

Chunking and Team Pattern Recognition

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ABSTRACT

A series of experiments was conducted in which teams made resource allocation decisions while physically dispersed and supported with a shared virtual work surface (What You See Is What I See - WYSIWIS). The task required teams to recognize patterns of information and collaborate to allocate their resources appropriately. The experimental treatment involved the use of tools specifically designed to minimize the cognitive effort required to recognize and share patterns among team members. Dependent measures included outcome quality, pattern sharing correctness and pattern sharing time. All teams received significant financial rewards in direct proportion to their outcome quality. Teams supported with the pattern-sharing tools had significantly higher outcome quality and significantly less resource movements. Further, the teams that used the chunk-sharing tool performed better than the teams that relied on an item-sharing tool. These results extend the theory of Recognition Primed Decision-Making by applying it to groups.

Keywords

Collaboration, Shared Cognition, Stimulating Structures

1. INTRODUCTION

The pace of business and military decision-making continues to quicken. Many situations involve high stakes, time-pressure, and uncertainty; these dynamic, continuously changing environments are called “naturalistic” decision settings. Researchers have found that in naturalistic domains, individual experts make almost 90% of their decisions by “feature matching” between the current situation and one from prior experience (Kaempf, Klein, and Wolf, 1996).

Dynamic decision environments are especially taxing to our limited cognitive resources of memory, attention and perception. Miller (1956) described the limitations of short-term memory as “the magical number 7,” suggesting that most people can remember about 7 things at any given moment. Humans also have difficulty dividing attention among several tasks, or attending

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to all the information provided by our senses (Broadbent, 1958; Treisman 1969). As a result, we often do not perceive most of the information that is available to us (Lavie, 1995).

Decision Support tools have been developed to support individual cognition in naturalistic domains (Morrison, et al., 1997) and these tools are successful because they support specific cognitive strategies (i.e. “feature matching” above). They mitigate the effects of stress on short-term memory and attention management. The successful application of cognitive science to decision support technology makes it possible to consider extending these advantages to other decision domains.

While this is applicable to individuals, teams (Keltner, 1989) rather than individuals make many decisions in naturalistic domains and thus, considerable effort has been devoted to the development of groupware to support these domains (McGrath and Hollingshead, 1994). Pendergast and Hayne (1999) have characterized groupware as software supporting group interactions. They categorize groupware by size, frequency of occurrence, composition, motivation and decision process, technology, dispersion and synchronicity. Furthermore, they suggest that a complete groupware infrastructure has four dimensions: communication (pushing or pulling information), collaboration (shared information leading to shared understanding), coordination, and control (management of conflict).

While there is a large body of literature on groupware (discussed below), we are not aware of any groupware that is specifically designed to optimize the utilization of human *cognitive* resources in dynamic situations; the systems have always addressed *behavioral* issues associated with human interaction. So, how can we apply theories of individual cognition to the design of collaboration and decision support tools for groups? In this article we propose a theory of group cognition for naturalistic decision domains. From this theory, we derived a collaboration and decision support tool for group-level feature matching (sometimes also called situation assessment or pattern matching). We have previously reported that teams do engage in pattern recognition (Hayne, Smith and Turk, 2002). We are now interested in whether information sharing structures that are more closely aligned with our cognitive structures lead to superior performance.

In the next section we describe the theories of individual cognition relevant to naturalistic decision domains. We explain our theory of group cognition, and describe the derivation of a

team-based pattern-recognition tool. In section 3, we describe an experiment to validate our theory. Section 4 presents the results of that experiment, and discusses the implications. In section 5, we list our conclusions and suggestions for follow-on research.

2. PRIOR RESEARCH

Most products in our environment are traceable to group activity rather than individual activity (Thompson and Fine, 1999). Groups can accomplish larger and more complex tasks than individuals. As the size of a project increases, so typically does the need for some form of supervisory activity. In general, we view these supervisory activities as not directly contributing to a desired outcome, but rather they facilitate the activities that contribute directly to an outcome. An efficient group would devote a large amount of resource to activities that directly contribute to the desired outcome and a relatively small amount of resources to facilitating activities. There are many factors affecting group effectiveness and are categorized into process losses and process gains (for a review see Jessup and Valacich, 1993; Nunamaker, 1997).

In our context, the goal is to provide information management mechanisms that maximize process gains while minimizing process losses. While this simple model has an intuitive appeal, it begs the question, “how does one maximize gain or minimize loss?” The answers to these questions require the integration of at least three broad areas of study:

- Individual psychology, including cognitive abilities and limitations,
- Groups and social interactions, including communications and motivations, and
- The role of artifacts as stimulating structures for human interactions.

A complete review of any one of these topics is beyond the scope of this paper, so we will limit our review to a subset of these topics that apply most directly to our research objectives.

To further reduce the scope of our inquiry, we make some assumptions concerning the nature of the groups we wish to study. For example, we assume that the members of our groups are drawn from an established organizational culture and that they share a common body of knowledge with respect to the task domain (e.g., military personnel). We assume that each group member understands their role in the group, and the roles of the other group members. We assume that the members are motivated to achieve the stated objectives of the group.

