section one

Introduction

chapter one

Overview

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Despite advances in information processing technology, there remains a necessary and critical role for the "human in the loop" in the interpretation of remotely sensed nonliteral imagery, in domains including planetary science, earth science, meteorology, and cartography.[5] On the side of information technology, workstation and display systems play a critical role in supporting scientific visualization, and in recent years it has become widely recognized that the visualization of complex data is critical in science,[9,11,12,14,15,23] including the domain of cartography, a field with a long-standing interest in issues of communication effectiveness.[3,4,8,10,17,20,21,22] That concern has been bolstered by psychological research showing that the features of display symbols, elements, and patterns can have clear effects on processes of perception and visual search.[6,7]

What are the implications of this for the field of remote sensing?

1.1 The challenge to contributors

Contributors were invited to present their newest research. Some of them are psychologists, whose research interests converge on issues in the area of remote sensing. Some of the contributors are remote sensing scientists, environmental scientists, or computer scientists. They were asked to look at their work from a psychological or human factors perspective. For most of them, this request was a challenge and a relief—they would finally have a forum for expressing their concerns about important human factors issues that the field seems to have de-emphasized. A host of questions are raised at this nexus of psychology and remote sensing, questions that formed a list of possibilities presented to the contributors:

1.1.1 Information and perception

- What is the nature of the information that is contained in remote sensing and cartographic displays?
- How is that information perceived?
- What sorts of things do experts see?
- How can individual, static displays permit the comprehension of underlying dynamics (e.g., weather, geobiological dynamics, etc.)?

1.1.2 Reasoning and perception

- How do experts reason?
- What "mental models" do experts have of the causal principles that govern the phenomena they study and that structure the information that is contained in the remotely sensed images?
- How does the expert "see through" the display to arrive at an understanding of a depicted world, its meaning, and significance?

1.1.3 Human-computer interaction

- How do experts work with their displays?
- How do the displays and workstation systems actually constrain their reasoning?
- What happens when experts "fiddle" with their displays?
- How does display interpretation integrate with the other things the experts do when performing their usual tasks?
- What are the implications of new expert systems and the role of the "human in the loop"?

1.1.4 Learning and training

- What are the phenomena of perceptual learning and concept formation that are important in display interpretation?
- What are the milestones in the developmental sequence of trainee-to-expert in image interpretation?
- What does it take to be an expert trainer?
- Can the expert trainer anticipate trainee errors, given a knowledge of the trainee's mental model?
- Given that it takes such a long time to achieve expertise at image interpretation, how can training be made more efficient?
- How can alternative approaches to training be evaluated?

As these questions show, discussions in this volume span issues ranging from the aesthetics of scientific visualization, to the mathematical analysis of perceptible objects, to the applied problems of training and interface design.

1.2 The organization of the volume

Following this Overview, the second chapter in the Introductory Section reviews some literature that attests to the role of human factors in remote sensing, and some research that helps to specify cognitive processes in a way that is pertinent to remote sensing.

Section Two focuses on topographics. Terrain analysis is the systematic study of image patterns relating to the origin, morphologic history, and composition of distinct topographic units called landforms, and their engineering significance for soil and rock identification. A great deal of experience is required to achieve expertise at terrain analysis, and senior experts possess consummate perceptual and comprehension skill.[13] In their chapter, Argialas and Miliaresis approach expertise at terrain analysis, with a focus on the creation of expert systems (see Chapter 3). Previous expert-system methods and tools that have been used to address terrain knowledge representation have modeled the landform "pattern element" approach, and have resulted in prototype expert-systems for inferring the landform of a site from user observations of pattern elements.[1,2] The first step is the formulation of a conceptual framework for knowledge, much of which can be found in books and technical manuals (interpretation "keys"). In such first-generation efforts in knowledge-based terrain-interpretation systems, knowledge related to the physiographic region of a site and to the spatial pattern of related landforms was not explicitly represented and used.

