Considering Visual Perception and Cognition in the Analysis of Remotely Sensed Images

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1 Introduction

The physiological effects of insect infestations on forests can be examined through the use of aerial and satellite images. However, in some cases, visual identification is difficult. The goal of this research is to understand the role of cognitive reasoning and visual perception in the analysis of multi-spectral satellite images for forest management. From that knowledge, we will implement geovisual analytic methods that enable integration of computational methods and human expertise to support identification and attribution of forest disturbances. To address this goal, we pose three research questions; *1) how do the high-level cognitive processes underlying the image analysis change when image analysts are faced with novel analyses?; 2) how do image analysts use perceptual cues to build a mental model of the image, and use aerial and satellite images to determine the presence and cause of forest disturbances remotely sensed?; 3) how can a geovisual analytic framework and a clearer understanding of reasoning and perceptual processes associated with image analysis be used to develop interactive visual-computational tools to support the identification and attribution of forest disturbances?*

2 Background

Forest disturbances can be attributed to a variety of causes, including natural disasters, anthropogenic activities, and insect infestation. The physiological impact of such disturbances can have dire consequences on ecosystem health. Since the early 20th century, remotely sensed images have been used to identify, monitor, and determine management strategies for forest disturbances such as insect infestations. Still, no two beetle outbreaks are created equal. In some cases, spectral characteristics of infestation damage can be discriminated computationally, but in other cases, such as the spruce beetle infestation where trees are quickly defoliated, visual image interpretation plays an important role in discriminating such outbreaks (Ciesla, 2006).

Today image analysis balances the flexibility of the human mind with the computational power of specially designed computer systems to find patterns, detect trends, and define relationships between phenomena within images, as no fully

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automated analytic system exists. Prior to the space age, aerial photographs taken from such diverse platforms as birds, balloons, and aeroplanes were examined using basic tools and the trained eye of the photo interpreter.

Air photo interpretation elements (perceptual cues and their combinations) for aerial image interpretation were described early in the development of remote sensing (Colwell, 1954; Olson, 1960). In later years, research was carreid out to inform the development of expert systems using the knowledge of trained interpreters (M. Hodgson, 1994). Still, as Gardin et al. (2011) suggests "an often undervalued but inevitable component of the remote sensing image analysis process is human perception and interpretation."

The major benefit of semi-automated image analysis is the flexibility of the human reasoning. Research concerning high-level cognitive processes associated with image analysis has examined visual search processes, learning effects, and pattern detection (Lloyd 1997). Thought processes such as these have been studied using knowledge elicitation in relation to general image analysis tasks (Hoffman & Markman, 2001). This previous research has failed to examine how explicit understanding of cognitive and perceptual factors of image analysis can improve current semi-automated analysis, and has failed to address reasoning practices and visual perception of homogenous surfaces (ie. forest landscapes).

Geovisual Analytics (GVA) is a specialization of Visual Analytics (VA), the science of supporting analytical reasoning with interactive visualization (Thomas & Cook, 2005). The goal of VA is to allow an analyst to address complex problems by exploiting their cognitive and perceptual skills in concordance with the computational power of supporting computer systems . This process is often described as *turning the information overload problem into opportunity* (D. A. Keim, F. Mansmann, J. Scheidewind, H. Ziegler, 2006). GVA techniques have the potential to improve an image analyst's ability to detect patterns, trends, and phenomenological relationships in images and assist them in accomplishing more complex tasks, such as forest disturbance attribution.The following section outlines major phases of research, as well as current plans for tool development.

3 Methods

This research consists of three phases of development: 1) assessing the human reasoning process that underlies image analysis; 2) evaluating the human visual perception of insect-driven forest disturbances in images dominated by continuous forests; and 3) developing an interactive visualization tools to support detection and attribution of insect-driven forest disturbances. The methods employed here are influenced by previous work on human factors of remote sensing (Hoffman, 1990) and visual perception of aerial images (ME Hodgson & Lloyd, 1986).

Traditional remote sensing image analysis relies on two parallel processes, a computer automated process of exploiting image data, and a human reasoning process to convert image data into information for complex problem solving. A better understanding of the nuances of this human reasoning process can be developed using knowledge elicitation. Cognitive Task Analysis (CTA) can "yield information about the knowledge, thought processes, and goal structures that underlie observable task performance"(Chipman, Schraagen, & Shalin, 2000).

CTA implements a set of knowledge elicitation methods to uncover the skills and knowledge of experts. Our experts for this study are image analysts with training in the identification of forest disturbances and the use of TimeSync (Cohen, Yang, & Kennedy, 2010), a imagery tool for forest disturbance monitoring. This tool is an ideal candidate for this research as it was designed spcifically to support the analyst's visual interpretation of LandTrendr (Kennedy 2010) Landsat image products.

A set of cognitive experiments carried out with both expert analysts and novices and modeled after Lloyd (1997) and Lloyd and Hodgson (2002), will be conducted in the second phase of research. As visual perception is a nearly instantaneous process where expertise has little effect on the results of such experiments; it is possible to use participants without in-depth knowledge of forest disturbance. The goal is to determine how shape and texture influence the analyst's speed, accuracy, and confidence in the identification and attribution of insect-driven forest disturbances. We hypothesize that discrimination of forest disturbances is more complex than the general land cover classes, and that shape will play a larger role in the identification of insect-driven forest disturbances than texture, due to defoliation.

Just as choice of images is critical to study of environmental processes, images used in the empirical research must be selected systematically. Both aerial and satellite images are used for forest management, and both will be used in this research based on several criteria; (1) a high certainty of spruce beetle disturbance presence (including verification from previous studies) and (2) the presence of a continuous forest stand (stands should occupy greater than 75% of the scene.

Findings from the first two research phases inform the development of an interactive geovisual analytics tool to support the identification and attribution of insect-driven forest disturbances. This interactive photo interpretation key will support the human reasoning process using interaction and visualization while providing functionality that aligns with the Geovisual Analytic strategy of: "analyze first, show important, zoom/filter, analyze further, and details on demand" (D. Keim, Mansmann, Schneidewind, Thomas, & Ziegler, 2008). Integrating this tool with tools such as LandTrendr (Kennedy, Yang, & Cohen, 2010) could improve user attribution accuracy in cases where insufficient spectral information exists for detection and identification.

4 Conclusions and Outlook

This proposed research offers both theoretical and practical contributions to remote sensing and earth system science. It is novel in its holistic approach to studying the both high-level and low-level aspects of image analysis, as well as its application of a Geovisual Analytic framework. This contribution will strengthen ties between the remote sensing and GIScience communities, inform theoretical development, and produce a tangible artifact that can then be used by image analysts to support earth system science missions.

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