In the following sections we review literature that describes the characteristics of natural task domains and the limitations of individual cognition as it relates to those domains. We review theories of group-level cognition related to transactive memory, shared mental models, and distributed cognition. Finally, we review the literature on stimulating structures and computer mediated interaction in order to offer a prescription for the development of computer-based tools for supporting group work in natural domains.

2.1 Decision Making by Individuals

Klein (1993) used the term “naturalistic decision making” to refer to dynamic situations that are characterized by high stakes, time pressure, and uncertainty. These situations are dynamic in the sense that they involve a series of judgments and actions. Each action may result in a change to the situation. In a typical situation, a decision maker must observe the results of his/her actions and adjust subsequent actions based on this feedback. Usually the decision maker operates with incomplete information which creates a degree of uncertainty with respect to their assessments of the situations and the effects of their actions. Often, the situation is changing rapidly due to influences beyond the control of the decision maker; this may create the feeling of time pressure.

Klein (1993) developed the theory of Recognition-Primed Decision Making (RPD) to describe how individual experts make decisions in these naturalistic environments. Klein’s theory is that experts make incremental decisions based on recognizing patterns in a developing situation. According to RPD, tactical decision makers recognize the current situation in so far as it is similar to some recalled and similar situation stored in their memory. This situation awareness, and its associated plan of action, is retrieved from memory for use in the current situation. Kaempf, Klein, and Wolf (1996) found that experts make almost 90% of their decisions by “feature matching” between the current situation and one from prior experience. Similar findings have been demonstrated in the domain of chess (Chase and Simon, 1973; Gobet, 1997; Gobet and Simon 1998; Gobet and Simon, 2000).

Experts have a large amount of prior experience from which they can adapt known solutions. Nevertheless experts periodically encounter novel situations. In unfamiliar cases when the RPD process does not yield a “feature-match,” decision-makers employ an “explanation-based reasoning” process (Pennington and Hastie, 1993). Here, decision-makers generate a “story”

that accommodates some of the observed data, thereby providing a plausible interpretation of the situation. Based on this explanation, the decision maker develops an expectation of what might happen next in the story. By comparing their expectations with their observations as the situation develops, the decision maker can confirm or disconfirm the story. Decision makers take actions that they believe will influence their stories to have a desirable ending.

Based on these descriptions of expert decision processes in naturalistic domains, we begin to see how we might build computerized tools to support individual decision making. The tools should be designed to facilitate the detection of patterns in the environment, and to display and replay sequences of events as an aid to explanation-based reasoning. Without computer tools, pattern recognition and story-telling require considerable cognitive effort. To be effective, these tools must be designed with consideration of human cognitive limitations (Hoffman, Crandall and Shadbolt, 1998).

2.2 Individual Cognitive Limitations

Humans have limited cognitive capacities for memory, attention and perception (Norman and Bobrow, 1975). Miller (1956) described the limitations of short-term memory as “the magical number 7,” suggesting that most people can remember about 7 things at any given moment. We also have difficulty dividing attention among several tasks, or attending to all the information provided by our senses (Broadbent, 1958; Treisman 1969). As a result, we often do not perceive most of the information that is available to us (Lavie, 1995).

Dynamic decision environments are especially taxing to our limited cognitive resources. Under time pressure people tend to focus their attention on immediate, highly structured, tasks while avoiding more important and complex tasks (Morrison, Kelly, Moore, and Hutchins, 2000). Limitations to short-term memory make it difficult to recognize patterns because we can't remember all the features of a developing situation long enough to recognize an emerging pattern. Similarly, it is difficult to recognize slow-developing trends. The limitations of short-term memory are exacerbated by the stress of time pressure: it has been shown that stress causes the release of a cortical steroid that interferes with memory (de Quervain, Roozendaal, Nitsch, McGaugh, and Hock, 1998; Kirschbaum, Wolf and Hellhammer, 1996).

Recently, decision support tools have been developed to support individual cognition in naturalistic domains (Morrison, et al., 2000) and these tools are successful because they support specific cognitive strategies, such as “feature matching”. They mitigate the effects of stress on short-term memory and attention management. The successful application of cognitive science to support individual decision-makers is a cornerstone of our strategy for the support of groups. In the following section, we review theories of group-level cognition in search of similar leverage points for improving performance.

2.3 Collective Memory, Shared Mental Models and Shared Cognition

Ideally, groups should be less affected by the cognitive limitations of their members. Consider a team attempting to recall the names of all the US state capitals. Most likely there will be several capitals that every member knows. This is information that the group holds in common. One would also expect that the gaps in the members’ knowledge would complement each other to some extent, so that the collective recollection of the group would be superior to the average individual recollection.

