COLLABORATIVE NAVIGATION IN REAL AND VIRTUAL ENVIRONMENTS

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ABSTRACT

Our study of collaborative land navigation in the real-world provides input for our design of the human computer interface of a virtual learning environment. Study findings reinforce the applicability of the Recognition-Primed Decision-Making model to the land navigation domain. Also, study of the interpersonal communication between team members informs our understanding of the relationship between tutor and student. Finally, we found that knowledge elicitation based upon narrative form generates valuable descriptive knowledge quite naturally and that team members exchanged information through the storytelling medium.

ABOUT THE AUTHORS

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INTRODUCTION

Overview

Last year, we presented work that emerged from our attempts to build a virtual environment in which we could train land navigators (Peterson & Darken, 2000). The focus of that work was selection of a knowledge representation that would drive a virtual tutor. Those findings feed our ongoing development of the tutor itself. While the tutor is one core component of such a virtual learning system, the work described here targets another component: that is the human-computer interface to the virtual learning environment.

The previous knowledge representation work and the current interface work are related in that both contribute to our overarching goal: we are constructing a virtual learning environment. In this type of work, we have identified five factors that inter-relate to provide an organized structure. Results from our previous work established system requirements for the executable knowledge representation, while results of the current work primarily inform system requirements for the learning environment interface. Secondarily, efforts directed to the interface design have aided refinement of the knowledge representation requirements and each of the other members of our five-factor model.

Major Themes

This paper has four major themes. The foremost concerns the immediate need to build an interface between the student user and the learning environment. Second, we have adopted the Naturalistic Decision-Making (N.D.M.) (Orasanu & Connolly, 1993; Zsambok, 1997) theoretical framework for guiding our knowledge elicitation and descriptive knowledge representations; furthermore, we have found its Recognition-Primed Decision-Making (R.P.D.) model (Klein, 1998) well matched to the land navigation domain. Next, past and current studies have continued to provide evidence that people naturally use stories to make sense of their surroundings and to communicate their knowledge; thus, it is very important that our knowledge representations can properly capture and describe story elements. Finally, this work differs from our previous work in that we have extended from the study of individual navigators to navigating teams. This extension has provided more benefits than we initially expected.

Motivations

Our previous study of the land navigation skill domain taught us that navigation usually happens within a team. Normally, the team will assign one person the primary navigation responsibility; however, there are continual, interactions between the assigned navigator and other team members across the duration of the mission. Additionally, we have been interested in the relationship between real-world and virtual environment navigation. Based upon these two points, our primary motive was to build an interface that would facilitate collaborative team navigation. Furthermore, of the many collaborative tasks of interest, we chose dismounted land navigation with the hopes that this work would build upon and extend our previous land navigation work.

Given our ultimate vision for a virtual learning environment, we would like our system to facilitate one human student's interactions with one virtual tutor. However, we have found many hurdles blocking our development of the virtual tutor. Therefore, in parallel with the virtual tutor's development, we seek to better understand the interpersonal relationships between a tutor and student; a collaborative team model provides a good foundation for the communications that characterize the tutoring interactions as well.

Organization of Paper

We write this paper to contribute to the virtual training community by describing our current work and relating it to our past work; it is organized as follows. First, we describe the experimental study. Next, we will discuss our findings by structuring them around the five-factor model. We close with conclusions.

THE FIELD STUDY EXPERIMENT

Our experiment was a field study of collaborative wayfinding, conducted in a natural, outdoor environment. It is summarized in this section; for more detailed information, see Boswell (2001).

Participants

Sixteen navigators participated in this study. Based upon their experiences in the military, we divided the participants into inexperienced and experienced groups, with a total of ten inexperienced and six experienced navigators. Each team was composed of either two experienced or two inexperienced navigators. This resulted in five inexperienced groups and three experienced groups.

Tasks

There were two experimental tasks: 1. route planning; 2. route execution. After completing administrative requirements, the participant pair was given thirty minutes to plan a navigation route and annotate the route on a map, scaled 1:5,000. After planning, the researcher transported the team to the orienteering course located on the former Fort Ord Army post in California. The terrain there had varying levels of vegetation, from impassable brambles to lightly wooded, open forests with relatively little elevation gain. The total length of the course was relatively short, measuring less than three nautical miles, and most teams completed the route execution in about two hours.

