

# Assessment of Resource Coordination Effectiveness Through Analysis of Distributed Cognitive Traces in Team Decision Making

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## Abstract

Computer supported collaborative work (CSCW) and computer supported collaborative learning (CSCL) are facilitated through deployment of complex multi-user systems. In order to increase the effectiveness of these systems, we must know more about how people interact with structures in the technology and the work space to sustain interaction, alleviate cognitive load, and enable restructuring of social and environmental elements thereby creating new knowledge structures. The present study suggests a way to capture evidence of artifact usage, emergence of knowledge and process structures, and resource coordination patterns during computer-mediated group interaction to better understand how resource coordination facilitates collaborative cognitive tasks. It is proposed that interactive use of emergent and accumulated cognitive information traces in a virtual decision-making task environment results in formation of an emergent group mental model through a discourse-driven distillation process. This collective mental model is the synthesis of the distributed shared understanding of the collaboratively-negotiated problem solution that is instantiated in the final decision model as the physical representation of the problem solution.

## Introduction

The availability of advanced communication technologies that provide effective support for work and learning enables the movement of knowledge as well as interactive learning and commercial activities across time, space, and organizations. Value added in the global economy derives from effective work processes that enable creation of more competitive products and services. This productivity is supported by effective interactive communication capability. The same environmental factors causing change in the workplace are also engendering change in education. Consequently, the advent of computer-supported collaborative work (CSCW) systems is matched by the growth of computer-supported collaborative learning (CSCL) systems as evidenced by the proliferation of synchronous and asynchronous learning environments offered by educational institutions as well as those supporting organizational training programs.

The rapid growth of knowledge increases the need for a broad range of expertise. Because it is impossible for individuals to keep up with this growing knowledge base, there is an increasing need for people to work in virtual teams to leverage the collective expertise of often widely dispersed individuals.

Although new technologies enable virtual working and learning, the body of empirical evidence indicates that people are resistant to change and that they often find it difficult to adapt to virtual work and learning situations. By examining how current technology supports or fails to support user needs, how people adapt to new work environments, and how people learn to use available resources, we can determine how technology can be better designed in terms of learnability, ease of use, and value derived from use.

Beyond "ease of use," however, technology must be conducive to development of real task understanding and user awareness of the applied contextual integrity of the developing solution. As a first step toward understanding implied feedforward and feedback requirements, the present study suggests a way to capture evidence of artifact usage, emergence of knowledge and process structures, and resource coordination patterns during computer-mediated group interaction. Because of the centrality of decision making in everyday activity, this study focuses on how distributed virtual teams engage in synchronous problem solving using decision modeling software. The results of this analysis will assist ongoing work aimed at understanding how to better facilitate collaborative cognitive tasks.

## Rationale for the Study

This study posits that a residue of information traces is left as a byproduct of interaction in a virtual work environment after meaningful activity. This "information trail" reveals how virtual team resource use evolved over time throughout the work session. Use patterns can be determined from these traces. Analysis of the traces reveals a history of how information-containing artifacts (e.g., online data stores, e-mail, the Web, manuals) were used, re-used, and created throughout the interaction process. Activated resources

might be internal or external to the work context, or they might emerge through use and re-use of resources.

The dexterity with which distributed teams coordinate resources available to them in a virtual work environment throughout the work process is a significant determining factor in the quality of their output. Thus, evaluation of resource coordination as a driving factor in group work outcomes can provide a history of interaction and use of information sources to assess the effectiveness of the work process. Use of a distributed cognition framework such as that proposed by Wright, Fields, & Harrison (2000) can be used for analysis of what this paper will refer to as "cognitive traces," bits of information present in artifacts during work and left as residue in the post-work environment. For purposes of this study, a "cognitive trace" is considered to be any piece of information that is stored and re-used during work activity, archived during the work process, or left in the work environment at the end of a work session. "Resource coordination" is used to mean "managing dependencies between activities" (Malone & Crowston, 2001, p. 10).

