경영정보학연구
제14권 제2호
2004년 6월

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A Dual-Level Model of Team Decision Making

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Team decision making is a collective behavior that needs to be understood by considering properties belonging to team and individual member domains together. This paper introduces a conceptual model called "Dual-Level (DL)" model that describes a team decision-making process in terms of team level, member level, and the relationship between them. The team-level view explains the decision-making process by considering the team as a wholeand divides the process into three stages: Problem Conceptualization, Alternative Generation, and Selection. The member-level view describes what happens to individual members when they go through the group process and splits it into the five phases: Individual Cognitive Mapping, Problem Decomposition, Subproblem Session, Subproblem Integration, and Team Decision. The DL model works as a theoretical framework to explore team decision making by using a set of computational models of team design and team members. In practice, the conceptual framework is used to build a computational model of decision making team, called "Team-Soar."

Keywords : Team-Soar, Dual-Level, Team Decision Making, Team Simulation

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* This paper is an extension of Kang[1999] published by Research Institute for Business and Entrepreneurship of Keimyung University.
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Ⅰ. Introduction

Teams make decisions when they engage in tasks. Team decision making as a group behavior can be viewed as emergent behavior from interactions of team members who act within the context of performing the team task[Prietula and Carley, 1994 Fisher, 1974]. Further, team decision making is a collective behavior that needs to be understood by considering properties belonging to team and individual member domains together. Two teams that display exactly the same team behavior might differ significantly in their individual member-level activities. Accordingly, team decision making should be understood in terms of both team and individual member properties. Although a study of team decision-making process requires a consolidated view of the multi-level phenomenon, past studies have concentrated more on either team level or individual members' level but not both in a parallel manner[Mintzberg et al., 1976; Fisher, 1970; Simon, 1960; Bales, 1953]. There exists relatively little, if any, research concerning both levels together. To resolve the problem, this paper proposes a new conceptual model of team decision-making called "Dual-Level" model. The conceptual model represents a team decision-making process from both mental model and information- oriented perspectives. This paper also shows how the conceptual framework is embedded into a computational model of team called "Team- Soar."

The remainder of this paper is organized as follows: Section 2 reviews general aspects of team decision making and previous studies on the subject. Section 3 describes the Dual-Level model. Section 4 introduces a computational model of team that is built based upon the conceptual model. The last section presents the conclusion.

Ⅱ. Team Decision Making

2.1 What is a Team?

In the literature, the terms "group" and "team" are used interchangeably[e.g., Johnson et al., 2002]. However, there is a distinction between them. If we define a group as two or more people who share something in common, then teams are a special class of groups[O'Neil et al., 1992]. Teams are goal-oriented groups that share a common goal among members [Johnson et al., 2002; Ilgen et al., 1995; Orasanu and Salas, 1993] and task-driven groups that are formed around frequently occurring problems [Ilgen et al., 1995; Streufert and Nogami, 1992]. Teams consist of highly differentiated and interdependent members who bring to their teams different knowledge and skills that apply to the teams' tasks[Ilgen et al., 1995; Cannon-Bowers et al., 1993]. Teams are comprised of interdependent and mutually accountable members who interact over time[Katzenbach and Smith, 1993]. In short, teams are sets of two or more experts, who interact interdependently and adaptively toward a common goal.

2.2 Individual Decision Making vs. Team Decision Making

The literature on group dynamics suggests that teams make better decisions than individuals[Streufert and Nogami, 1992], especially for complex tasks. A team has more information, knowledge and reasoning capacity than an individual[Stasser, 1988]. Teams are expected to cope with the problems of complexity by increasing information processing capacities [Streufert and Nogami, 1992]. Complex problems can be decomposed andassigned to individual members based upon their expertise or roles [Brehmer and Hagarfors, 1986; Fisher, 1974]. The additional information resources available to a team can aid in reducing complexity and uncertainty by identifying constraints, and, therefore, identifying regions of infeasibility [Zannetos, 1987]. The result is that the team can carry out tasks, particularly in turbulent environments, that are beyond the capabilities of an individual member.