Data Collection

The researcher measured wayfinding performance and spatial awareness tests. Relevant results of these tests are briefly summarized here. During route planning, the groups conducted map studies. From these studies, the experienced groups made realistic assessments of route difficulty and formed flexible landmark expectations. In contrast, the inexperienced groups exhibited overconfident planning, resulting in unrealistic assessments of route difficulty. Furthermore, the inexperienced navigators' landmark expectations were rigid and narrowly defined. During route execution, these planning differences extended to differences in quality of spatial awareness and wayfinding performance. The inexperienced groups would mistakenly walk right past desired landmarks because the real-world appearances did not match their exact expectations. Each of the inexperienced groups became lost enroute from the start point to the initial checkpoint; during planning, each of these same teams had assessed this portion of the route to be "easy." The reader who is interested to learn more about the wayfinding results is again directed to Boswell's thesis (2001).

In addition to these tests, the researcher also conducted a cognitive task analysis with the objective of identifying the cognitive aspects of collaborative land navigation, which the virtual interface should support. During both experimental task phases, the researcher video-taped the team members' performance. After completion of the entire task, this tape was used to facilitate the knowledge elicitation interview.

DISCUSSION USING THE 5-FACTOR MODEL

Based upon our efforts to specify the virtual tutor's knowledge representation, we proposed a framework to help conceptualize the interaction and contributions of the overall system's components (see Figure 1). The framework contains five components: 1. The Theoretical Framework; 2. The Skill Domain; 3. The Knowledge Elicitation; 4. The Learning Environment; 5. The Knowledge Representation.

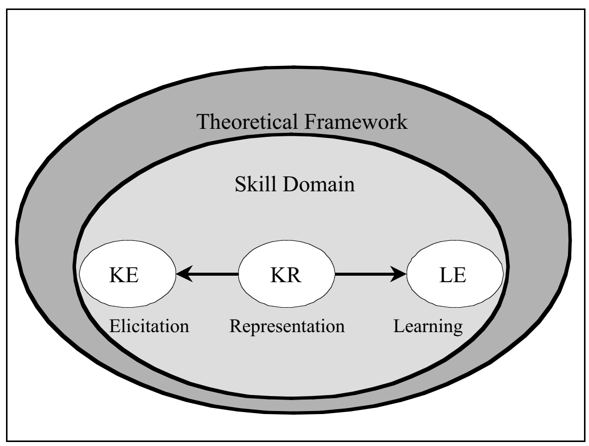

Figure 1. The Five Factors of the Training System (Peterson & Darken, 2000).

The Theoretical Framework encompasses and constrains the content of the other four factors. We conceptualize this framework to describe relevant theory about how people make decisions and ways to train better performance. The Skill Domain further constrains the other three factors by emphasizing key knowledge elements that are important to performance in the particular task domain. The inner three factors interrelate across the development of the system itself. The Knowledge Elicitation is the factor that informs selection and execution of the methods the developers use to learn about the cognitive elements of task performance. The Knowledge Representation is the descriptive and executable representations that capture and organize the information resulting form the elicitation. Finally, the Learning Environment is the embodiment of the training interventions developed to improve student performance. (Peterson & Darken, 2000)

Theoretical Framework

We highlight two issues regarding the theoretical framework: we make a further assessment of our chosen theoretical framework and make additions to extend it from the individual to team performance. Our study of individual navigators encouraged us to adopt the Recognition-Primed Decision model. The current study provided an opportunity to revisit the R.P.D. and reassess three of its five unique aspects that attracted us originally since each of them matched our characterization of navigation performance. 1. Navigators base their decisions and performance on continual Situation Assessments. 2. Mental Simulation in the forward and reverse direction is an integral component of the decision-making process. 3. When options are considered, the navigator considers each option sequentially rather than simultaneously.

The R.P.D. was designed to model and describe individual decision-makers cognitive processes. Since we seek to study collaborative navigators, in addition to the R.P.D., we want to include a model of collaboration in our theoretical framework. Rather than attempting to adapt the R.P.D. to span team decision-making, we adopted the team process model developed by Dickinson and McIntyre (1997).

Findings:

We are reminded that both N.D.M. and the R.P.D. are based upon performers who have experience in the skill domain. Indeed, the R.P.D. proposes cognitive processes that cannot be effectively performed by inexperienced performers. The fact that we designed our study to include both novice and expert level navigators complicates this distinction. We did not attempt to assess the quality of each navigator's mental process, however, our descriptions of team planning and execution do demonstrate significantly different behavioral strategies. As described by Stine (2000), experienced navigators spend more time and effort building accurate cognitive maps of the operational area than do novices. These more elaborate cognitive maps provided a basis for the frequent discussions observed between experienced team members during planning and execution.