Hollan, Hutchins, & Kirsh (2000) list core principles of distributed cognition theory that can be seen as complementary to the propositions of AST (DeSanctis & Poole, 1994). It can be said, for example, that the "structural features and characteristics of technologies" (DeSanctis & Poole, 1994) are leveraged by people to "establish and coordinate different types of structure in their environment" and to "off-load cognitive effort to the environment" (Hollan et al., 2000, p. 181). At the same time, information structures exist as abstract concepts (e.g., in the form of plans, goals, action-effect relationships, and possibilities) (Wright et al., 2000). These abstractions become resources for action as they are put into use and are modified through re-use.

Addition of a distributed cognition construct makes AST even more helpful as a way to explain mediated interactive decision making. The movement and emergence of information structures through the work environment evolves into a representation of the problem solution that is shared by the group. Intentionally or unintentionally off-loaded cognitive information becomes "distributed cognitive information traces" (DCITs) that are used, re-used, and created through use. The addition of a shared mental model construct to AST provides a mechanism whereby cognitive information that is stored or emerges throughout the group work process is "distilled," forming a group mental model that is an abstract or, in the case of the decision models in the present study, a physical representation of the team problem solution. Together, the constructs of distributed cognition and the shared mental model contribute a dynamic element to AST.

It is proposed that interactive use of emergent and accumulated cognitive information traces in a decision-making task environment results in formation of an emergent group mental model through a discourse-driven distillation process. This collective mental model is the synthesis of the distributed shared understanding of the collaboratively-negotiated problem solution that is instantiated in the final decision model as the physical

representation of the problem solution. The suggested investigation of mediated collaborative processes using the proposed enhanced AST model provide for fine-grained assessment driven by analysis of interactive use that can lead to better collaborative system design. Better design will enable the increasingly important integration of discrete knowledge distributed among humans and artifacts in work and learning environments and will motivate greater acceptance of technology-mediated support for group tasks.

### **The Naturalistic Decision-Making Paradigm**

Naturalistic decision making (NDM) using "ill-defined" problems was chosen in order to simulate the reality of constant change and the ongoing potential for unanticipated problems. Originating in the need for analysis of ways to improve military and other kinds of critical team operation decision support systems, NDM differs from traditional decision research in that NDM positions the balance of analysis at the front end of the decision process. The reason for "front-loading" the decision process is due to the chief concern being situation assessment and "refreshing ... situation awareness through feedback, rather than developing multiple options to compare to one another." The chief problem is that use of "rational standards" and "formal models" of decision making fail "to take into account effects of most contextual factors that accompany decision making in real-world settings, nor do they adequately model the adaptive characteristics of real-world behavior (Zsambok & Klein, 1997, p. 4).

Teams engaged in naturalistic decision making are generally dealing with ill-structured, or "wicked," problems and may pursue idea generation and solution formation intermittently and in a cyclical fashion. The process may continue until a designated boundary is reached in terms of time, an intrinsic boundary is reached due to lack of new ideas, or until some other required input to the decision-making process becomes exhausted.

In contrast to the traditional paradigm, NDM research, by design, selects ill-structured problems that occur in uncertain and changing conditions and that have changeable, indefinite or competing goals. These decisions do not involve one-time problems. Instead, as Figure 1 shows, they imply "action/feedback loops" where several participants work towards a solution in which they have a personal interest. The decision-making activity is situated in reality. Organizational goals are at stake and the decision is made under time constraints. In addition to these "task and setting" factors, other characteristics of NDM research are that participants are experienced decision makers, the purpose of the research is to discover how "real-life" decisions are made, and the main focus is on situation awareness and the decision as an episode rather than as a selection process (Orasanu & Connolly, 1993; Zsambok & Klein, 1997, p. 5). Unfortunately, the close focus on application orientation and differentiation from traditional decision research has prevented development of a theoretical foundation for NDM (Zsambok & Klein, 1997, p. 39).

