

CONCEPTUAL DEVELOPMENT OF AN ASSISTANT FOR CHANGE DETECTION AND ANALYSIS BASED ON REMOTELY SENSED SCENES

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ABSTRACT:

Because automatic methods for thematic interpretation purposes are not (yet) able to handle complex data sources and criteria, we propose to go back to, respectively to integrate, the classical visual approach and to improve it with methods and tools of geovisualization. For the case of a change detection and analysis we developed a concept for an assistant that applies the principle of the basic questions related to spatio-temporal phenomena (“where”, “when” and “what”) from which two parts form the input and the remaining one the output of such an operation. A simple example shows the additional value of this approach, in particular the chance to differentiate between existential changes and property changes of objects.

1. INTRODUCTION

Remotely sensed scenes have a steadily increasing impact on describing, modelling and simulating landscape structures and processes. Nowadays new applications (like urban monitoring) or classical applications at larger scales can be addressed due to technical developments of the sensing systems concerning their spatial, spectral and radiometric resolutions. With this increased potential a stronger integration of the derived geo data in binding decision and evaluation processes takes place. On the other hand it has to be stated that automatic and time saving approaches for a thematic interpretation of remotely sensed scenes is by far not operational yet, a status that is caused by several reasons (like variance and complexity of topographic knowledge representation) and that probably will be valid for the next ten years or so.

Based on these deficiencies - and concentrating on the task of monitoring and analysing land cover changes - our general idea is to go back to (respectively to integrate) the classical visual approach and to improve it with methods and tools of geovisualization. Section 2 will justify the need for the application of geovisualization for the processes of object recognition and in particular for change detection and analysis based on remotely sensed data. Based on the existing deficiencies section 3 demonstrates a new concept for the actual use of geovisualization methods and, by giving an example, their additional value.

2. NEED FOR GEOVISUALIZATION IN INTERPRETING REMOTELY SENSED SCENES

Although since many years the main research focus in Remote Sensing and Photogrammetry is on the *automatization* of interpretation processes, we will follow here the key hypothesis that there is *also* an increasing need for enhancing and integrating *visual* methods for recognizing objects as well as for detecting and analysing changes from remotely sensed scenes.

2.1 Object recognition

With respect to the process of object recognition, i.e., the detection and processing of scene features for certain primitives and their subsequent classification, the following aspects have a major influence on the accomplishable (and limited) grade of automatization:

With the advent of new and modern remotes sensing systems and the advanced availability of other geo data not only the **amount** but also the **complexity of data sources** in the overall interpretation process are increasing. Due to enormous sensor developments it is possible to obtain not only multi-spectral, but also hyper-spectral imagery with improved geometrical resolution, as well as 2.5D and 3D data (e.g., from operational LIDAR or RADAR systems), or sometimes even 4D data.

While the potential of the data sources and along with that the potential to model more complex structures or phenomena of the real world increase, also the **criteria for the classification of remotely sensed data** and the subsequent decision making process become more and more complex. For example, features like pattern or neighbourhood have to be used more frequently. On the other hand there is a lack of well accepted and generally meaningful quantitative measures for those parameters, so that a qualitative (visual) interpretation has to be taken into consideration. With the increasing number of available scene features also an appropriate selection becomes necessary – a process that needs huge pre-knowledge, which in general can only be supported by the human interpreter. Finally it is well known that criteria can strongly vary as a function of the used sensors, date, region, etc. Here again the ability to select features with a large grade of flexibility is needed.

On the other hand we can state that **automatic methods** for object recognition are not operational yet. Of course, there exist numerous solutions for specific applications. However, those are very often limited to a subset of data sources, scene features or objects that shall be derived – by this the overall potential of

the data set is not exploited. Furthermore, the transferability to other scenes, dates or sensors is quite limited.

2.2 Change detection and analysis

Another key task in the processing chain is concerned with the detection and analysis of changes. For simplification purposes we assume the existence of classified data for two or more dates which have to be compared. Applied to this specific task all related **spatio-temporal questions** can be grouped according to Peuquet (1994) to the following categories:

- “when” + “what” à “where”: Describe all the locations occupied by a given existential change type (i.e., appearance, disappearance, revival, or none of them) at a given pair of dates;
- “when” + “where” à “what”: Describe the existential object change that is present at a given location (a single pixel or area) at a given pair of dates;
- “what” + “where” à “when”: Describe the pair of dates for which a given existential object change occurs at a given location.