What distinguishes team decision making from individual decision making is varied expertise, the existence of more than one information source, and multiple perspectives, all of which must be integrated to reach a decision[Orasanu and Salas, 1993; Stasser, 1988]. This integration often results in conflicts among team members. The resolution of these conflicts by a team requires more processing time than would be needed by an individual to reach a decision on the same problem. Therefore, for timely, simple decision-making tasks, individuals may outperform teams. Research has shown that teams are not always better problem solvers than individuals[Libby et al., 1987; Miner, 1984].

2.3 Team Decision Making as a Problem Solving Activity

Newell and Simon[1972] view problem solving as a fundamental human activity. A problem may be conceptualized as the difference between a desired state(i.e., what is expected) and a current state(i.e., what is actually perceived)[Larson and Christensen, 1993; Bartee, 1973]. Problem solving refers to the activity that reconciles this difference [Bartee, 1973; Newell and Simon, 1972]. Therefore, all cognitive work, including decision making, can be viewed as a problem-solving activity [Masuch, 1992].

When engaging in a task, humans as problem solvers formulate the task as aproblem to be solved and conceive the task and their potential behavior in terms of a problem space[Newell and Simon, 1972]. Then they solve the problem by finding a sequence of actions, that is, by finding a set of operators within the problem space, that transform the initial problem state into the desired goal state through one or more intermediate states [Newell and Simon, 1972]. The problem space changes continually from the results of applying actions(i.e., operators) to the current state during the problem-solving activity [Newell, 1990]. As a symbolic construction, the problem space can be conceptualized as a limited knowledge domain in which a mental model of the task situation(current state and goal state) and the symbolic representations of the actions(operators) reside. Here, mental models refer to abstract constructs used by humans to represent their knowledge about problems and to guide problem-solving behavior[Newell, 1990].

Teams make decisions while working on tasks. Teams that make decisions must process information in such a manner that the information which might be relevant to the goal is collected and analyzed. Therefore, team decision making can be viewed as a group cognitive process that involves gathering, processing, integrating, and communicating information in support of arriving at a task-relevant decision [Larson and Christensen, 1993; Cannon-Bowers et al., 1993]. Members of teams tend to seek new and additional information in order to assist their efforts in performing decision-making tasks[Grunig, 1969].

Though teams act as problem solvers, they work differently than individual humans do when solving problems. One notable distinction between team and individual problem solving is that in team problem solving, searching for alternatives is carried out by multiple intelligences. Teams solve problems in a distributed fashion. Often, a team decomposes its team problem into a set of subproblems; then, different team members, who are problem solvers themselves, work on the different subproblems simultaneously. When all the subproblems have been solved, the results are integrated into a team-level solution to the team problem.

When each team member engages in a task, she or he develops a mental model of the task and its domain. Such model is a unique mental representation that reflects the member's own perspective, expertise, experience, role, etc. However, a shared mental model evolves as team members interact with one another while carrying out a task. If they are successful, this shared representation will encompass common understanding, common goals and shared view-points among the team members. This shared mental model is believed to affect team performance. Research by Katzenbach and Smith [1993] reveals that failed teams rarely develop relevant shared mental models, while high performance teams do.

2.4 Team Decision-Making Process

Group or team decision making can be defined as the process of reaching a decision undertaken by interdependent individuals to achieve a common goal[Orasanu and Salas, 1993]. Several models have described the group decision-making process from different perspectives.

Simon[1960]split the decision-making process into three phases: Intelligence, Design, and Choice. The main activity of the intelligence phase is searching the environment for conditions calling for decisions. Problem finding and problem formulation activities belong to this intelligence phase. During the design phase, groups invent, develop and analyze possible courses of action. Development of alternatives happens in this phase. In the choice phase, groups make decisions. Simon views decision making as a choice among alternatives. Mintzberg and his colleagues[1976]also support Simon's view by dividing the decision-making process intothree similar phases: problem identification, solution development, and solution selection. In the two models, groups can return to previous phases from an advanced phase.