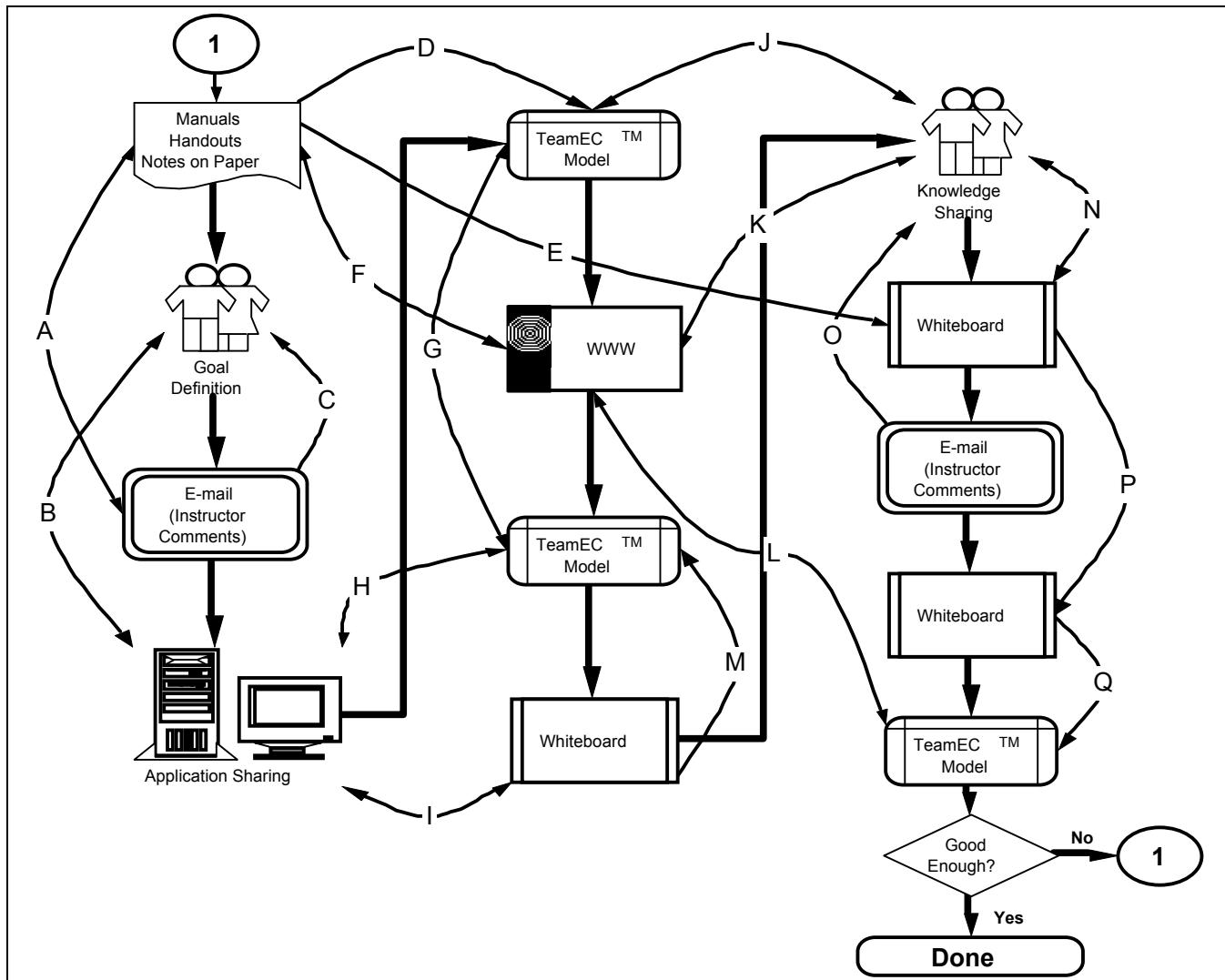


Figure 1: Team workflow showing alternating intervals of different types of information gathering, synthesis, and processing. Dark straight lines represent the linear group work process over time. Curved lines represent use and reuse of distributed cognitive information traces spread throughout the work environment.

