International Workshop on Visual Analytics (2011)
S. Miksch and G. Santucci (Editors)

A Framework for the Multi-Temporal Analysis of Land Cover Change using Visual Analytics

C. Kinkeldey and J. Schiewe

HafenCity University Hamburg, Germany

Abstract

Land cover change analysis serves as a basis for planning processes in a wide range of applications. For this task, the use of remote sensing data has become more popular over the last decades. However, despite much research in the field of change analysis based on remote sensing data, effective and efficient methods are not available yet. In order to get closer to this goal, we propose the application of Visual Analytics to this field combining computational methods with interactive visualization. We expect that the close integration of the user into the change analysis process will lead to more powerful solutions. However, for the design of tools following this approach we see the need for instruments to formalize workflows. For this reason, we are developing a framework that allows for a systematic workflow description. This contribution presents the basic concept of the framework including an exemplary application.

1. Introduction

The analysis and documentation of land cover changes provide the basis for planning processes in various fields such as climate research, environmental science, or urban planning. They are often conducted using remotely sensed data, especially satellite imagery, which is widely used providing large-scale coverage of the Earth at relatively low costs.

Generally, most of the procedures in this field are focused on the detection of changes. For this task, various semi-automatic procedures exist. However, despite much research in the past these are not yet applicable effectively and efficiently. The high complexity and dimensionality of the data as well as the lack of transferability of parameters from one dataset to the other lead to problems such as the high amount of incorrectly detected changes [CJNM04].

Besides, we see the disadvantage that common change detection methods are limited to bi-temporal (pairwise) analyses. This often results in an incomplete view on the change over time. But with the analysis of spatiotemporal changes, aspects of time can be highly relevant. Depending on the application, diverse temporal scales can be of interest ranging from long-term changes (e.g. geologic processes) to relatively rapid developments (as in disaster management).

Another drawback of conventional methods is that uncertainty information is widely neglected though this information is usually available, e.g. in terms of class membership values or class probabilities that come with most classification algorithms. One of the reasons for the rare use of uncertainties is the lack of proper means within GIS software to communicate this information to the user.

Under these circumstances, the aim of fully automated methods does not seem reasonable. Consequently, we propose the application of Visual Analytics to this field. The combination of visualization with data analysis and the close integration of the user makes highly interactive workflows possible [KMS*08]. This shows great promise for tackling the drawbacks of currently available change analysis methodology.

In this paper, we present a basic framework for change analysis in remote sensing imagery. It provides means to formalize workflows supporting the development of interactive change analysis tools. The paper is structured as follows: In Chapter 2 we sum up related work from the field of visual analysis of remote sensing data. The main part of this contribution, the description of the basic framework, can be found in chapter 3. An example workflow is presented to clarify the idea of workflow formalization. Chapter 4 describes the extension of the framework as part of future work. The conclusion in chapter 5 completes this paper.

DOI: 10.2312/PE/EuroVAST/EuroVA11/033-036

2. Related Work

Related work in the field of change analysis can rarely be found. Hoeber et al. present GTDiff, a system for the visualization of geo-temporal differences. It allows for interactive exploration and analysis of multi-temporal changes based on the visualization of spatiotemporal difference graphs [HWH*10].

Other work related to Visual Analytics in remote sensing is mostly focused on the field of classification. On the one hand, there are approaches for the improvement of the classification process. Lucieer presents a Visual Analytics system called 'Parbat' [Luc04]. It serves as a tool for the optimization of segmentation parameters focusing on the uncertainties during this process. On the other hand, a number of visual tools deal with the enhancement of class definitions, e.g. Ahlqvist handles incompatibilities of class definitions for land cover and land use by visualizing semantic similarity and overlap between class definitions [Ahl08].

Regarding the analysis of time series, a lot of relevant work has been done by Andrienko & Andrienko. Their work comprises a suite of Visual Analytics tools for the multi-temporal analysis of massive movement data, e.g. from mobile phones, especially for detecting and analyzing events within the data [AAM*10].