In order to achieve the benefits of collective recall, the individual group members will require a system for encoding, storing, retrieving, and communicating. This system has been called a transactive memory system (Wegner, 1987). This system includes the cognitive abilities of the individuals as well as meta-memory, that is, the beliefs that the members have about their memories. Thus, the members of a group have access to the collective memory by virtue of knowing which person remembers which information.

Under certain circumstances group memory has been shown to be superior to individual memory (Hinsz, 1990) and can lead to superior task performance (Moreland, 1999). More typically, however, the performance of groups rarely exceeds the performance of the group’s best individual member (Hill, 1982). Ineffectiveness in transactive memory systems may be a result of inefficient sharing of information within groups. Research has shown that during collective recall, groups are more likely to exchange and discuss “common” information shared by all group members than information known by only one group member (Dennis, 1996; Wittenbaum and Stasser, 1996). Other factors that have been shown to affect information sharing in groups include the experience of the team members and the disconfirming nature of information (Kim, 1997; Stasser, Vaughan & Stewart, 2000; Stewart, 1998). The stress of time

pressure in naturalistic situations may compound the problems with transactive memory systems because the cortisol released impairs the meta-memory of “who remembers what,” leading to breakdowns in collective recall.

Of course, there is more to group cognition than collective memory. Cannon-Bowers, Salas, and Converse (1993) suggest that for teams to be effective, the members must have common cognitive representations of task requirements, procedures, and role responsibilities. Cannon-Bowers, et al. refer to this as a shared mental model. These shared mental models provide mutual expectations that allow the teams to coordinate their efforts and make predictions about the behaviors and needs of their teammates (Cooke, Salas, Cannon-Bowers, and Stout, 2000). A team’s understanding of a complex and dynamic situation (team situation awareness) is influenced by the collective knowledge, skills, and attitudes of the team (Cooke, Stout, and Salas, 1997).

In the same way that transactive memory systems are dependent upon the existence of meta-memory, shared mental models require that group members maintain a meta-model of “who does what, when.” However, meta-models are not universally effective and are vulnerable under the stress of time pressure. Thus, there is an opportunity to improve group performance through support of transactive memory systems and shared mental models. Hutchins’ (1991, 1995) work on distributed cognition suggests one mechanism to accomplish this goal.

Group activity necessitates a division of labor, which in turn requires some distributed cognition to coordinate the activities of the participants (Thompson and Fine, 1999). For distributed cognition, Hutchins (1991) defines the unit of cognitive analysis as a distributed socio-technical system. The cognitive properties of this system are produced by an interaction between the structures internal to individuals and structures external to individuals. In particular, that portion of cognition that governs the coordination of the elements of a task might be represented in the external environment, and be available for inspection. By making this representation “public”, the group can share it. Hutchins (1995) describes how a group’s use of a technical artifact can transform a complex computational task into a simple perceptual task. For example, a pilot team sets the airspeed “bug” on the desired airspeed so they can share perceptions of whether the aircraft is being flown at, above or below the target airspeed. This

technical artifact, when used as a part of a distributed socio-technical system, is an example of the use of a stimulating structure.

2.4 Stimulating Structures

Grassé (1959) coined the term stigmergy, referring to a class of mechanisms that mediate animal-animal interactions. The concept has been used to explain the emergence, regulation, and control of collective activities of social insects (Susi and Ziemke, 2001). Social insects exhibit a coordination paradox: they seem to be cooperating in an organized way. However, when looking at any individual insect, they appear to be working independently as though they were not involved in any collective task. The explanation of the paradox provided by stigmergy is that the insects interact indirectly by placing stimulating structures in their environments. These stimulating structures can direct and trigger specific actions in other individuals (Theraulaz and Bonabeau, 1999).

As mentioned above, experts in various domains vastly outperform novices in the recall of meaningful material coming from their domain of expertise. To account for this result, Chase and Simon (1973a, 1973b) proposed that experts acquire a vast database of chunks, containing, as a first estimate, 50,000 chunks. When presented with material from their domain of expertise, experts recognize chunks and place a pointer to them in short-term memory (STM). These chunks, each of which contains several elements that novices see as units, allow experts to recall information well beyond what non-experts can recall. Since then, intensive research in skilled memory has extended our understanding. For example, Staszewski (1990) has shown that highly trained subjects can encode large amounts of information into retrieval structures using mnemonics as the method of loci. The number of retrievable chunks is much larger than originally proposed. Gobet and Simon (2000) have shown that the time required to encode and retrieve these chunks is much shorter than previously thought. Furthermore, an expert can increase the size of their chunks based on new information; effectively increasing short-term memory (Gobet & Simon, 1998).

We believe that effective team performance requires transactive memory systems and shared mental models. The cognitive effort required to maintain these meta-models may not always be available to teams operating in naturalistic situations, so if a stimulating structure (artifact) that maps to a cognitive chunk is placed in the external environment; their placement should not

diminish the limited memory resources of the team. Interpretation of stimulating structures is primarily a perceptual task; such tasks require less cognitive effort than reasoning or computational tasks. Thus, we suggest, the opportune application of a cognitive “chunk” stimulating structure may be the key to enabling transactive memory systems and shared mental models to function under dynamic conditions.