- A Clarifying handout instructions by referencing e-mail feedback sent by instructor.
- B Application-sharing among team members.
- C Team referencing e-mail feedback from instructor.
- D Verifying model structure against problem specifications specified on handout.
- E Verifying whiteboard model structure against problem specifications specified on handout.
- F Referencing glossary on class Web site.
- G Comparing two versions of the model created through application-sharing and multi-tasking.
- H Building the model using application-sharing.
- I Multi-tasking on the whiteboard via application-sharing.
- J Discussion of previous TeamEC model building.
- K Referencing Web site for information on current technology availability.
- L Comparing TeamEC model against an earlier example on the Web.
- M Revising model based on whiteboard information.
- N Brainstorming on the whiteboard.
- O Clarifying the whiteboard model structure based on instructor's e-mail.
- P Adding brainstorming on the whiteboard based on previous entry.
- Q Transferring final contents of whiteboard to final TeamEC model that will be turned in.

## Groups as Adaptive Decision-Making Systems

While a variety of theories of group communication and decision-making in small groups have been proposed (e.g., Ellis & Fisher, 1994; Hirokawa & Poole, 1996; Klein et al., 1993), few theories have actually been specifically aimed at explaining and predicting the effects of technology on collaborative work. Even fewer theories have focused specifically on technology-supported group decision-making. A relatively recent theory that is of particular value in analyzing the cyclical nature of small group decision-making in the context of computer-mediated decision support systems (DSSs) is Adaptive Structuration Theory (AST). Although AST is proposed as a useful general framework for analysis of cooperative technology (DeSanctis & Gallupe, 1987; DeSanctis & Poole, 1994; Poole & DeSanctis, 1992), few empirical studies have actually tested the theory.

Poole and DeSanctis developed adaptive structuration theory based on Giddens' structuration theory of society (Giddens, 1984, 1993; Giddens & Turner, 1987), which originated in his attempt to synthesize the functional-structural orientation of the objectivist (e.g., Marxism, functionalism, structuralism) and the individual free will orientation of the subjectivist (e.g., symbolic interactionism, ethnomethodology) schools of sociological thought. Human agency (action) is central to Giddens' theory of society and exists in conjunction with the roles, rules, and resources that make up the structure of social systems. Social systems function through instantiation of social relationships that develop, are integrated, and persist through interaction over time and space (Münch, 1994, pp. 176-177; 189).

## Coordination Theory

Although there have been diverse efforts at coordination in specific areas (parallel and distributed computer systems, human-computer systems), there has been a lack of focus. The interdisciplinary study of coordination is a research area that attempts to bring different disciplines together in an effort to create awareness of the work of one discipline among other disciplines where similar research streams may provide mutual insights. The goal of coordination research is to develop theory to explain how coordination occurs in different systems. The rationale behind the effort is that it should be possible to answer the question: "How will the widespread use of information technology change the ways people work together" (Malone & Crowston, 2001, p. 8)? The question is more relevant than ever due to the networking of the computers to which a large percentage of the world now has access and because of the growing number of interrelated global business activities. If "coordination" is defined as "managing dependencies between activities," it takes on extremely broad connotations in the growing global network environment.

In order to effectively follow the "plan" imbedded in a system, the user will need to determine how to conduct appropriate inquiry-response sequences. Because the user tends to be encumbered by expectations created during human-human interaction, the user's actions are to a large extent determined by the plan or script the machine

employs: "organization of situated action is an emergent property of moment-by-moment interactions between actors, and between actors and the environments of their action" (Suchman, 1987, p. 179). This is, basically, a coordination problem.