Another domain related to this research field is modeling uncertainties and their visualization. Fisher et al. show in [FAWW06] that incorporating uncertainties during change detection (based on fuzzy classifications) can reveal subtle landscape phenomena especially with the analysis of ecotone change. Bastin et al. compile typical sources of uncertainty in remote sensing imagery and present the VTBeans toolkit for uncertainty visualization [BFW02].

All in all we still see the need for a systematic, generalized approach dealing with change analysis using Visual Analytics.

3. Framework concept

The basic idea of our approach is to overcome the drawbacks of existing (semi-)automatic approaches by integrating them into a Visual Analytics framework. The aim is to improve the user's insight into the data by the combination of visualization, human factors, and data analysis. For the systematic design of workflows, their documentation, and for reasons of interchangeability, we see a need for a formalization concept. Hence, we propose a framework for the specific field of multi-temporal change analysis of remotely sensed data.

3.1. Basic workflow structure

The change analysis workflows we are aiming to describe can be mapped to a basic structure. Figure 1 shows a first design of a basic workflow graph containing the following nodes:

- Data: All data used in the workflow which can be remote sensing imagery, GIS layers etc.
- Hypothesis: A hypothesis about a change event
- Event: The change event as result of the workflow
- Computation: Computational steps in the workflow
- Visualization: Visual communication to the user
- User: User interaction involved in the workflow

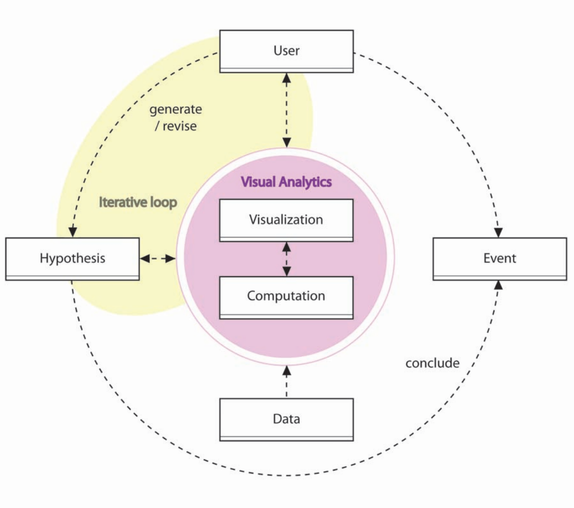

Figure 1: *Basic workflow structure*

The central parts of the graph are the two nodes Visualization and Computation, summarized under the term Visual Analytics. They form the link between the User, Data and Hypothesis nodes. A crucial part of this workflow structure is the iterative loop:

1. The user generates a hypothesis about a change event (Hypothesis)
2. Information about this change event is created (Computation)
3. The information is communicated visually to the user (Visualization).
4. The hypothesis can be revised iteratively.
5. If the hypothesis is stated the change event can be concluded.

3.2. Workflow graph

For the description of specific workflows we define a graph containing the basic workflow nodes as different levels: Data, Hypothesis, Event, Computation, Visualization, and User. Each step in the workflow is mapped to a node in the graph. Directed edges indicate possible paths in the workflow. In Figure 2, we present an exemplary description of a simple workflow: The extraction of stable change events for a specific change pattern (i.e. the change of classes) on the basis of change uncertainty. This is a way to reduce the amount of false positive changes that come along with the