We suspect that more elaborate cognitive maps enabled the rich content of the conversations between our experienced navigator team members. Our observations of the discussions closely match the R.P.D.. During the planning phase, the teams made joint decisions about the route to take. Team members mutually generated and communicated stories throughout the route planning.

During navigation execution, the teams would follow the original story until they detected an anomaly in the environment that violated their expectancies. This triggered a reassessment of the situation. When this happened, the teams began retelling the story to make senses of the changes they detected.

However, team members did not always agree on the circumstances of the situation. In these cases, they again reverted to storytelling to communicate the different assessments. Each member of the team would weave various cues and expectancies into their individual story in attempt to reach a consensus on the situation assessment. Typically, one member would generate and verbalize his story while the other watched and listened. Then the second team member might either verbalize a completely different story or in essence repeat the same story in his own words. Eventually, they mutually crafted one story to explain their situation. It is important to note that when considering different options in both planning and execution, the team members did so sequentially. They did not list a multitude of various stories and then attempt to evaluate this set. Rather, they worked with one or two storylines and continued to discuss them until reaching a decision. A revised situation assessment, complete with its usually unspoken by-products was the result of the story generation (Klein, 1998). Once the reassessment was finished, the team continued navigation until environmental conditions prompted another reassessment.

The R.P.D. makes distinctions between stories and mental simulations (Klein, 1998). Basically, a story is more complex, with more elements and a specific chronology of events. A mental simulation has fewer elements and is relatively simple. We did not attempt to investigate this distinction. Functionally, whether the narrated events could be classified simple or complex, they served the same purpose: the narrations provided a means for team members to share their understanding of the situational elements in a way that could be tested and modified when necessary. We found that when attempting to determine the course of action to follow, team members generated stories that began from the present situation and progressed to a future state. They tested these stories by mentally and verbally simulating and predicting how they might turn out. When attempting to make sense of the current situation, the team members again generated stories; the starting point for these stories was a point in the history of the mission. The story would then progress from that historic point to the present situation. Again, mental simulation was used to hypothesize about aspects of the story that were not directly sensed and to explain events that might have caused the current situation.

Skill Domain

Our previous studies within the land navigation domain involved study of individual navigators. Our most recent work clearly showed that within this domain, navigation is naturally performed collaboratively. Therefore, we wanted to better understand team navigation and if possible validate our model of the individual navigator.

Findings:

The behavior of the experienced team members closely matched our previous studies of individuals (Peterson, Stine, and Darken, 2000). Although part of a team, the individual team members each exhibited the cognitive processes similar to one another. The main difference between individual and team performance is that collaboration necessitated communication and sharing of these cognitive processes.

The two environmental cues that were most commonly relied upon were pace count and terrain association. The pace count is the method whereby the navigator counts his or her steps and estimates distance traveled based upon this count. Terrain association is the process by which the navigator makes sense of the observed terrain features and compares them to either the cognitive or paper map of the environment. It involves identifying key terrain features from multiple perspectives in three-dimensions and visualizing how they would appear on a two-dimensional map.

In addition to these two commonly used techniques, navigators also reported using the "feel" of the ground underneath their feet. Experienced navigators reported monitoring the orientation or tilt of the ground as they walked across it. This information was used to modify pace count distance estimations and to sense elevation changes.

Knowledge Elicitation

We conducted structured interviews in our earlier attempts to elicit knowledge from navigators; their structure was based upon Klein's Critical Decision Method (Klein, Calderwood, and MacGregor, 1989). While it proved valuable, our experiences motivated us to find a way to combine observation with interviews, and we attempted to follow such a methodology this time.

The method we did use was once again based upon Klein's cognitive task analysis work. After examining Klein's ACTA (Applied Cognitive Task Analysis) product (Militello, Hutton, Pliske, Knight, Klein, and Randel, 1997), we determined that it could yield results similar to the Critical Decision Method (C.D.M.). We chose to follow the ACTA methodology primarily because the tools are more easily learned. ACTA provides a suite of tools for the analyst, and from them we chose to use a modified version of their simulation interview tool (Militello, et al., 1997).