In the following section, we formulate our model of group decision making in naturalistic conditions, and provide prescriptions for the design of technical artifacts that provide cognitive support at both the individual and team level.

2.5 Model of Team Recognition Primed Decision Making

Our model of team decision-making in naturalistic environments is shown in Figure 1. Hutchins (1991) asserts that a distributed socio-technical system engages in two kinds of cognitive work: the cognition that is the task, and the cognition that governs the coordination of the elements of the task. The portion of cognition that is the task is carried out internally to the individual members of the system. Because of this, we believe that our model of team decision-making in naturalistic environments can be adapted from Klein’s (1993) model of individual experts.

We suggest that teams perform essentially the same steps as individual experts, with some additional executive functions. Similar to individual experts, we hypothesize that teams assess the situation and perform “feature-matching” tasks which trigger recall of similar situations from their collective memory. Next, teams select a response by adapting a strategy from their previous experience. Finally, teams execute their plan, and observe the results. The additional tasks required of teams involve synthesizing their assessments of the situation among members, communicating their expectations of what might happen in the near future, and (for teams with semi-autonomous members) their intentions for response. As mentioned earlier, these additional functions are dependent on effective transactive memory systems and robust shared mental models.

Kaempf, Klein, and Wolf (1996) found that individual experts spent most of their time scanning the environment and developing their situation assessments. Relatively little time was spent selecting and implementing responses. If the situation assessment task has the same

relative importance for teams as for individuals, then the initial focus for team decision support should be directed towards the development of tools to support collective situation assessment. For individual members, these tools should be designed to reduce the cognitive effort required to perceive patterns, attend to the highest priority tasks, and remember the most important features of the task environment. For the group, these tools should facilitate sharing of assessments through placement of stimulating structures. Our theory suggests that teams will also derive some benefit from stimulating structures that facilitate sharing of expectations and intentions.

In the next section we review current research into groupware that might involve sharing stimulating structures.

2.6 Computer Mediated Interaction

To mitigate the process losses and gains mentioned above, much research has been conducted into software to support computer-mediated interaction (CMI) or groupware. This includes areas of research into group decision support systems (GDSS) and computer-supported cooperative work (CSCW).

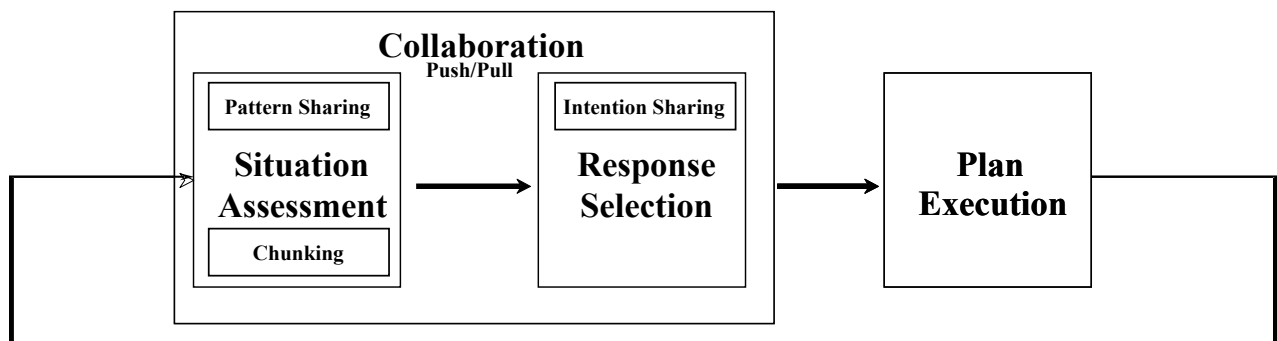


Figure 1: Team Recognition Primed Decision Making

GDSS enforces rules of meeting protocol and structure in an “interactive computer-based system that facilitates the solution of unstructured problems by a set of decision-makers working together as a group” (DeSanctis and Gallupe, 1987). Existing GDSS tools facilitate both small (3-6 members) and large (7-30) groups through the various stages of the decision-making process (Gallup et al., 1992; Valacich, Dennis, and Nunamaker, 1992).

On the other hand, CSCW is defined as “the study and theory of how people work together, and how the computer and related technologies affect group behavior” (Rein and Ellis, 1990).

CSCW implementers build “computer-based systems that support two or more users engaged in a common task (or goal) and that provide an interface to a shared environment” (Ellis, Gibbs and Rein, 1991; Stefik et al, 1987). These systems usually facilitate communication between members of a small group and provide task-specific tools (Hedlund, Ilgen and Hollenbeck, 1998). The software rarely regulates the actual meeting process; the designers expect that normal social protocols between participants will suffice. These systems have branched into Collaborative Virtual Environments (Singhal and Zyda, 1999) with *relaxed* WYSIWIS (What You See Is What I See), *shared views/awareness* and *telepointers* (Greenberg, Hayne and Roy, 1995; Hayne and Pendergast, 1995), among other techniques.