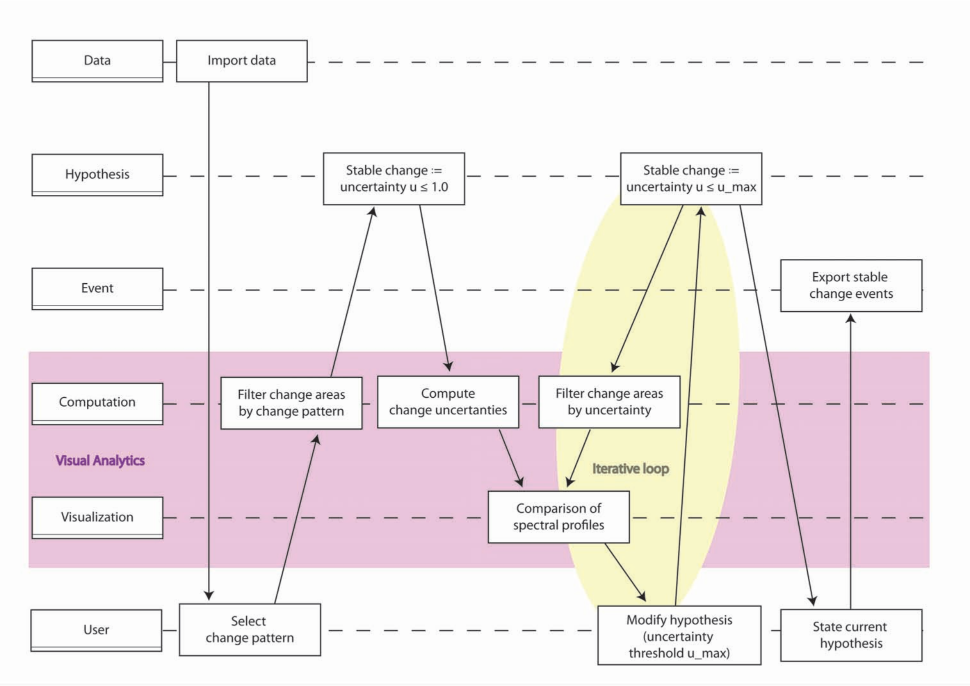

Figure 2: *Workflow graph for the task 'Extracting stable change areas'.*

change detection result. The workflow graph ranges over the six levels starting with the import of data and ending with the export of stable change events as the result of the workflow. Note the iteration in which the hypothesis is revised by the user, the change areas (areas where a change takes place) are filtered based on the modified uncertainty threshold and the result is visualized again. This iteration is repeated until the user decides the hypothesis has been fulfilled, i.e. the current uncertainty threshold leads to a well-defined distinction between unstable and stable change events. This graph is a means to describe workflows for the purpose of documentation and interchangeability. For the development of a software tool on the basis of the graph we need to derive a specific implementation though. The following list describes the implementation of the workflow 'Extracting stable change events'.

1. Data: Import data
   A number of remote sensing scenes are imported as raster files in GeoTIFF format as well as the related change areas as vector files in ESRI SHAPE format including classification uncertainty as attribute.
2. User: Select change pattern
   The user selects a change pattern (e.g. from 'deciduous' to 'arable land'). This is done using a combo box widget showing all occurring change patterns.
3. Computation: Filter change areas by change pattern
   Remove all change areas that do not fit the change pattern using a filter script.
4. Hypothesis: Stable change := uncertainty u <= 1.0
   The initial hypothesis is that the changes in all change areas are stable (expressed as 'change uncertainty u <= 1.0').
5. Computation: Compute change uncertainties
   Determine the change uncertainty for each change area. The change uncertainty is computed by determining the maximum of the classification uncertainties of all scenes.
6. Visualization: Comparison of spectral profiles
   For this task, we have chosen parallel coordinate plots providing a comprehensive overview of all profiles making the identification of outliers possible. Please refer to Figure 3 for further description.
7. User: Modify hypothesis (uncertainty threshold u_max)
   The user varies the uncertainty threshold that separates stable from unstable changes. A slider widget fulfills this task (Figure 3).
8. Hypothesis: Stable change := uncertainty u <= u_max
   The hypothesis is revised using the new threshold.
9. Computation: Filter change areas by change uncertainty
   Remove all change areas that exceed the uncertainty threshold using a filter script.
10. User: State current hypothesis
   The user states the current hypothesis about stable change events. This is done by pressing a button in the uncertainty slider widget.

11. Export stable change events
    The result of the workflow is a set of stable change events for the chosen change pattern. The output is a vector layer in ESRI SHAPE format containing the change areas where stable changes took place.