As with the C.D.M. method, a simulation interview is conducted with an experienced domain participant to elicit his or her knowledge regarding a task performance. However, where the C.D.M. relies upon the participant's recollection of a past event from memory, the simulation interview is based upon the participant's interaction with or viewing of a simulation. The simulation could take many forms, from pen and paper through three-dimensional computer simulations. In our case, we chose to use videotape; the participants watched a videotape of the navigation mission they had just completed. We further modified the procedure by interviewing the team with both members present rather than with the members individually.

Findings:

These modifications to the simulation interview provided a way for us to combine observation with interview tools. The videotape told and documented the navigation performance and provided an archive of observations made by the researcher. Whether solely from memory or assisted by videotape, both the C.D.M. and the simulation interview are based upon the regeneration of the participant's story of the event. These methods differ from the more traditional knowledge elicitation approaches that attempt to draw general rules from the participant. Based upon both the data collected from the simulation interviews and the observations of story-generation behavior during planning and execution, we are becoming increasingly convinced that knowledge is stored, associated and communicated quite naturally through narrative methods. Therefore, we expect that knowledge elicitation methods based on narratives will produce better descriptions and representations than those elicitations that are not.

Our experimental design mandated interpersonal communication. While we did not specify that team members must use stories, it is interesting to note that people did default to storytelling as the medium for exchanging information. It is possible that the collaborative nature of our experimental tasks may have influenced the navigators to tell each other stories. Thus, in future work, we will be sensitive to our protocol's influence on the medium participants choose for conveying knowledge.

Knowledge Representation

While requirement specification of the executable knowledge representation was not one of our current goals, we did learn some things that we will add to our list of requirements.

Findings

Our executable knowledge representations are based on descriptive representations. Thus, while our specifications are geared toward the executable versions, it is implied that our descriptive representations are required to have in their raw form, the same data elements. The findings from our study emphasize situation assessments and stories. To our list of knowledge representation requirements, we now add stories.

Situation assessments and stories are related in that stories are generated and used when situation assessments are revised or evaluated. While we did not use Situation Assessment (S.A.) Records (Hoffman, 1998) in this study, have successfully used them in the past (Peterson, et al., 2000) to establish a chronological trace of events and cognitive processes. These S.A. Records are based upon the R.P.D., and the enumeration of the by-products of each situation assessment. If one considers a story to be a similar trace, then it might be possible to use a set of S.A. Records to effectively tell the story.

Learning Environment

Our ultimate learning environment is a virtual environment that allows us to situate the user inside a synthetic task environment, in which he or she performs domain-authentic tasks under the supervision of a virtual tutor. One component of such a virtual learning environment is the human-computer interface. The main goal of the current study was to observe collaborative navigation in the real-world and use the data as inputs to the interface design (see Table 1).

Findings:

Regarding interpersonal communication, this study shows that people gather a great amount of information from the faces of their team member. Team members attended to their teammate's facial expression and gaze direction frequently. During story generation and evaluation, team members studied their partner's face and it was noted that the team member who told his story with more conviction, as evidenced by body language and facial expression, often carried more weight. Team members used their partner's eyes to guide them to points of interest in the environment, as the gaze indicated particular cues and landmarks.

The virtual interface can be designed to facilitate the natural transfer of real-world navigation strategies into the virtual environment. Our findings regarding the skill domain influence such design. Interface specifications revolve around the two techniques used most commonly by the navigators: these are pace count and terrain association. The interface should provide a means for the navigator to sense and count the paces as he locomotes. Environmental cues used for terrain association are mediated mainly through the visual modality, which traditionally receives the greatest level of effort in environmental modeling and display device resolution. However, we also learned that the kinesthetic modality provides valuable redundant cues used to modify distance estimations and spatial location and orientation. Therefore, the ideal interface would also provide information about the orientation or tilt of the ground underneath the navigator.

One may question how the study of human-to-human collaborative behavior can inform human student to virtual tutor communication. The interpersonal relationships we observed were based upon a collaborative, team task in which both members are peers; it was not a tutoring interaction. The team's goal was the successful completion of the navigation task. However, if we changed the team's goal to improvement of the knowledge of one team member, and assigned tutor and student roles, we can constrain the collaborative relationship. In essence, collaboration in the general sense is the superset for the specific tutorial collaboration that our system will facilitate. Therefore, we expect that many aspects of interpersonal communication observed in this study will transfer to the specific case of the tutorial collaboration.

Design Characteristics of the Learning Environment's Virtual Interface		
Interpersonal Communication		***Locomotion***
Implements Shared Visual Pointing		Provides Pace Count Customized to the User
Provides Gaze Tracking		Stimulates Kinesthetic Modality to Simulate Ground Tilt Information
Conveys Team Member Body Language and Facial Expression		

Table 1. The design characteristics of the Virtual Interface.

