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Visual Knowledge in Tactical Planning:

Preliminary Knowledge Acquisition Phase I Technical Report

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Over the past twenty years, much has been learned about the structure and use of human knowledge and the potential values of computer representation and manipulation of knowledge and reasoning for a variety of problem solving purposes. However, very little of this work has concerned itself with those components of human knowledge that are not easily expressed in verbal terms, for reasons both of difficulty in assessing the knowledge involved and of representing it within the confines of a computer representation. The work described here is part of a project focused on the non-verbal (visual) components of knowledge used in a map-based planning task. This phase of the project involved knowledge acquisition activities oriented toward identifying the visual objects and features of objects that are of tactical importance. The long-term intent of the work is to combine the verbal components of the task and required knowledge with the visual components to generate a user interface for a tactical planning decision support system whose displays and behavior are compatible in form and content with the cognitive representations of its users whose internal representations support direct manipulation of both visual and verbal knowledge. During their planning sessions, the experts referred to five types of map characteristics, and mentioned a total of 13 man-made terrain units (roads, towns, bridges), 22 naturally occurring specific terrain units (hill, river, stream), and 11 composite terrain units (avenue of approach, field of fire).

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VISUAL KNOWLEDGE IN TACTICAL PLANNING: PRELIMINARY KNOWLEDGE ACQUISITION PHASE I TECHNICAL REPORT

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Visual Knowledge in Tactical Planning: Preliminary Knowledge Acquisition Phase I Technical Report

Introduction

Program Goals and Motivation

Over the past twenty years, much has been learned about the structure and use of human knowledge and the potential values of computer representation and manipulation of knowledge and reasoning for a variety of problem solving purposes. However, very little of this work has concerned itself with those components of human knowledge that are not easily expressed in verbal terms, for reasons both of difficulty in assessing the knowledge involved and of representing it within the confines of a computer representation. Similarly, computing capabilities in image understanding and in graphics displays have advanced considerably, but little has been accomplished in terms of reasoning with or about images themselves. The work described here is part of a project focused on the non-verbal (visual) components of knowledge used in a map-based planning task. This phase of the project involved knowledge acquisition activities oriented toward identifying the visual objects and features of objects that are of tactical importance. The long-term intent of the work is to combine the verbal components of the task and required knowledge with the visual components to generate a user interface for a tactical planning decision support system whose displays and behavior are compatible in form and content with the cognitive representations of its users and whose internal representations support direct manipulation of both visual and verbal knowledge. To fully investigate this area, the project will draw and build on work in three major research areas, each of which is discussed briefly in the following sections.

Knowledge-based Planning

Planning and problem solving are the primary areas of reasoning addressed by "intelligent" or knowledge based systems. Planning is generally viewed as the process of finding a series of actions that will eliminate differences between the initial state and some goal state (Hammond, 1984; Minsky, 1975). Numerous techniques have been developed and used successfully for various planning situations including: building plans for every situation from rules (Sacerdoti, 1975); searching for complete (or fixable) plans from within an index of existing plans (Hammond, 1984); and reasoning from earlier cases or experiences (Kolodner, 1985). Applications have been built that deal with planning domains and problems ranging from extremely simple "toy" domains with few or no interactions between goals to highly complex domains with conflicting or competing goals. Research and development efforts in knowledge based planning have been highly successful and several large-scale, complex planning systems (such as DARPA's Pilot's Associate and AirLand Battle Management FORCES planner) have been prototyped. These systems derive complex plans in short time-frames and, when necessary, use different planning techniques depending on the knowledge and reasoning demands of the task.

One thing all these approaches have in common is that the domains in which the plans are generated (or the problems for which plans must be made) are expressed solely in semantic terms: there are no illustrations or diagrams provided. All information provided is in some verbal form. In human experience, however, we rarely encounter a situation that provides only semantic or verbal input. Instead, any situation perceived provides information in multiple modalities and, in fact, we may rely on a non-verbal mode for much of our understanding of the situation (Anderson, 1984; Larkin & Simon, 1987). In particular, much of what we perceive and manipulate in day-to-day planning is visual in nature, and, in some tasks, almost all the pertinent information is provided via diagrams, maps, and other illustrations.