We do not review this entire literature here because for our research, we are concerned with enhancing, from a *cognitive* perspective, a small group's real-time interaction when there is no time or ability to have a face-to-face meeting, no facilitation available, nor the bandwidth to support rich interaction, e.g. video (a naturalistic decision environment). We focus on enhancing human cognitive limitations in our prescriptions for group decision support in naturalistic conditions.

2.7 Prescriptions for Group-level Cognitive Support

We believe that the cognitive effort required to perform group tasks can be reduced through placement of stimulating structures in the external environment of a socio-technical system. We hypothesize that the guiding principles for the design of these stimulating structures are as follows:

- The stimulating structures should be pushed to the external environment rather than directly to individual group members. Likewise, the stimulating structures should be pulled from the external environment rather than directly from group members. This principle follows from the work of McFarlane (2002) in which he found that “negotiated interruption” yielded the best results for coordinating actions. As Hutchins (1991) points out, every distributed task requires two types of cognition: cognition that is the task, and the cognition that governs the coordination of the elements of the task. Thus group work will necessarily involve frequent interruptions as group members switch their attention between task-cognition and coordination-cognition. Pushing and pulling the stimulating structures to/from the external environment implements a negotiated interruption strategy.

- The stimulating structures should require minimal effort to place into and retrieve from the external environment. Ideally they should transform complex cognitive tasks into simple perceptual tasks.

- The most important stimulating structures for group work in naturalistic situations are related to situation assessment. The structures should convey information regarding “feature-matching” from the current situation with a previously recalled situation.

- Our theory suggests that teams will also derive some benefit from stimulating structures that facilitate sharing of expectations and intentions. In this case, the stimulating structures might indicate the nature or location of an expected event, or the type of intended response.

In order to isolate the effects of individual-level support from group-level support, we apply only our group-level stimulating structures in our study. Furthermore, we have limited the stimulating structures to situation assessment phase of a task (pattern recognition and sharing), to eliminate potential confounds with the effects of other stimulating structures. In particular, the group will benefit from a single stimulating structure that:

1. implements a negotiated interruption strategy,
2. requires a minimal effort to place into the environment,
3. requires only a perceptual effort for interpretation, and
4. applies to the situation assessment phase of decision making.

Thus, our hypotheses are:

H1: The average outcome quality of the groups supported with a stimulating structure for sharing patterns will be greater than the average decision quality of the groups without.

H2: Among groups supported with a stimulating structure for sharing patterns, the average sharing correctness will be greater for groups using a “chunk” sharing tool.

H3: Among groups supported with a stimulating structure for sharing patterns, the average sharing time will be less for groups using a “chunk” sharing tool.

To test our hypotheses, we have created a cooperative decision task that involves elements of pattern recognition and response selection. We have built a shared visual surface and a “thin”

tool for pattern sharing. Our decision task, tool and research design are described in the following section.

3. METHOD

3.1 Decision Task

In order to validate our model, we created a collaborative game consisting of a java applet client incorporating real-time tele-pointers and a pattern-sharing tool (<http://www.speedofheat.com/hayne/onr>).

The game is an extension of McGunnigle, Hughes and Lucas' (2000) two-player game. In our game, groups of three players confront independent, discrete decision scenarios. There are seven regions of confrontation for each scenario; the outcome measure is the count of the number of regions in which the players "win." Players within each group have to combine their resources to overcome the "enemy's" resource in each of the seven regions.

The game is played on a computerized board consisting of 3 large intersecting circles with sectors defined by the intersecting areas (see Figure 2). Three patterns were defined (see Figure 3 for the pattern set). Each pattern is a unique representation of the strength of the enemy's forces (ranging in value from 1 to 20) in each of the seven sectors.

Prior to data collection, participants were provided a sheet of paper containing a drawing of each of the 3 patterns, and allowed to play six practice trials while viewing the patterns. After the practice trials were completed, the participants surrendered the pattern drawings.

Each data collection session involved participants playing 24 (excluding the 6 practice trials) independent trials. By displaying the three basic patterns in one of three different rotational orientations (spun 120°) and varying the sectors in which the enemy's forces are revealed (for instance, only the 20, 19, 9 and one of the 1s is revealed during the trial shown in Figure 2), the players were confronted with unique scenarios for every trial.

All three members of a team were shown the same scenario at the start of each trial. Each team member was supplied with 7 resource tokens, with values from 1 to 7. Each sector had 3 positions where tokens could be played. Tokens could be played by any combination of players within each sector. In other words, a single player could play 3 of their tokens within the sector, or each team member could play 1 token within the sector, etc. Only one token could be played in any particular position. Participants could see each other's tokens being played in real-time

(relaxed WYSIWIS). Players could not move another player's tokens but they could "bump" (replace) a teammate's token from a sector by playing his/her own token in the same location.