Fisher[1970] suggests a four-phase model in the process of decision making: Orientation, Conflict, Emergence, and Reinforcement. Group members in the orientation phase search tentatively for ideas and directions to aid their decision-making efforts. The conflict phase is characterized by dispute - ideational conflict over decision proposals. The emergence phase is the crucial stage in the group decision-making process of this model. During this phase the conflict and dissent dissipate, and the eventual outcome of group interaction becomes increasingly apparent. While group members tend to reach decisions during the emergence phase, they achieve consensus on those decisions during the reinforcement phase. All members seem to agree and strive to show agreement through positively reinforcing each other[Fisher, 1974]. Fisher argues that groups do not make decisions but that decisions emerge from group interaction[Fisher, 1974].

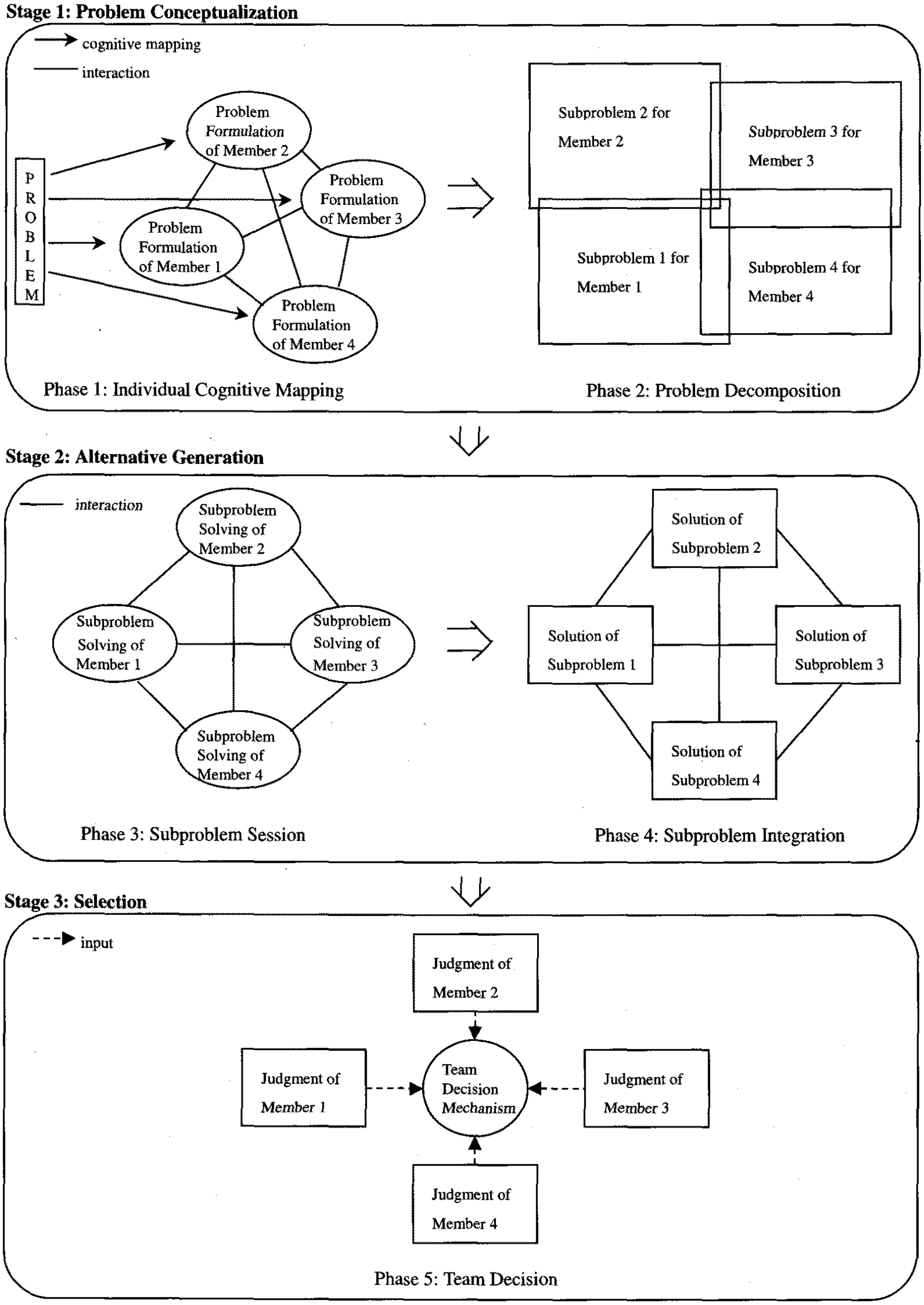
Bales[1953]built a three-phase model from Interaction Process Analysis(IPA). Groups deal first with problems of orientation, which are characterized by deciding what the situation is like(group members give and ask for facts and information). Secondly, groups deal with problems of evaluation, which are characterized by deciding which attitudes should be taken toward the situation(group members give and ask for opinions, evaluation, and analysis). Finally, groups deal with problems of control, which are characterized by deciding what to do(group members give and ask for suggestions and direction). His model focuses on interactive behaviors performed by group members during group decision making.