Furthermore, our study considered human-to-human, face-to-face interactions while our envisioned learning environment is based upon interaction between a human student and a virtual tutor. We consider interaction from the student's perspective, across a spectrum. At one endpoint of the spectrum, we find real-world human to human communication. At the far endpoint, we set communication between a human and a virtual agent. In between these two endpoints, we identify a point where we have two humans in communication although physically not collocated. In this case, they communicate through a human-computer interface. From the student perspective, the features of the interface are the same whether the entity she communicates with is human or virtual. Hence, while today we cannot create a virtual tutor who communicates as well or naturally as a human tutor, we can begin to specify the user interface to that virtual tutor by studying distributed, communication through the virtual interface.

Interactions Between the Five Factors

In addition to the mapping of experimental design and findings to each of the five factors, we have found there are a few experimental issues that do not neatly or entirely fit into one of the five factors. We consider these issues to be interactions between certain individual factors.

Theoretical Framework and Knowledge Elicitation

We discovered an unexpected interaction between the modifications we made to the theoretical framework and the knowledge elicitation methods we used. Our primary modification was to extend from the individual to the collaborative navigator. Since the experimental task was now collaborative, we required the navigation team members to communicate. In essence, by observing and recording the interpersonal communication that naturally happens in the teams, we were collecting verbal protocol as if we had instructed the participants to "think aloud." The key difference between the think aloud procedure and the collaborative procedure concerns alteration of the task; verbalizing mental simulation and thought processes was naturally inherent to the collaborative task while individuals do not normally verbalize their mental processes when alone. In conclusion, we found that the collaborative task setting afforded natural opportunities to reveal mental processes. Of course, as with any verbal protocol, we must be wary that the verbalized processes may or may not reflect the person's actual mental processes, and design our knowledge elicitation methods to be sensitive to this concern.

Theoretical Framework and Knowledge Representation

Within the Naturalistic Decision-Making community, there is a general understanding of how the N.D.M. framework differs from other Decision-Making frameworks (Zsambok, 1997). Many researchers have generated a number of individual models that all fit under the umbrella of the N.D.M. framework, though each has subtle differences. Practically, we are not motivated to draw the distinctions between the N.D.M. Framework and the R.P.D. Model. However, it is important to call attention to our usage of the two terms relative to our Five-Factor model.

N.D.M. is a core part of our Theoretical Framework, but it does not provide the level of detail to guide our knowledge representations. The R.P.D. complements N.D.M. and fleshes out the general skeleton of the Theoretical Framework and there it helps guide our overall experimental design. In addition, the R.P.D. provides enough detail to reach down into the Knowledge Representation. The R.P.D. provides terminology and elements that help us build and communicate our descriptive models. Indeed, we consider the results of our Cognitive Task Analyses to be domain and task specific instances of R.P.D.-based descriptions. Since the executable model is based upon the descriptive model's foundation, we use the R.P.D. model to inform the generation of requirement specifications for our executable knowledge representations.

Knowledge Elicitation, Knowledge Representation and Learning Environment

One common element spans all three of the inner factors: that element is storytelling. Stories contain knowledge, and we have found that eliciting stories is a good way to elicit knowledge. Therefore, we must use knowledge representations that capture and maintain the richness and specificity that characterize the narrative form. Furthermore, we should consider ways to incorporate storytelling into the learning environment itself.

CONCLUSIONS

In this paper, we have described a study intended to inform the design of a collaborative virtual interface. We organized the discussion of the experimental issues and findings around our Five-Factor model of virtual learning environments.

This study has helped us specify our human computer interface requirements. In addition, our findings have raised our awareness of the relationships between peer-to-peer team interactions and tutor-to-student interactions. While the goal shifts from team performance to student learning, we expect that many of the interpersonal communication features are the same. The virtual interface between human collaborators or human student and virtual tutor should support these common features. Furthermore, our growing understanding of the skill domain can inform key elements of the locomotion interface.

In addition, we uncovered more evidence that indicates the R.P.D. nicely matches the land navigation domain. We were able to use R.P.D.-based methods in our knowledge elicitations and knowledge representations.

Finally, we observed how naturally people use stories to communicate knowledge. Future work will be alert and sensitive to incorporating storytelling across the spectrum of system development activities.

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