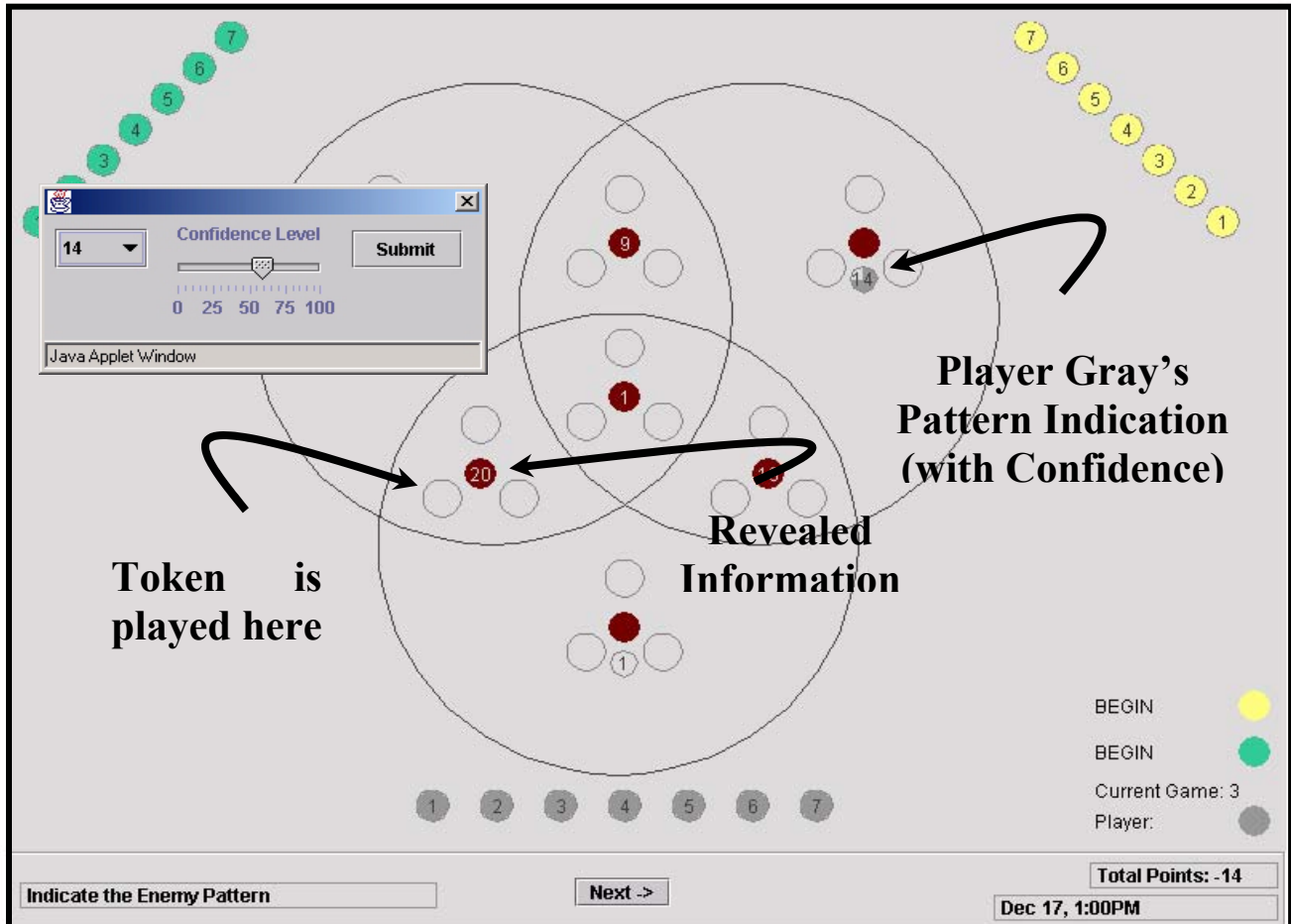


Figure 2: Multiplayer Collaborative Game

The objective of the game was for the team to win as many sectors as possible in each trial. A win was scored for a sector if the sum of the values of the groups' tokens for that sector was greater than or equal to the resources required in that sector. Each of the 3 resource patterns was constructed in a way that the participants could win all 7 sectors if they placed their tokens appropriately. Thus, the scores could range from 0 to 7 on each trial (although scores less than 4 required a deliberate error, such as the players neglecting to place their tokens.) In pilot testing, we determined that the task of recognizing partially revealed patterns is sufficiently difficult to provide a significant test of team performance.