All the group decision-making models described so far view the group mainly as a whole. However, group decision making is a multi-level phenomenon that must consider the individual and group process[Ilgen et al., 1995] in a parallel manner. The next section proposes a team decision-making model that describes the team decision-making process in terms of team-level process, individual member-level process, and the relationship between the two process levels.

Ⅲ. Dual-Level Model

Dual-Level(DL) model is a conceptual model of team decision making, which delineates a team's decision making process in terms of team level, member level, and the relationship between the two levels from both a mental model and an information-oriented perspective. This conceptual model provides a theoretical framework to explore team decision making by using a set of computational models of team design and team members.

The DL model of team decision making consists of a team-level view, member-level view, and the relationship between the two level views. The team-level view explains the decision-making process by considering the team as a whole, while the member-level view describes what happens to individual members when they go through the group process. As shown in <Figure 1>, the team-level view divides the team process into three stages, while the member-level view splits the process into five phases. Each member-level phase belongs to a team-level stage that is thought of as a phenomenon emerging from the activities in the member-level phases belonging to that stage.We may say that the two different level views are interrelated in that each views represents the same process only at different levels, that is macro(team) and micro(member) levels. There exists a view hierarchy. The member-level view is a hierarchical decomposition of a macro-level view(i.e., team-level



<Figure 1> A Conceptual Framework for the Dual-Level Model of Team Decision-Making

view). Therefore, each stage of the team-level view can be formed by abstracting the associated member-level phases.

The aforementioned relationship between the team-level and member-level views can provide deeper understanding of the team process. Particularly, the relationship can be used to study how the changes at member-level affect the team-level process. For example, researchers can explain why two teams that display exactly the same team-level behavior differ significantly in their individual member-level activities.

3.1 Team-Level View

The team-level view of the DL model represents the macro-level process that a team as a whole goes through for carrying out a decision-making task. The view divides a team decision-making process into the following three stages: Problem Conceptualization, Alternative Generation, and Selection. When a team engages in a decision-making task, the team starts to formulate and conceptualize the task as a problem in its team mental model. Here, a team mental model is a hypothetical model defined as the composite of individual members' mental models. The next stage of the team-level process is to generate and evaluate alternatives. At the final stage, a team makes a decision by selecting one among different alternatives.