Another area of concern in coordination theory research is distributed cognition. Part of the interest here is on the role played by perspectives (individual world views) and how they might be visualized to enhance collaborative communication. This requires determining how best to support the subjective, interpretive processes of perspective making and taking:

What is required from information technology in distributed cognition are facilities of self indication, reflection, and interpretation – an environment for active sense making in which individuals can construct representations of their changing understandings and can explore them in conversation with others. (Boland & Tenkasi, 2001, p. 63).

## Distributed Cognition

In a recent discussion of the potential for distributed cognition to serve as a new foundation for HCI research, Hollan, Hutchins, and Kirsh (2000, p. 175-176) stress the nature of distributed cognition as a unique perspective that takes into account all cognition – not only individual cognition. The distributed cognition perspective is distinguished by two principles: (1) distributed cognition understands cognitive processes as those that are based on functional relationships among entities working together within a process and so the boundaries of the unit of analysis is determined by these relationships rather than spatial collocation and (2) distributed cognition encompasses a broad range of objects that may be part of cognitive processes. This means that cognitive processes can be distributed across members of a group, they may involve internal and external structures, and they can even be distributed through time given the transformational effect of present events on later events. As part of their effort to establish an integrated research framework, Hollan et al. specify four core principles of distributed cognition theory:

1. people establish and coordinate different types of structure in their environment
2. it takes effort to maintain coordination
3. people off-load cognitive effort to the environment whenever practical
4. there are improved dynamics of cognitive load-balancing available in social organization. (p. 181)

A recent framework for representation of information structures as abstract concepts but also as resources for action fits well with the AST model as an analytical tool. The Distributed Information Resources (DIR) framework (Wright, Fields, and Harrison, 2000) designates a cycle of interaction where a given information resource configuration is brought into coordination for use and subsequently is recycled through use back into the interaction process as an updated resource.

## Adaptive Structuration Theory (AST)

Other artifacts in a work or learning environment affect what users do and how and when they do it. The reciprocal nature of the impact of activity on context and context on activity is a coordination activity that is central to the emergence of new social and contextual structures in Adaptive Structuration Theory (Poole and DeSanctis, 1994). The original specification of AST, although developed to describe collaborative activity in general, did not include representation of the ongoing synthesis of the meaning and results of activity. The original framework does not reference the development of a group representation (group mental model) of the state of the work process. Neither does the original framework reference the fact that cognition is distributed in such a system. This study extends AST to include the group mental model as a distiller of interactive use of artifacts stored in the collaborative work environment in the form of "cognitive traces." This modification of AST increases its explanatory value and its potential as an evaluative tool. The term "group mental model" as used here refers to team work where the team has developed a shared representation of the task goal, and has developed a shared understanding of how to best manage the work process, product, and state of project (including task and sub-task distribution). The implication is that there is common understanding of the situated cognition of other team members with regard to the distribution of task knowledge, skills, performance capabilities of other team members, and the distribution of resources among artifacts and users.

The cognitive information traces stored in the work environment and team resource coordination patterns can be used to identify development of effective or problematic team work styles. The premise of this study is that analysis of patterns of time and cognitive information trace use and re-use during the work process can be used to evaluate how effectively a team manages available resources under a variety of circumstances. Knowledge of these patterns can be used to facilitate improved team resource management through enhanced human and/or computer support.

## Method

### Participants

The study included 27 senior-level undergraduate students in an elective course on use and design of computer supported collaborative work systems. Participants were randomly assigned to three four-member and three five-member teams. The six zero-history, self-directed teams were placed in an unfamiliar work context using unfamiliar software where they developed decision models to solve "ill-defined" problem scenarios within specified time frames. Teams remained intact through a series of 10 simulated synchronous virtual team meetings. In preparation for the naturalistic simulation of a distributed teamwork environment, students received background in basic business concepts, business models, case studies, project management, marketing, and systems analysis techniques during the lecture and discussion portion of the

course. This enabled students to better accomplish the tasks required by the decision-making scenarios they used during the laboratory simulation portion of the course. Teams were autonomous and self-directed. Each team assumed a real-life role within the assigned scenario. The roles were rotated during the initial training series of team meetings as well as during the domain-specific work series of meetings. In this way, each group was exposed to each role by the end of the series. Laboratory sessions ranged from 38-90 minutes (average 63 minutes) in duration.

