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# Human expertise in the interpretation of remote sensing data: A cognitive task analysis of forest disturbance attribution

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ABSTRACT

The visual analysis of remote sensing imagery is useful for the extraction of information not readily available through automated image analysis. Previous studies have shown that the replication of human reasoning about image content is difficult due to human creativity and mental flexibility. Development of automated image analysis programs continues; however, geovisual analytics suggests that it may be more beneficial to design symbiotic computer-human interpretation systems. It is imperative to understand the experiences, knowledge, and cognitive processes that image interpreters rely on. Cognitive Task Analysis (CTA) is a methodological framework developed from Cognitive Systems Engineering (CSE) where expert users are studied with the goals of explicating their needs, wants, and cognitive abilities for dealing with complex technological systems. Here we report the results of a CTA process carried out with users of a geovisual analytic tool to support forest disturbance detection and signification. These results suggest that different facets of the cognitive processes undertaken by users are not always explicit, and differences in the participant's attentiveness to their mental processes vary greatly. Despite these differences and pathways to their final interpretations, participants were able to successfully come to similar judgments as for their peers.

## 1. Introduction

Satellite imagery is used to support scientific research concerning some ecological processes (Boyd and Danson, 2005; Carneggie and Lauer, 1966; Ciesla, 2000). To derive meaningful insights from satellite imagery, analysts must have strong skills pertinent to the interpretation tasks at hand (Gardin et al., 2011). Expert analysts apply specialized knowledge, honed perceptual ability, and flexible reasoning skills to derive new insights from imagery (Bianchetti and MacEachren, 2015). Early attempts to generate rule-based models that replicate human reasoning for these tasks have fallen short due to the flexibility and creativity that humans can employ (Darwish et al., 2002). One of the biggest challenges to developing such expert systems is the elicitation of experts' cognitive processes and knowledge as they often cannot explicitly verbalize why and how they perform cognitive tasks (Crowther et al., 1997).

Knowledge elicitation methods provide a means for extracting reasoning information directly from the experts themselves (Cooke, 1994). Cognitive Task Analysis (CTA) is systematic framework for describing cognitive aspects of work processes using multiple knowledge elicitation methods (Bisantz and Roth, 2007). Within a well-structured CTA framework, knowledge elicitation methods can provide new insights into the expert's cognitive skills, knowledge, and perceptual abilities for visually-supported analytic tasks like image interpretation (Mirel et al., 2011).

The present study improves our understanding of the differences between expert and trainees' cognitive processes undertaken when interpreting remote sensing imagery for identifying land use and land cover change (LULC). Understanding these processes can inform the development of new visual tools and automated analysis methods. CTA has been used to assess image analyst's expertise in the past (for examples see (Hoffman, 1984; Hoffman et al., 1995)). While these previous studies have focused on reasoning specifically by terrain experts, there is still a need to evaluate the interpretation processes for other scientific contexts, such as LULC change detection. This current study identifies important perceptual cues, cognitive tasks, and knowledge required by interpreters to perform a land cover change analysis using Landsat imagery.

### 1.1. Background

Derivation of new information from remote sensing imagery by visual interpretation requires a combination of mental processes. Cognitive tasks are mental processes that require information to be perceived, attended, compared, stored, and recalled (Blades and Spencer, 1986). Understanding the cognitive tasks that image

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interpreters undertake is important for improving design guidelines and user experiences (Olson, 1979, Olson, 1976). Our current knowledge of cognitive factors of image interpretation stem from active research within cognitive GIScience and early military research about interpreter training.

#### 1.1.1. Image interpretation

Image interpretation is the process of extracting information from remote sensing imagery, and despite providing a realistic representation of the Earth's surface, it differs from direct observation in perspective, scale, and the ability to provide historical context (Rabben et al., 1960). Image interpretation can be conceptualized as a visual problem-solving activity whereby the analyst draws upon previous knowledge and experience to derive meaningful insights from the patterns of visual cues in an image (Philipson, 1980). Some analytical tasks can be identified as being related to image interpretation, such as direct object identification, or pattern recognition. Humans excel in such tasks when creativity and flexibility are needed to make correct interpretations.

Given the inefficiency of manual interpretation, attempts have been made to develop computer models that replicate human interpretation with faster processing speeds. This continues to be an important research thrust for vision scientists, and evidence suggests that the processes underlying object recognition by machines do not necessarily mimic those of humans (Ullman et al., 2016). Computational image understanding includes both the identification of objects in imagery as well as understanding the relationships between objects (Crevier and Lepage, 1997). Human and computer analysts use spectral and geometric properties of a visual image to identify image objects and their relationships. These visual cues have been acknowledged within remote sensing imagery since the early 20th century (Bianchetti and MacEachren, 2015). The elements of image interpretation, formalized by Olson (1960), are found throughout early texts and facilitate the identification and signification of patterns and objects in remotely sensed images (Estes et al., 1983). Expert analysts can use them to support reasoning with images captured from an aerial vantage point (Rabben et al., 1960). This perceptual cues continue to be a cornerstone for training modern remote sensing image analysts.