The team-level view was designed based upon the literature in team decision-making process described in section 2. 4. That is, this view can be considered as a generalization of past studies that focus on the group process at team-level[Mintzberg, et al., 1976; Fisher, 1970; Simon, 1960; Bales, 1953]. Hence, there existsa similarity between the team-level view of the DL model and the group decision-making models reviewed in Section 2.4. For example, three stages of the team-level view are comparable to the orientation, evaluation, and control phases of the Bales'[1953] model. Although each model focuses on different aspects at each step, virtually all the models are not different significantly. For example, the DL model focuses on formulating and representing the problem cognitively, whereas Mintzberg model focuses on identifying what the problem is for the same step of the group decision making process. Refer to <Table 1> for comparing the stages of the team-level view with the steps of the group decision-making models.

Each member-level phase belongs to a team-level stage thatis thought of as a phenomenon emerging from the activities in the member-level phases belonging to that stage. We may say that the two different level views are interrelated in that each views represents the same process only at different levels, that is macro (team) and micro(member) levels.

3.2 Member-Level View

The member-level view of the DL model describes the micro-level process that individual members go through when engaging in a decision-making task. Focusing on individual members' activities underneath team level, the member-level view splits a team decision-making process into the following five phases: Individual Cognitive Mapping, Problem Decomposition, Subproblem Session, Subproblem Integration, and Team Decision. These five phases may occur individually and in the sequence noted, or may be combined and carried out parallel to each other.

The member-level view describes the team decision-making process in terms of mental model and information-oriented perspectives. It is necessaryto view team decision making process from these perspectives owing to that decision making involves cognitive activities and cognition is information processing done by humans.

The mental model perspective explains how individual members' mental models are developed through the decision-making process. In particular, this perspective describes how team members develop individual goals(i.e., local goals and low-level goals) under a team goal (i.e., a global goal or a high-level goal) and explains the relationship between the two different types of goals. The perspective is originated from the assertion that team decision making isthe process of reaching a decision undertaken by interdependent individuals to achieve a team goal[Orasanu and Salas, 1993]. In general, the team goal is given by a task the team engages in or imposed from outside the team, and team members are supposed to accept the team's goal as preordinate, as opposed to the individual member's goal[O'Neil et al., 1992].

The literature in group study highlights the emerging view of groups as information processors[Hinsz, et al., 1997]. Much like individuals, groups process relevant and available information to perform intellectual tasks[Hinsz, et al., 1997]. The exchange of decision-relevant information among group members is an important function of group decision making[Gigone and Hastic, 1997]. The information-oriented view of the DL model focuses on which type of information flows at each phase of the team decision-making process. Since the way of exchanging information among-group members is an important determinant in deciding the effectiveness of group decision making[Levine et al., 1993], it is useful to examine the information flow during a team decision-making process. However, previous studies have focused mainly on examining which types of informationare exchanged during the team process and how they affect the team performance[Hinsz, et al., 1997]. But, in order to understand the roles of information in the group process better, it is necessary to examine what kindsof information are exchanged at

<Table 1> Comparison the team-level view with the group decision-making models

Dual-Level Model (Team-Level View)	Problem Conceptualization	Alternative Generation	Selection
Simon's Model	Intelligence	Design	Choice
Mintzberg's Model	Problem Identification	Solution Development	Solution Selection
Fisher's Model	Orientation	Conflict	Emergence, Reinforcement
Bales' Model	Orientation	Evaluation	Control

different stages in the team process. There exist few researches in the literature in this direction. For example, Bales addresses the topic of information transfer at each stage of his group decision-making model[Bales, 1950]. According to the model, different types of information are transferred at different stages: facts are transferred during the orientation stage, opinions are transferred during the evaluation stage, and suggestions are transferred during the control stage. The information-oriented view proposed in this paper refines the Bales' model because unlike the Bales' model that splits the team decision-making process into just three stages, the member-level view refines a team process into 5 phases.

Phase 1. Individual Cognitive Mapping

This phase corresponds to the problem conceptualization stage of the team-level view.

