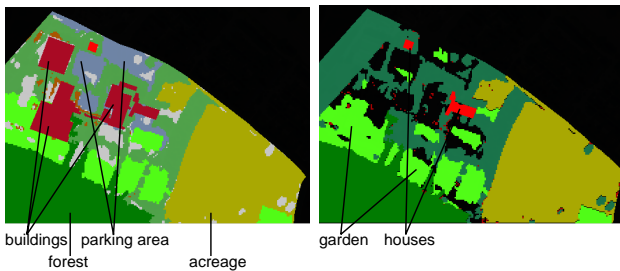


Figure 6: Example 2

On the left side of figure 6 objects that permit the inter-

pretation *industry* (e.g. *buildings* or *parking areas*) are illustrated with different colors, on the right side the same region is shown with illustrated objects that permit the interpretation *settlement* (e.g. *houses* or *garden*). Black regions illustrate areas that are not compatible to the supposed class. The decision for the region between the two competing interpretations is motivated by the hypothesis *industry*. The areas that are interpreted as *buildings* have attributes with high quality values for this interpretation. The areas of the different *buildings* have values between $120m^2$ and $1000m^2$ and the orthogonality of the objects is fulfilled. The other objects, like *parking area* and *group of trees* have expected realistic values for the class *industry*. For the classification of the examined region the quality values of the objects and the ratio of the whole area of the region and the sum of the *building* area is used. For the hypothesis *settlement* the analysis is similar, but the objects and object types are taken from class *settlement*. The analysis has the following results: the hypothesis *industry* has a quality value of 0,92 the competing hypothesis *settlement* has a value of 0,42. The analysis selects due to the quality values the interpretation *industry*. The sum of all objects of the class *industry* build the result area.

The big regions on the lower left and lower right side of the image in figure 6 are not included to the interpretation *industry*, because this *acreage* and *forest* areas do not match the class *industry*. These areas are interpreted as own classes, so that a separation of a region into three sub-regions is realized.

The third example should explain the use of spatial relationships between the extracted objects for grouping the objects. The classes *forest* and *settlement* implicit that the included objects have a special spatial relationship among each other. The *houses* or *trees* of these classes have distances less a normal value. To illustrate this issue in figure 7 the result of extracted trees, extracted with use of laser-scan data, is given. In addition to the extracted sin-

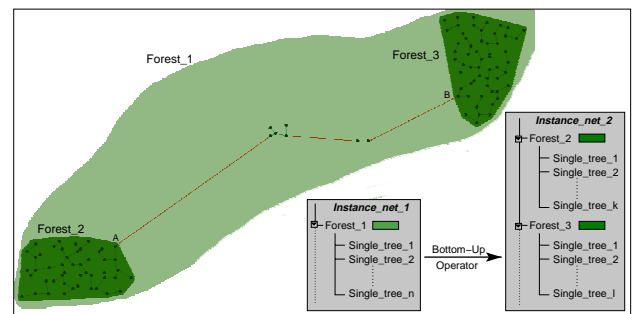


Figure 7: Example 3

gle trees a graph that connects all trees is plotted. The sum of all distances of the connections is minimized. The disconnection of the graph at the marked positions A and B generates two groups of trees, that have enough trees to be interpreted as *forest*. The two found regions of *forest* are marked with dark color. The two interpretation steps in figure 7 show the change of the instance net. This method

can also be used for the detection and separation of the class *settlement*.

The described functions of GEOAIDA are easy to use, the operators can solve complex grouping tasks by use of a functional language.

4 CONCLUSIONS

The very flexible knowledge based interpretation system GEOAIDA was introduced. GEOAIDA is based on the functionality of existing image processing operators that can be used context specific and can be initialized problem specific. The arising hypothesis of the first step are grouped and valued by use of context knowledge in the second step. This approach enables a decision between alternative interpretations and provides consistent results. The results can be used as basis for maps or for geographic information systems. The further development of GEOAIDA should allow the multi-temporal interpretation of remote sensing data. The detection of alteration can be used for environmental studies, the development of urban areas and for examination of natural disasters.

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