For answering those spatio-temporal questions a couple of **standard representations** are possible:

- A *change matrix* gives a pure numerical representation of the type of existential change for all object classes for a given pair of dates. However, this neglects information about the spatial occurrence and correlation of changes (in other words, the “where” component gets lost).
- A *simultaneous display of all classified images* in a single static form demands for *multiple linked views* (for details see Roberts, 2005). In this context a geographical linkage (assuming a georeferenced data set) facilitates simultaneous pointing and digitizing in all windows. Figure 1 gives an example using Erdas IMAGINE. One disadvantage of this solution is that it might lead to several windows in relation to the given dates. Furthermore numerous eye movements have to be performed from window to window. Furthermore, the user has still to filter out the actual changes versus the non-changed areas from the given layers. In other words: Answering the “what” questions is not straightforward.
- Alternatively the various classified images can be displayed in an *animated form*. Besides the above mentioned disadvantages this form makes the evaluation difficult because a currently displayed status has to be compared with mental images of earlier states (Andrienko et al., 2005).

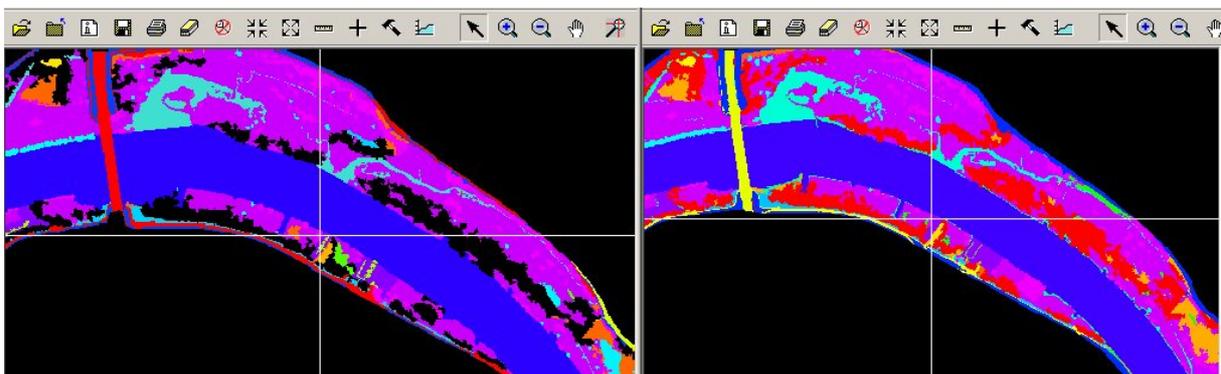


Figure 1. Principle of multiple linked windows for change detection

- *Overlaying multiple scenes in one view* demand for special interactive techniques (like blending, flickering, or swiping) in order to make the respective scenes visible at desired points of time (see figure 2). While eye movements are clearly reduced, changes have still to be filtered out and the superimposition techniques always lead to an occlusion of some parts of the images.

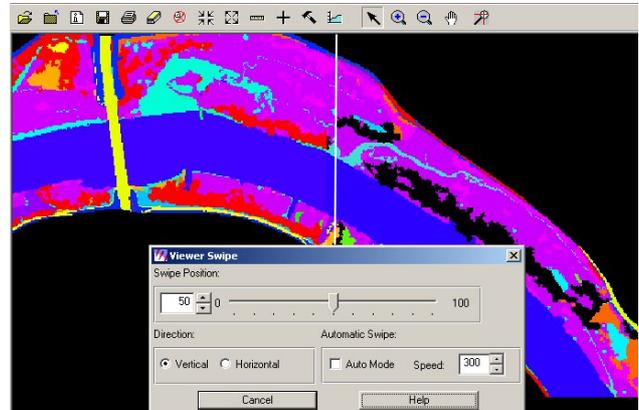


Figure 2. Principle of swiping for using one window for multiple scenes

- *Difference images* (displayed in a single view) generally summarize all changes at a glance, class specific information which might be of interest get lost. If several class specific difference images are generated, we have to apply interactive techniques (layer selection) for their display in a single window. However, the above listed disadvantages concerning eye movements and necessity of change filtering are avoided or minimised. Moreover, the usage of a difference image allows for other data sources as additional background information when transparent display techniques are applied.