Visual Knowledge

Visual experience forms a major part of our total fund of knowledge (Chipman, 1987). The knowledge we gain and retain from visual experience is often itself imagistic or visual in nature and differs from verbal or semantic knowledge in form, content, and style of reasoning. In other words, visual knowledge is the internal representation of our visual experience and differs from verbal knowledge just as visual experience differs from linguistic experience. However, to date, no theoretical model has been developed that adequately captures the nature of visual knowledge or the relationships and interactions of verbal and visual knowledge.

By visual knowledge, we refer to that part of human knowledge that is difficult to express in spoken or written language, but easy to communicate through pictorial means such as photographs, diagrams, charts, and graphs. This includes, but is not limited to, information about the details of appearances of objects in a scene, the spatial relationships among objects in a scene, and specific characteristics or features of individual or collective objects. Visual knowledge can be considered in contrast to verbal knowledge--that part of human knowledge that is easily communicated in spoken or written language, such as information about the names or number of items, concepts, actions, and relationships among actions. While substantial evidence has been obtained supporting the existence of visually-based internal knowledge representations (Anderson, 1984; Pavio, 1986; Vekker, 1974) and demonstrating the value of external graphic representations in supporting reasoning (Gentner, 1989; Larkin & Simon, 1987), no one has developed a sufficient model for the organization and content of internal images and their manipulation during reasoning processes. This lack of a theoretical model of the cognitive representation and manipulation of visual knowledge restricts our capability to fully utilize the graphic display and image processing capabilities of existing computer systems in several critical ways, particularly:

- imparting knowledge for training purposes;
- representing imagistic information in computer storage; and
- supporting visually based communication between human and machine.

Image Understanding Systems

Image understanding systems have also developed dramatically in recent years. In fact, several "knowledge-based" systems have been developed (Draper, et. al., 1989; Gilmore & Shapiro, 1988). However, in almost all these systems, the application of KB processing to image understanding occurs only at a high level, after the input image has been mapped (Gilmore & Shapiro, 1988). In addition, the most developed uses of such systems are primarily oriented toward identification of objects and extraction of semantic information providing the name and location(s) of each object. Consequently, in current applications, additional reasoning done relative to the image is based on the semantic information extracted from the image. Brady (1987) lists ten such areas in intelligent vision that are sufficiently mature for applied use. He places direct reasoning about images and integration of computer vision systems with other techniques in a class of areas of research interest likely to pay off in the near future.

With this, however, we return again to the evidence that much of human reasoning involves the direct perception and manipulation of visual or imagistic information, rather that translation of that information to semantic form for reasoning. Each of the technology areas discussed in the previous sections has begun to consider the problem of how humans manipulate visual information and/or how intelligent systems should act on images, but none has yet structured an approach to mimicing human behavior in a knowledge based system. It is the goal of this project to address this critical issue.

Methodology

For the current project, the domain of interest is military tactical planning at the brigade level. Above this level, particularly at echelons of corps and above, planning is not tightly bound to the specifics of terrain as portrayed on a map. Planners at such levels are concerned with broad expanses of terrain and generally work with maps at levels of detail insufficient to support actual reasoning about specific terrain objects and their relationships. Planning at the brigade level is done using maps of sufficient detail to allow consideration of individual terrain features and is concerned with the placement of units small enough for their performance to be affected by such terrain units.

Materials

Domain experts were provided with a 1:50,000 scale map of the Fulda region of Germany and an operations plan for defensive actions by the 2nd Brigade of the 23rd Armored Division. The operations plan was taken from US Army subcourse 313/4-Defensive Tactics, Lesson 4-Brigade Defensive Planning. The operations plan included the brigade order of battle and task force organization as specified by the division commander and all major paragraphs required in an OPLAN, but no annexes. Sufficient map sketches were included to locate brigade boundaries, task force boundaries, FEBA, and critical defensive positions. For the counterattack and full offense problem solving sessions, the same geographic location and order of battle were used, but no operations plans were available.