In more recent work (see Chapter 3), Argialas and colleagues have identified, named, described, and organized "book knowledge" pertaining to physiographic regions (provinces and sections), physiographic features, topographic forms, and associated landforms in terms of geomorphologic, topographic, and physiographic indicators. They have captured a number of "intermediate-level concepts" that are perhaps the most important tools available for organizing knowledge bases, both conceptually and computationally. Next, they developed an object-oriented model for the factual and structural representation of these terrain features, and a rule-base for representing the strategic knowledge needed for inferring these features from their own indicators. The conceptual scheme was formalized and implemented in a knowledge-base resulting in the Terrain Analysis eXpert (TAX-4) system, which assists the user in physiographic reasoning. In Chapter 3, Argialas et al. point out that a considerable amount of research is needed to specify the perceptual knowledge of experts.

A major thrust of research on digital information processing involves the goal of obviating the human factor through automated analysis and classification. In his chapter on geomorphometry (see Chapter 4), Richard J. Pike makes the point that mathematical analyses of terrain ultimately hinge on questions of meaning and perception. Measures of the shape and form seen in topography are needed in order for the analyst to understand natural processes and represent the Earth's surface as locus of human activity. The information content of images (e.g., synthetic aperture radar) is often extracted by traditional visual interpretation, but more effort is being undertaken to extract information by parametric computations. The key issue is how to link visual perception of terrain form with computational metrics.16 Verbal expressions of perceived land form (e.g., "rolling hills") are ambiguous and under-specific. Also, such attributes as terrain "roughness" and spatial asymmetry must be captured in numerical terms if they are to be incorporated into models of geomorphic process, ecological interaction, and hazard identification. Because statistical descriptions, too, can be ambiguous, direct linkages are needed between perceived terrain form and its parametric expression. For example, can differences in standard deviation and kurtosis of slope curvature be detected visually in real terrain? Pike's chapter reviews morphometric representation of the ground surface and then describes selected results of an experiment designed to explore some of the important issues (see Chapter 4). An analysis of 90 small digital elevation models (sampled from 1:24,000-scale U.S. contour maps) involved fifty measures that were reduced to a provisional "geometric signature" of uncorrelated attributes. This study suggests it might be possible to "calibrate" a sample's visual appearance against its statistical characterization.

The chapters in Section Three address a basic phenomenon of expertise—experts can see things that novices cannot. Pattern recognition begins with observing something. It could be things that occur naturally, or things one sees in pictures, maps, or charts. The human mind is able to perceive the information, remember it for later use and conceptually link it to related observations. Once several similar data sets have been analyzed, a pattern can be determined.

Experimental psychologist William R. Uttal and colleagues (see Chapter 5) recently conducted some research on the ability of people to discriminate objects depicted by light amplification. Scenes viewed through light-amplifying (or "night vision") goggles produce an image that is considerably different from the view obtained with literal vision, even literal vision under conditions of dim illumination. Under certain conditions, light amplifiers provide an enormous enhancement of the observed scene. However, the displayed enhancement of luminance comes with a perceptual cost. The displayed images are degraded in terms of color, contrast, shadows, resolution, and depth cues, among other parameters. Effective use of light amplification technology requires an understanding of how humans see under these, and related conditions of degraded nonliteral viewing. Uttal and Gibb review some recent empirical findings concerning the perception of light amplified images, and go on to consider how contemporary developments in the psychology of perception may contribute, in general, to our understanding of how such important new sensing, imaging, and display devices can best be used in remote sensing and nonliteral imaging applications (see Chapter 5). The goal of the research and the theoretical considerations is, ultimately, to suggest how one might improve the observer's ability to process nonliteral informational displays, especially so as to avoid perceptual error.

In addition to seeing features and patterns that the novice cannot, the expert can also perceive dynamics. The terrain analyst sees not just terrain or even landforms, but perceives the dynamics that led to the formation of the terrain. In a meteorological satellite image, the meteorologist not only sees high and low pressure systems, fronts, and other phenomena, but also perceives the dynamics and forces that are at work. The climate and general atmospheric circulation patterns are the statistics of a large number of individual events in a rapidly changing three-dimensional fluid. A remote sensing observation, however, is a snapshot. The chapters in Section Four focus on the experts' perception of dynamics, and the displays and information processing systems that support the perception of dynamics.