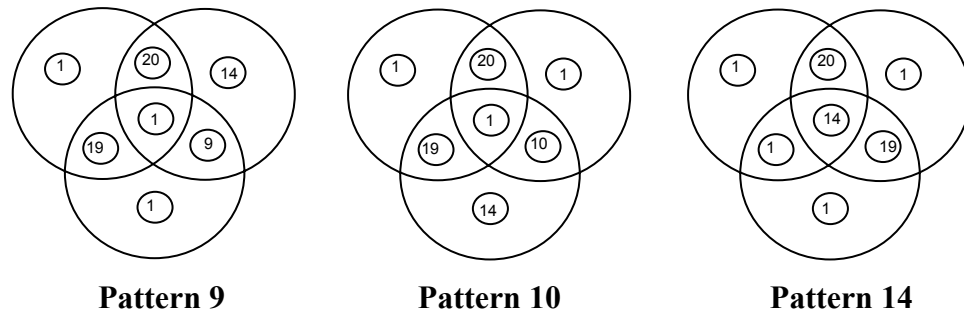


Figure 3: Game Patterns

3.2 Independent Measures

Our study included three treatments – baseline (BL), item sharing (IS), and chunk sharing (CS). The BL treatment played the experimental game without any support for pattern sharing; i.e., they moved their tokens to the different sectors without any prior sharing of pattern information. Participants in the other two treatments played their games in two phases; in the first phase they used a tool to share pattern information, and in the next phase they moved their tokens. While the IS group members used the tool to indicate the values in specific sectors, the CS group participants indicated the pattern they thought they were playing against using labels (thus tapping into the chunking concept). Participants in the CS treatment were trained to chunk by associating a label for each of the three basic patterns (see Figure 3). The labels are based on the occurrence of a specific value (for example 14) in a specific location. In addition to sharing information, both IS and CS participants also indicated their levels of confidence in their value or pattern assessment (the dialog box in Figure 2). The IS and CS team members could see all other team members’ pattern indications in real-time.

For each data-collection session, a predefined set of patterns was chosen and partially revealed to the participants in random order. These partially revealed patterns were categorized into one of three types: definitive (D), luck (L), and strategy (S). A definitive pattern was one that each participant should be able to identify completely. A luck pattern was one in which the amount of information revealed made the pattern equivocal. A strategy pattern was one in which the amount of information revealed was such that the participants could choose a strategy for minimizing the sectors lost, even though they would not know definitively which pattern was presented.

3.3 Dependent Measures

The following data were captured: 1) patterns indicated along with confidence levels; 2) all player moves; 3) sectors won/lost by the team during a trial; 4) the timing associated with the above events; 5) player demographics; 6) perceptions of team behavior (through a survey) that is not reported in this paper.

3.4 Subjects

For this study, we used 57 3-person teams of undergraduate students enrolled in a junior level course at a state university in the western United States. The sessions took place in a large computer lab (40 workstations). Participant seating locations were assigned so as to physically separate group members as much as possible. A maximum of 2 hours were available for each data collection session. Except for one, all teams finished well within the allotted time.

3.5 Incentives

In order to provide additional realism, subjects were externally motivated to take these experiments seriously and to behave “as if” they were making real business decisions (Cox, Roberson and Smith, 1982). This was accomplished by instituting a salient monetary payoff function directly related to the groups’ decision quality, as measured by the number of sectors won in every trial:

$$\text{Individual payoff per trial (US\$)} = (\text{correct sectors} - 5) * \$0.50$$

Subjects were informed of this function and told that money would be paid to their group in cash at the end of the experiment.. The incentive money was displayed (\$1500) to encourage them to believe they would indeed be paid. Subjects were also paid \$5 to show up on time for the session. Individual participants typically earned \$15-20 for the two-hour session.

3.6 Experimental Procedures

All subjects received training in the patterns and in the use of the system immediately prior to the game. During 6 initial practice sessions the subjects were shown the results of their decisions, and informed of the payoff that they would have received if the practice session had been real. The subjects were given the opportunity to ask questions about experimental procedures. At the completion of the last trial, the subjects filled out a survey, were debriefed, paid, and dismissed.

4. RESULTS

4.1 Outcomes

Analysis of Variance (ANOVA) and post-hoc Scheffé tests were conducted to test for differences in outcome quality among the three treatment groups. Outcome quality was measured as a) the points (number of sectors won) earned by each team per trial, and b) as a normalized score: the ratio of the number of sectors in which the teams scored a “win” to the expected value for the partially revealed pattern. The descriptive results are shown in Table 1. Outcome quality differs significantly among the treatment groups ($F=29.54$, $p<.000$). Specifically, the CS group out-performed the other two treatments, and the IS treatment had better scores than the BL treatment. Therefore, the results support Hypothesis 1, that the use of a pattern sharing tool improves outcome quality.

In addition to differences by treatment type, we found that the pattern type had a significant impact on outcome quality. As can be expected, teams, irrespective of treatment type, performed better when confronted with definitive pattern types ($p<.000$).