### The Virtual Team Support System: NetMeeting

In order to create an environment that would enable teams to simulate synchronous distributed teamwork in a single computer laboratory, Microsoft NetMeeting was used to provide communication support via its chat facility and to enable application sharing so that team members could work simultaneously on the collaborative building of decision models. Other features of NetMeeting available for use by the teams were the whiteboard, shared clipboard, and file transfer. The teams also had access to the class Web site and e-mail for referencing class notes and comments on their prior work. Web access enabled searches for external information that might assist problem solution.

NetMeeting chat enabled capture of a transcript of the entire chat complete with speaker identification, date, and time stamps on each comment. The detailed transcript along with the model and the whiteboard content were the deliverables each team was responsible for submitting at the end of each lab session. These digital records of the team work process were created in the virtual workspace during each lab session.

### The Decision Support Software: TeamEC™

The primary measure of effectiveness of group learning and performance over time was the soundness of the decision models produced by the teams. TeamEC™, a package of group decision support software tools produced by Expert Choice, Inc. (<http://www.expertchoice.com/>), was used for analyzing, synthesizing, and justifying complex decisions and evaluations in a group setting. Among the advantages of this software are: (1) it brings structure and organization to the decision-making process and (2) it provides an easily quantifiable measure of team progress (model score).

### Decision Tasks

During a series of five decision-making sessions, participants were given a decision-making problem (Scenario 1) that was of a general nature and was removed from the computer science and engineering learning domain of the participants. The problem for Scenario 1 was one that is common to all locations and cultures (revitalizing the local economy) so that it could be readily understood by all participants regardless of individual demographic differences. The sixth lab session of Scenario 1 was a competition (Face-Off 1), that served as the first benchmark for the course. The team models produced during the Face-Off were reviewed and ranked in a face-to-face classroom session to share all model results so that teams could gauge

their progress relative to one another. Scenario 1 was followed by another problem (Scenario 2) that focused on a collaborative system design, development, and deployment decision problem specific to participants' domain of expertise. This work series consisted of three role rotations followed by a second benchmark (competitive Face-Off 2) to complete the series of ten decision modeling lab sessions.

## Results

The dependent variable in this study was the Model Score achieved by teams during a series of simulated distributed team decision-making sessions. The independent variables, were the percentages of meeting time allocated to: Idea Generation (IG), Model Building (MB), Situation Assessment (SA), and Resource Coordination (RC). The repetition of lab sessions over the period of a semester provided sixty measurements. Descriptive statistics and frequency analysis were used to explore the overall results of the study. There were significant differences between teams on model score. Correlation analysis indicated a significant inverse relationship between Resource Coordination (RC) and Idea Generation (IG).

## Conclusion

This paper proposes a modification to the original AST model to include the constructs of distributed cognition and the group mental model. If progress is to be made in analysis of how complex systems work and in evaluation of their effectiveness, it is vital that these constructs be made a part of the AST model in order to refine the granularity of the model's diagnostic value through analysis of the use and re-use of distributed cognitive information traces. The distributed information resources framework (DIR) clearly describes a number of types of information resource on the abstract level (plans, goals, possibilities, history, action-effect relations, states) and describes these resources in terms of their internal ("in the head") and external (artifacts in the interface) representations. In parallel with their internal and external representations, the same resources are distributed across a given resource configuration in varying internal and external proportions. This is a useful analytical device for describing interaction within a team as a complex system engaged in use of artifacts within a given context where "structures-in-use" are appropriated for use and are subject to emergence in changed form. There is good potential here for explanation of differing group outcomes.

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