In all cases, due to the standard raster representation *existential changes* (i.e., the appearance, disappearance or revival of an object) can not be distinguished from *changes of the spatial properties* of an object (i.e., concerning its location, size or shape) without the help of a visual interpretation. Furthermore, a solely use of a cartographical representation will neglect underlying statistical or thematic data so that quantitative information about the percentage or absolute area of change or about changes in attributes are not available.

Going even one step further, from detecting to **analysing changes**, the underlying complexity increases even more.

Because core objective of the analysis is to explain the functional reasons of changes we switch from low level spatio-temporal questions (like: “what is at a given location at a given time?”) towards high level questions that try to extract complex spatial features like one-pixel wide lines, anomalies like single outliers, or neighbourhood to certain classes. Answering these high level questions needs an iterative process, i.e. a fast switch between different representations according to different perspectives, parameter settings, etc.

Furthermore it should be overseen that prior to the actual change analysis the **separation of inherent classification errors** from actual changes should take place. This necessity is demonstrated by sensitivity investigations by Pontius & Lippitt (2006) who show that half of the detected changes are due to errors and not to actual changes if we assume an overall classification accuracy of 91% in both input data sets. As a consequence, additional (geo) data and complex criteria should be considered. For example, it might be of great interest to look not only at the classified layers but also to rely on the original imagery or on other geo data. Again, this means an increase in amount and complexity of the process that is hardly manageable by automatic processes.

Based on these considerations our idea is to combine the strengths of automated and visual methods for interpreting remotely sensed scenes and related geo data. In particular we want to support the visual interpretation with advanced tools of *geovisualization*, which following the definition of Crampton (2002) is a “method and approach for the visualization of geographic data in order to explore patterns, generate hypotheses, recognize connections or disruptions, and identify trends”. In contrast to classical cartography the exploration aspect is stressed much more and with that advanced user interfaces and interactive elements become necessary. In the following section we will describe a corresponding possible design for the task of change detection and analysis.

3. CONCEPT FOR A VISUAL CHANGE DETECTION AND ANALYSIS ASSISTANT

3.1 Introductory remarks

The previous section has pointed out the necessity for the application of visual methods – in combination with automated ones – for recognizing objects as well as for detecting and analysing changes based on remotely sensed and eventually classified data. The idea is to apply methods and tools coming from the domain of *geovisualization* (Crampton 2002; MacEachren & Kraak, 2001) in order to improve the overall interpretation process. So far, most of the *geovisualization* approaches have been designed for processing vector data (e.g., Andrienko et al. 1999), and only some for analysing classified raster data (e.g., Andrienko et al. 2003) or for detecting objects in remotely sensed image data (Schiewe, 2006).

In the following we focus on a change detection and analysis based on classified (i.e., thematic) raster images. In this domain Andrienko et al. (2005) designed a tool for analysing the temporal variation of numeric attributes over time (consisting of several dates). They linked a choropleth map with a time plot showing the attribute values over time. In contrast, in our case we treat the more “simple” case of only one nominal attribute value (the object class) for several (generally only two) dates.

Based on the above described deficiencies the general goals of the following conceptual development are

- a user defined selection and combination of underlying representation types,
- the choice of efficient interactive elements for iterative interpretation operations, and
- a near real time performance of these operations.

3.2 Design aspects

In the following we assume the existence of two (or more) classified scenes, i.e. thematic raster images, from which changes shall be detected and analysed. Due to the general advantages as outlined in subsection 2.2 we will follow and extend the approach of visualizing *difference images* displayed in a single window. For that reason we assume not only the availability of the classified scenes but also of the corresponding change detection matrix. Based on this once so called *cell images* have been derived, which represent the content of each matrix cell (indicating changes from the i-th class at date 1 to the j-th class at date 2). With that the desired combination of numerical and cartographical representations is enabled.

For modelling the above mentioned spatio-temporal questions (“when”, “where” and “what”) an assistant is developed that controls the necessary input parameters and allows for a display of results. All parameters attached to each question are grouped into a separate block within the user interface (see figure 3):

“When”:

- If the dates are regarded as input (i.e., for the cases “when”+“where” à “what”, or “when”+“what” à “where”) two drop-down list boxes are used.
- The case that the date is regarded as output (from “where”+“what” à “when”, i.e. the question, when a certain existential change occurred at a given position) is more or less only meaningful if more than two dates exist. In this case the respective results are displayed in alphanumeric form.