Table 1 – Outcome Quality

Outcome Quality	Treatment	Pattern Type									Total		
		Definitive			Luck			Strategy					
		Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
Raw Scores	Base Line	6.00	0.87	141	5.36	0.89	118	5.48	0.81	308	5.59	0.88	567
	Item Sharing	6.26	0.79	119	5.64	0.85	99	5.66	0.87	256	5.81	0.88	474
	Chunk Sharing	6.65	0.60	78	5.78	0.93	65	5.85	0.80	169	6.04	0.86	312
	Total	6.24	0.82	338	5.55	0.90	282	5.63	0.84	733	5.77	0.89	1353

4.2 Decision Processes

Our results on outcome quality lend support to our arguments for the use of pattern-sharing tools in collaborative decision-making. But, what impact does the use of the tool have on decision processes? To answer this question, we first compared the degree of pattern-sharing correctness between the IS and CS treatments. For the IS treatment, we calculated the pattern-sharing correctness for each trial as the ratio of correctly identified values in critical sectors to

the total number of item sharing for those critical sectors. A critical sector is one whose value had to be ascertained to reveal the underlying pattern. The identification of these sectors, which depended on the pattern type, was done by two of the researchers. For the CS treatment, pattern-sharing correctness was derived for each trial as a ratio of the number of team members who correctly identified the pattern to the total number of team members who shared pattern information. Results of ANOVA and post-hoc Scheffé tests indicate that the CS group performed better than IS group ($F=9.88$, $p<.000$), supporting Hypothesis 2. Further, although the CS treatment's performance on pattern sharing correctness was superior to the IS group for both the strategy and luck pattern types, the disparity is greater for the latter type (however, the interaction effect was not significant).

Further analyses of decision processes was conducted by examining the amount of time taken for exchanging pattern information, and also the total time taken to move the tokens. These results show that the CS treatment spent less time in pattern sharing when compared to the IS treatment ($F=370.06$, $p<.000$), supporting Hypothesis 3. Interestingly, the CS treatment also took less time to move the tokens in comparison to the IS and BL treatments ($F=60.76$, $p<.000$). Overall, it appears that the pattern sharing tool, whether used to share item or pattern information, had a significant impact on the time taken to complete the response selection phase of our collaborative decision-making game.

While not the focus of this paper, the time taken to actually move the tokens (allocate the resources) was significantly less for the CS treatment ($F=86.82$, $p<.000$). More details will be presented at the conference.

5. CONCLUSIONS

Previous research has shown that individual experts use feature-matching to make decisions in naturalistic environments. These studies have demonstrated that tools designed to facilitate recognition of features or patterns seemed to improve the performance of individual experts. In our study we have demonstrated that a tool designed to promote sharing of patterns among team members was associated with significant improvements in performance in a strategy game. In particular, sharing a "chunk" label associated with a pattern, led to superior performance. These pattern-sharing tools improve the collective recognition of patterns by our teams. We believe that the improvements in collective pattern recognition were a direct result of reducing the

cognitive effort involved with perception and memory during the Situation Assessment phase of our model in Figure 1. This leaves more cognitive resources available to attend to the task at hand.

The normal concerns regarding the use of students as subjects could be viewed as a limitation of the study (external validity). However, we feel that basic cognitive processes apply across all populations. Another possible weakness of this study is that the experimental resource allocation task may be considered too simple. But, by using 3 patterns in 3 possible rotations with differing levels of revealed information, and no verbal communication, our pilot studies demonstrated that the task had enough complexity to be challenging within a two hour time block. Thus, the task required effortful cognition of the sort that is typical of many naturalistic domains. Further, we are confident that we simulated an appropriate naturalistic decision making environment through the use of properly aligned incentive techniques. The groups in this study were ad-hoc, yet they were well-trained in the task and exhibited spirited, cohesive, collective identity during payment and de-briefing.

5.1 Future Research

In our study, we revealed the same partial pattern to each member of a team. Teams usually share some common information, but also typically have some specialized local information. This is problematic because prior research has shown that during collective recall, groups are more likely to exchange, discuss and focus on information shared by all group members than information known by only one group member (Wittenbaum and Stasser, 1996; Stasser, Vaughan, and Stewart, 2000). We believe that the pattern recognition tools should mitigate the problems associated with sub-optimal sharing of private information in pattern-recognition tasks. A follow-on study of this phenomenon is planned in which we will provide each team member with different (private) information concerning the patterns: some information will be common to the team, and some will be “local.”

In naturalistic environments, decision makers are faced with dynamic situations in which the patterns are constantly changing and they are faced with significant time pressure. In our study, the patterns were static for the duration of a trial. We are in the process of developing a version of our strategy game in which the patterns change slowly during the course of a game trial and team members are faced with making their resource allocation decisions under time pressure.

Once again, we believe that a pattern-sharing tool should reduce the cognitive loads on the team members, and promote improved performance.

Humans have limited cognitive resources for perception (e.g. of patterns), attention, and memory. The pattern-sharing tool seemed to improve collective perception and collective recall of patterns by allowing the team to bring its collective cognitive resources to bear on the task. In naturalistic environments, team members are often required to perform multiple simultaneous tasks. In multi-tasking environments, tools that support attention management will be especially important. Thus, another possible extension of this research involves the development of tools that provide cognitive support for attention management.

We believe that our model can be applied to settings characterized by high stakes, time pressure, and uncertainty. We believe that our model applies to groups that have shared goals and either no direct supervision, or insufficient time for supervisors to micro-manage their actions.

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