Participants

Two former Army officers participated as domain experts. One (BB) has 25 years of experience in the US Army with command experience up to the brigade level. In addition, he served one tour as a tactics instructor at the Armor school. The other expert (RP) has 20 years of experience in the US Army, primarily as an engineer and is a graduate of the US Army Command and General Staff College. Both experts were familiar with the European area used in this study and with both US and Soviet doctrine and tactics for fighting in that area.

Procedure

Seven knowledge engineering sessions were held with BB and six with RP for a total of approximately seven hours of interactions. The first session with each expert was a semi-structured interview covering basics of military planning and determining what information and materials would be needed to support the subsequent problem solving sessions. The first session was recorded on audio tape and transcribed for analysis. The problem solving tasks for subsequent sessions were presented in the following order:

- general terrain analysis--primarily from Blue perspective;
- terrain analysis from Red (offensive) perspective;
- position Blue troops for defense;
- "play back" one battalion sector of defense;
- position troops for limited counterattack by brigade; and
- position troops for division offense from Fulda river to regain international border

Results

All problem solving sessions were recorded on video and audio tape. The audio tapes were transcribed for coding. The initial coding scheme was established to extract from the transcripts terms of reference for and some relationships between visual features of the map itself and the terrain features of importance to the planners reasoning processes. Specifically, the transcripts have been coded for visual map characteristics that identify features of terrain units, specific and composite terrain units, features of specific terrain units that are of tactical importance, and roles of terrain units in defensive and offensive planning. All coding has been done by the principal investigator.

During their planning sessions, the experts referred to five types of map characteristics: specific symbols that are defined in the map legend such as those for deciduous and coniferous trees; map coloration such as green for forested areas and brown for cleared areas; contour lines indicating slope of the land; absolute locations of terrain features; and relative locations of terrain features. Each of these was vital to the identification and consideration of the terrain units discussed. The two experts mentioned a total of 13 man-made terrain units (roads, towns, bridges), 22 naturally occurring specific terrain units (hill, river, stream), and 11 composite terrain units (avenue of approach, field of fire). Composite terrain units are formed based on the relationships among specific units.

The coded information from the transcripts has been structured into a knowledge document and is attached to this report as Appendix A. Further analysis of the transcripts and of the video tapes will continue during Phase II of the project.

Program Accomplishments

As proposed, Phase I of this project has focused on selecting an appropriate planning problem for knowledge acquisition and completing initial knowledge acquisition efforts. From the elicited transcripts and initial coding, the project thus far has succeeded in:

- establishing the immediacy and importance of visual information in tactical planning;
- identifying a set of terrain objects and their features and roles that are critical in tactical considerations;
- identifying a set of map characteristics that inform the perceiver about the terrain objects and their features;
- identifying a set of composite terrain features that are important in tactical planning; and
- capturing substantial evidence of the types of reasoning applied to visual information during tactical planning.

Phase II Goals

During the second phase of this project, several subgoals will need to be met in order to complete Phase II with adequate specification of the knowledge representation and functional capabilities required by a user interface to support map-based tactical planning. Briefly, these subgoals are:

- complete analysis of video tapes with a focus on the reasoning or mental operations applied to map characteristics and terrain objects;
- further knowledge engineering sessions to focus on the relationships between terrain objects that identify composite terrain features;
- develop a statement of the functional capabilities needed by a user interface capable of supporting such reasoning;
- review the types of data and knowledge representations currently used or generated by knowledge based planning and vision systems;
- select and revise an appropriate representation;
- develop functional specifications for an interface; and
- begin prototyping efforts.