Perceptual processing is just one of a set of cognitive skills that experts draw on when interpreting imagery. Experts develop cognitive skills based on contextually dependent tasks. Some taxonomies have been developed to determine basic cognitive skills that are utilized in the analysis of visual displays; a consensus on tasks associated with image interpretation have evolved. Examples include MacLeod and Hone (2005), Lillesand et al. (2004) and Campbell (2002a). The processes of *detection* and *identification* are common across these typologies though their defintions may differ. For example, definitions of identification and recognition are contradictory. To Lillesand, identification is an act of recognizing an object, but to MacLeod identification and recognition are two separate tasks, respectively naming of an object and determining whether an object is hostile or not, and recognition as a specific form of classification. The remaining tasks that Lillesand and Campbell describe are delineation, enumeration, and mensuration.

#### 1.1.2. Empirical studies on image interpretation

A relatively small body of research has emerged concerning the cognitive aspects of remote sensing image analysis. These studies have addressed expert-novice differences, domain differences, computational and manual performance, perceptual processing, and the extraction of expert knowledge for the development of new computational systems. Closely related to this, cartographic research has addressed map reading tasks in the presence of remote sensing imagery under various methods of image processing.

The use of cognitive research methods to systematically account for expert knowledge used in the development of computer systems has its roots in Cognitive Systems Engineering (CSE). CSE has the intent to improve human experience in complex socio-technological settings (Rasmussen et al., 1994). CSE determines the cognitive demands of work, including knowledge and reasoning, for the design of computational systems (Hollnagel and Woods, 1983).

Within the CSE discipline, it is possible to identify two major perspectives on the study of work (Bisantz and Roth, 2007). First, a Cognitive Work Analysis (CWA) perspective emphasizes the functional system components in a workplace and focuses on the tasks that actors perform, the environment within which they work, and the perceptual, cognitive, and ergonomic attributes of work (Vicente, 1999). CWA is adopted when the intent is to study tasks required to achieve an end goal in addition to the environment through which the actor completes those tasks. In contrast, CTA framework focuses on the tasks an actor performs emphasizes the perceptual and cognitive attributes of those tasks (Schraagen et al., 2000a), rather than the work environment (Chipman et al., 2000). CTA has been employed in other science domains that leverage imagery, such as meteorology, where analysts utilize a combination of imagery and external data to understand environmental patterns (Hoffman et al., 1998, 2001).

The goal of CTA is to improve human work. This method typicallyl results in a characterization of the work domain, with descriptions of the strategies and knowledge used to perform the given task (Bisantz and Roth, 2007). Methods appropriate for knowledge representation include collecting mental models (Seamster, 1993), semantic networks (Graesser and Clark, 1985), and diagramming activities (Schraagen et al., 2000b; Crandall et al., 2006). A major benefit of CTA is the flexibility that a researcher has regarding the selection and implementation of knowledge representation methods (Cooke, 1994). This flexibility not only provides multiple lenses from which to view the work, but it also allows for integrating different approaches. CTA was chosen in this particular case, because of its descriptive quality and ability to uncover sentiments not readily available with quantitative psychophysical methods.

Experts have developed domain-specific skillsets that set them apart from novices (Colwell, 1966). Visual perception and problem-solving interact in the completion of visual tasks, from medical diagnostics to satellite image interpretation. Numerous studies have shown explicit differences in the ways in which novice and expert analysts review imagery. Most of these studies have been conducted in the domain of medical diagnostics, but it is likely that many of the same processes underly remote sensing image analysis. More experienced interpreters have more accurate and quicker responses than less experienced counterparts (Lloyd et al., 2002), and their search processes are influenced more by object saliency (Davies et al., 2006). These studies echo the arguments of early air photo interpretation studies that sought out to identify key characteristics of optimal performance, such as Enoch (1960). As noted by Hoffman et al. (1998) the transition from novice to expert also affects the appearance of problem-solving as formerly explicit judgments become implicit automated pattern recognition processes.

Research concerning the reasoning processes of expert image interpreters is relatively sparse due to difficultly in explicating the implicit mental processes that become ingrained through development of expertise. While recognition of the importance of expertise in these tasks is as old as the profession itself, very few empirical studies have been conducted to describe the interpretation process, and most of what is presented in the remote sensing literature has come from personal experience. It is the goal of this research to begin to systematically describe the image interpretation process using CTA. In this present case, the tasks of identifying and signifying land cover change are identified through verbal reporting and diagramming.

## 2. Methods

CTA can be used to explicate the knowledge and cognitive processing of experts in a variety of settings (Crandall et al., 2006). The use of