In his chapter, Richard K. Lowe investigates how novices and experts perceive meteorological dynamics that are implicit in weather charts composed from remotely sensed data (see Chapter 7). This abstract type of display gives a highly selective and decontextualized presentation of a meteorological situation and depicts information that is beyond the realm of direct, everyday experience. Meteorologically, the importance of the visuo-spatial properties of chart markings lies in the way they capture particular aspects of the atmosphere that reflect its nature as a dynamic gaseous fluid. Appropriate patterning of these individual graphic elements into higher levels of meteorological organization is not apparent to the novice. Rather, the novice focuses on superficial and domain-general visuo-spatial characteristics. In Lowe's research, college student participants carried out various tasks that required them to physically manipulate or generate meteorological markings from a given weather map. These tasks included: copying then recalling markings, sorting markings into groups, drawing extensions of given (incomplete) markings, and generating predictions of future patterns. Expert meteorologists' performance during these weather map processing tasks indicates that their knowledge covering relational aspects, such as the spatial and temporal contents of a given weather map, allows them to develop a meteorologically coherent mental model of the depicted situation. In contrast, novices appear to construct limited mental models that are insufficiently constrained, lack hierarchical structure, and provide an ineffective basis for interpretation.

Although the communities of researchers studying the Earth's climate and those studying the atmospheres of the other planets barely overlap, the questions posed and the challenges to understanding in the two fields have much in common. In his chapter, Anthony Del Genio discusses the expert's perception of dynamics in the "weather" on other planets (see Chapter 8). Converting remotely sensed data into maps of physical parameters for scientific interpretation requires the application of computer algorithms based partly on physics but also partly on untested assumptions, which can introduce errors of unknown magnitude into the resulting product. Furthermore, conceptual models for the Earth's atmosphere are more advanced than those for other planets. Applying terrestrial understanding to planetary visual displays can sometimes aid interpretation but at other times might bias it. A major challenge for the planetary scientist is to use displays to deal effectively with the time domain. In many cases the important changes with time are small, and displays of *differences*, rather than data values or value averages, can be the most physically revealing. In other situations, changes with time are large, necessitating either animation or a sequence of static displays.

Ultimately, though, it is not feasible for the human to view and assimilate every image produced by every instrument on an orbiting spacecraft. To deal with the large data volumes, scientists use displays of limited segments of the data set to conceive and design computer programs that collect statistics on the phenomenon in question over the full duration of the data set. This is generally an iterative process; displays of the resulting statistics may simply confirm physical expectations, but often they reveal unanticipated behavior. The scientist must then decide whether the "objective" definition on which the algorithm is based is correct (i.e., the result is a discovery of new information) or whether the definition itself is biased and needs revision. Throughout these processes of data analysis, and despite the foundations of planetary remote sensing in physical science, psychological factors of comprehension, perception, and expertise play a critical role.

In his chapter, H. Mike Mogil takes us back to planet Earth in a discussion of the interpretation of meteorological satellite images (see Chapter 9). Since the beginning of modern meteorology about 200 years ago, meteorologists have relied upon their pattern recognition skill to gain an understanding of weather processes and to develop forecasting techniques. Currently, information gained from human-based pattern recognition efforts is being routinely used to develop automated techniques. For example, dozens of algorithms have been incorporated into the National Weather Service's new Doppler Radar system, and multispectral satellite imagery is being used in automated icing analysis programs. In asking the question, "What patterns are there in satellite imagery?" Mogil tapped into his experience at training meteorologists, and elementary school children and teachers. He had used tasks in which images and maps are sorted and classified. To his surprise, the number of patterns that novices (children and teachers) found was far greater than he had expected. A similar experiment using cloud photographs showing basic cloud types, yielded patterns involving geography, geology, colors, and other patterns. These investigations point out the myriad ways that information can be perceived and organized.

1.3 Prospectus

Chapters by experimental psychologists (Essock, et al. [see Chapter 6], Hoffman and Markman [see Chapter 2], Lowe [see Chapter 7], and Uttal, et al. [see Chapter 5]) illustrate a range of psychological research methods that can be brought to bear on issues on remote sensing, including judgment and interpretation tasks, memory tasks, and psychophysical tests of discrimination. Chapters by remote sensing scientists (Argialas and Miliaresis [see Chapter 3], Pike [see Chapter 4], DelGenio [see Chapter 8], and Mogil [see Chapter 9]) discuss the ways that human factors, including expertise and perceptual skill, play a role in their domain. A defining goal of the volume is to address issues of both basic and applied science that fall at the nexus of remote sensing and applied cognitive psychology. We hope that this volume serves as a springboard for more discussion of the issues, and more cross-disciplinary research to address the issues.

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