“Where”:

- The input of locations is performed via typing in numeric co-ordinates or clicking to a certain position within the cartographic display. Alternatively also a region could be defined by drawing a corresponding rectangle.
- If the locations are regarded as output (in the most important case “when”+“what” à “where”) the respective pixels are colour-coded (generally in a transparent colour in order to keep the underlying information of the selected layer visible). This process implies an union of respective cell images and their common visual presentation through the principle of *attribute brushing* or *highlighting*, respectively. This highlighting enables the visual interpreter to detect significant structures (like isolated points or elongated features) in order to answer high level questions as pointed out in section 2.2. Furthermore the aggregated cell images can be superimposed onto any existing cartographical representation (i.e., not only onto the classified images, but also onto the original spectral imagery or other geo data). Finally, it is possible to display numerical information (as derived from the change detection matrix).

“What”:

- In the case of an input firstly the existential change type (win, loss, win or loss, or none of them) has to be selected via a radio button. In addition the class or classes under consideration have to be defined for the two dates using drop-down list boxes.
- For the case of an output (from “when”+“where” à “what”) the change type is automatically ticked and the respective classes of the selected pixel are displayed in alphanumeric form.

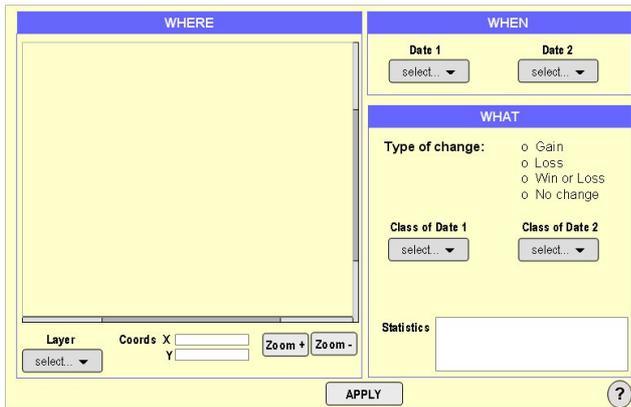


Figure 3. Raw design of the proposed change detection and analysis assistant

The user fills in the necessary input parameters for two blocks (e.g., “when” and “what”) and obtains an immediate result (here: “where”). Due to the assistant encapsulation the desired iterative loop can be performed very quickly which is an important feature for an effective and efficient change detection and analysis.

Finally, we propose the insertion of a protocol board for saving the observations (including parameter settings, selected screenshots and statistics) during the iterative analysis process. In a first step this board is just an integrated text editor, for future implementations also an audio input (eventually with optional speech-to-text conversion) might be of interest.

3.3 Example

In the following a simple prototype based on the application of a biotope type monitoring along the River Elbe near Hamburg will demonstrate the additional value of the outlined approach. The underlying data set consists of multi-spectral imagery and LIDAR elevations as well as classified images for two dates (2000 and 2002). For more information on the underlying project as well as on the classification strategy refer to Ehlers et al. (2006).

For a subset (spatially and thematically) a change detection matrix has been generated from which an overall change rate of 14% has been derived. In the following it will be shown that the application of the change assistant tool leads to a deeper understanding of the inherent changes. We focus here on the most important “when”+“what” à “where” question: “At which locations can observe a potential loss of class BAT (a certain type of bush) between the years 2000 and 2002?”

The resulting areas are marked via a transparent red colour on top of a RGB image which is displayed for a spatial orientation and correlation reasons (figure 4).

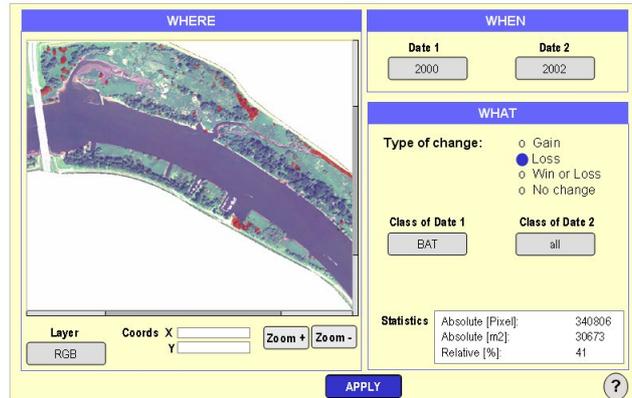


Figure 4. Result of analysis “when”+“what” à “where” (overview, background RGB image)

So far only the existential changes (her: loss) are displayed. Figure 5 shows how a visual interpretation (in an enlarged view) also leads to an analysis of object properties: It can be clearly seen that we have not only existential changes but quite often only a reduction of object sizes (which might be due to another phenological state). Also very small areas can be detected which are candidates for classification errors.