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Appendix A: Preliminary Dictionary of Map Objects

Object Tactical Signif.	Features	Map Characteristics
Man-made, Single Object:		
Road	Width, Direction Capacity, Speed	Color (Red or White or R/W alternating)
Supports high speed movement May prohibit cross-country movement If in wooded or hilly terrain, may be constricting Defense should plan to block or obstruct		
Highway	Width, Direction Capacity, Speed	Color (Red)
Trail	Width, Direction Capacity, Speed	Color (White)
If near river, may indicate fording site If on hill and twisty, indicates constricted movement		
Candy-stripe	Width, Direction Capacity, Speed	Color (R/W alternating)

Redball	Width, Direction Capacity, Speed	Color (Red)

For RED offense, used as Avenue of Approach
Supports high speed movement

White Road	Width, Direction Capacity, Speed	Color (White)

Autobahn	Width, Direction Capacity, Speed	Color (Red)

For RED offense, used as Avenue of Approach
Supports high speed movement
Usually elevated, restricts cross country movement

Bridge	Width, Capacity	Symbols from legend

For defense, can destroy to slow offense
For offense, must locate and know tr op & equipment capacity

Road Network	Density	# roads, # crossing roads # roads with same direction

If dense, supports movement options
If sparse and terrain wooded, limits movement
If sparse and terrain level and open, allows cross country movement

Railroad Track | Direction | Symbols from legend

For defense, good terrain
For defense, supports fields of fire
Usually elevated on man-made embankment

Embankment | Height, Steepness | Close contour lines from road or RR track

Restricts cross country movement from or across road and RR track
Usually built to support autobahn or RR track

City; Town | Density, Size | Cluster of black boxes

For defense, good to occupy town
For defense, avoid when retreating
For defense, avoid unless town/city is *objective*

Church | | Box with religious symbol attached

For defense, usually provides observation point

Natural, Single Object:

Mountain; Hill	Height, Rel. Height	Numerical indicator
	Slope, Roads	Density of contour lines
	Vegetation, Visibility	Color (Green or Brown)

For defense, highest in area provides best line of sight and fields of fire
For defense, position on highest available
For defense, if wooded and steep, will be hard to retreat from
For defense, do not use if bare
For offense, difficult to cross, plan to go around
If wooded, provides cover and concealment

Ridge; Ridge Line	Height, Rel. Height	Numerical indicator
	Slope, Roads	Density of contour lines
	Vegetation, Visibility	Color (Green or Brown)

For offense, provides cover during movement
For offense, may be difficult to leave
If wooded, provides cover and concealment

Valley	Width, Vegegation	

Escarpment	Height, Slope	Close contour lines to water

For offense, if steep becomes restricting or blocking terrain

Cliffing | Height, Slope | Close contour lines to water or lower ground

For offense, if steep becomes restricting or blocking terrain

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Ravine; Defile | Depth, Width, Length | Close contour lines to bottom
| | Width at bottom

If wide at bottom, may be considered a compartment instead
For offense, confining terrain
For defense, good position, allows small force to trap larger force

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Gauntlet

For offense, confining terrain
For defense, good position, allows small force to trap larger force

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Funnel

Constricting terrain, forces movement through specific locations

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River | Width, Depth | Symbols from legend

Presents obstacle to rapid movement
For defense, supports fields of fire, exposes enemy

Stream | Width, Depth | Symbols from legend

For defense, supports fields of fire, exposes enemy
For offense, poort terrain, creates exposure

Ford

Water Course

Crossing Site

Allows easy *fording* or *crossing river*

River Bank | Height, Slope | Contour lines

If low and/or gentle, supports crossing river
If steep, becomes escarpment, restricts movement

River Valley

River Line

Swamp; Marshland | | special map symbol from legend

Except in winter, uncrossable
Generally restricting terrain

Forest; Wood | Density, Composition | Color (Green)

Provides concealment
If thick, inhibits movement

Trees | Type (evergreen, deciduous) | symbol from legend for each

Plateau

For defense, provides visibility, long fields of fire

High Ground

Low Ground

Composite:

Compartment

Cross-Compartment

Gap

Avenue of approach

Breadth determines number of troops
Watch for constricting or blocking terrain
Supports movement by offense

Route

Supports movement by defense
May be single road

Field of fire

Choke Point

Any constricting terrain
For defense, important to control
For defense, usually easy to control

Opening

Stoppage

Poor terrain for offense, indicates location where defense can stop movment

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Breach Point

Drop Point

For offense, allows shifting forces to new route or avenue of approach

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