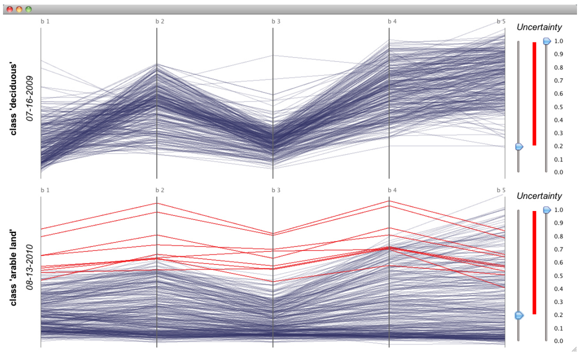

Figure 3: *A multiple parallel coordinate plot for the comparison of spectral profiles. The axes correspond to the spectral bands, each line in the plot represents a pixel in the change areas. This is a comparison of two scenes from 2009 and 2010 for the change pattern 'deciduous to arable land'. The current uncertainty threshold is 0.2, lines with uncertainty values exceeding the threshold are colored in red.*

4. Future Work

When designing a software tool for a specific task on the basis of the workflow description, some of the steps do not need further clarification - the import of data for instance is a straightforward step. On the contrary, the creation of a visualization part is much more complex. From a great amount of visualization methods an appropriate combination must be chosen. Our future goal is to support this decision by the framework so that a developer gets recommendations on how to create suitable visualizations for typical tasks. The objective is to build up a catalogue of recommended visualization types. This will serve as a guideline to support developers with the implementation of Visual Analytics tools for change analysis.

5. Conclusion

The analysis of land cover changes using remotely sensed imagery provides a basis for planning processes in many fields of application. However, existing methods for this complex task do not provide satisfying results and often do not meet the users' requirements.

In this paper, we presented a conceptual framework for the application of Visual Analytics methods to this field. The necessity for this research lies in the drawbacks of available change analysis methodology. We see Visual Analytics as the key to change analysis approaches with a higher degree of effectiveness and efficiency than the methods used today. Our framework allows for the structural description of change analysis workflows providing a basis for the systematic design, documentation, and interchange of workflows. We presented an implementation of the workflow graph for a specific task, the extraction of stable change events from a result set of detected changes. It showed how such a workflow can be mapped to a graph and how a concrete implementation can be derived.

Our current work comprises the collection and categorization of visualization tasks from the field of change analysis with the aim to find recommended visualization types for them. In parallel to the conceptual work we are developing prototypes for typical tasks in this research field in order to show the advantages of the general Visual Analytics approach by means of practical application.

References

[AAM*10] Andrienko G., Andrienko N., Mladenov M., Mock M., Poelitz C.: Discovering bits of place histories from people's activity traces. In *IEEE Conference on Visual Analytics Science and Technology 2010*, MacEachren A., Miksch S., (Eds.). IEEE Press, 2010, pp. 59–66. 2

[Ahl08] Ahlqvist O.: Extending post-classification change detection using semantic similarity metrics to overcome class heterogeneity: A study of 1992 and 2001 u.s. national land cover database changes. *Remote Sensing of Environment*, 112 (2008), 1226–1241. 2

[BFW02] Bastin L., Fisher P., Wood J.: Visualizing uncertainty in multi-spectral remotely sensed imagery. *Computers & Geosciences 28*, 3 (2002), 337–350. 2

[CJNM04] Coppin P., Jonckheere I., Nackaerts K., Muys B.: Digital change detection methods in ecosystem monitoring: a review. *International Journal of Remote Sensing 25*, 9 (2004), 1565–1596. 1

[FAWW06] Fisher P., Arnot C., Wadsworth R., Wellens J.: Detecting change in vague interpretations of landscapes. *Ecological Informatics 1*, 2 (2006), 163–178. 2

[HWH*10] Hoeber O., Wilson G., Harding S., Enguehard R., Devillers R.: Visually representing geo-temporal differences. In *IEEE Conference on Visual Analytics Science and Technology 2010*, MacEachren A., Miksch S., (Eds.). IEEE Press, 2010, pp. 229–230. 2

[KMS*08] Keim D. A., Mansmann F., Schneidewind J., Thomas J., Ziegler H.: Visual analytics: Scope and challenges. In *Visual Data Mining: Theory, Techniques and Tools for Visual Analytics*, Simoff S., Boehlen M. H., Mazeika A., (Eds.). Springer, 2008. 1

[Luc04] Lucieer A.: *Uncertainties in Segmentation and their Visualization: Ph.D. Dissertation*. 2004. 2