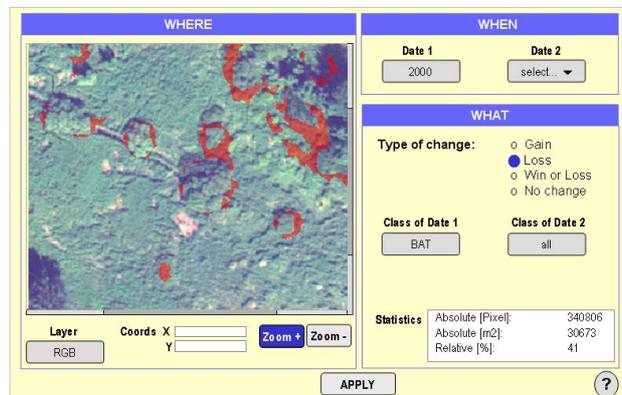


Figure 5. Result of analysis “when”+“what” à “where” (zoom-in)

Going one step further, figure 6 that overlays changed areas (now marked in white) onto the classification of date 1 gives some indications about the neighborhood which might have an influence on the occurrence of changes.

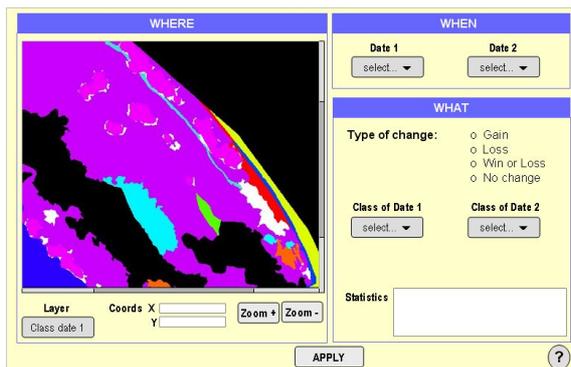


Figure 6. Result of analysis “when”+”what” à ”where” (background classified image for date 1)

Summarizing this example it can be seen that important additional information about patterns and neighborhood can be derived with this visual approach. In particular the differentiation between existential changes and property changes of still existing objects leads to a more precise explanation of actual landscape variations. Especially the rather “dramatic” overall change rate of 14% can be attenuated significantly.

A detailed implementation under the system Erdas IMAGINE® or an open source GIS is envisaged, like also an empirical testing of the environment concerning its usability factors is planned.

4. CONCLUSIONS

With the advent of new and modern remotes sensing systems and the availability of other geo data not only the amount and complexity of data sources increase but also the demands concerning the interpretation with respect to thematic details and the speed of the process. Hence, the tasks of object recognition and change detection rely more and more on high level questions that are looking for patterns, neighbourhoods, etc. On the other hand automatic methods for thematic interpretation purposes are not (yet) able to answer those questions in an operational manner. Therefore we propose to go back to, respectively to integrate, the classical visual approach and to improve it with methods and tools of geovisualization that allow for a user defined selection and combination of underlying representation types, the choice of efficient interactive elements for iterative interpretation operations, and a near real time performance of these operations.

For the specific case of change detection and analysis we developed a concept for an assistant that applies the principle of the basic questions related to spatio-temporal phenomena (“where”, “when” and “what”) from which two parts form the input and the remaining one the output of an operation. A simple example already showed that important additional information about patterns and neighborhood could be derived with this visual approach. In particular the differentiation between existential changes and property changes of still existing objects leads to a more precise explanation of actual landscape variations.

Future work is concerned with the implementation of this concept (e.g., under the system Erdas IMAGINE® or an open source GIS) and an profound usability assessment. Furthermore, the visualization has to be extended for a simultaneous evaluation of more than two dates at the same time.

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