- Mental Model Perspective:

Individual member's understanding of a team problem occurs in this phase. Humans understand the world by constructing working models(i.e., mental models) of the world in their minds[Johnson-Laird, 1983]. In this phase, each team member constructs an initially internalized representation of the problem through cognitive mapping. Each member becomes aware of the team goal, then develops his/her own team problem space in his/her mental model with respect to the team goal. The initial team state associated with the team goal is represented in the problem space. Usually, different team members build different mental models for the same problem, since individual differences such as position or role, personal interest, expertise, and experience can affect the mapping. In fact, the variation among members' mental models is one of the major factors preventing rational team decision making.

A member's initial mental model may contain knowledge about other members, such as the position of other members, beliefs about or expectations of other members, and the specialty of other members. The initial mental model built for each member evolves through interaction as the member participates in the team process. Further, member-level cognitive processes are combined into a team-level cognitive process [Larson and Christensen, 1993].

- Information-Oriented Perspective:

During a team decision-making process, different types of information can be exchanged among members through interaction[Prietula et al., 1990]. In the member-level view of the DL model, the following six different types of information are identified from the literature in group dynamics: data[Hollenbeck, et al., 1995], evaluations[Hollenbeck, et al., 1995], opinions [Gigone and Hastic, 1997; Bales, 1950], arguments [Reicher and Sani, 1998; Hinsz, et al., 1997], judgments[Hollenbeck, et al., 1995; Stevenson, et al., 1990], and team decisions[Hollenbeck, et al., 1995; Stevenson, et al., 1990]. Data provide information about facts. Evaluation is the interpretation of data. Opinion, which is a belief or view based on evaluations, implies a conclusion thought out yet open to dispute. Argument is a basis of an opinion presented in support of, or in opposition to, theopinion. Judgment is a member's final recommendation about the team problem. Finally, team decision is a team-level solution to the team problem. The distinction between judgment and decision is that a judgment is an assessment of an object, whereas a decision leads to a change in the environment that has external consequences for those involved[Stevenson et al., 1990]. Note that according to the definition described here, the six types of information are mutually exclusive. The types of information flow at each phase of the member-level view are listed in <Table 2>.

In the phase of individual cognitive mapping, data are mainly exchanged to help members understand the team problem at hand. These data are used to build initial mental models for individual members.

Phase 2. Problem Decomposition

This phase corresponds to the problem conceptualization stage of the team-level view.

- Mental Model Perspective:

Usually, a team decision problem is too complex or too large to be handled as a whole. Therefore, often the decision problem is broken into smaller pieces of subproblems, andthe subproblems are assigned to the members capable of handling them[Davis and Smith, 1983]. For teams, the assignment of subproblems is generally straightforward because teams consist of experts, who have specialties in certain areas. This process of division of labor is called problem decomposition.

As problem solvers, humans hold explicitly defined goals and subgoals[Newell and Simon, 1972]. Accordingly, problem decomposition may be interpreted as goal decomposition from the mental model perspective. That is, the team goal identified at the previous phase is decomposed into a set of individual members' goals. Usually, goal decomposition is affected by factors such as team structure, roles, and interaction. For routine problems, the decomposition often happens automatically without member interactions. Different members may have a common member goal, conflict goals, or independent goals.

During the goal decomposition process, each member develops an individual member goal (i.e., local goal or subgoal) constrained by the team goal(i.e., global goal). When the member realizes themember goal, he/she comes to develop a problem space in his/her mental model with respect to the individual goal. Thecurrent state associated with the member goal is represented in the member problem space. At the end of this phase of problem decomposition, two different problem spaces exist in the member's mental model: one for the team goal and the other for the individual goal.

- Information-Oriented Perspective:

In this phase, data, if there are any, are

<Table 2> Types of information flow at each phase of the member-level view

Team-Level Stage	Member-Level Phase	Main Type of Information Flow
Problem Conceptualization	Individual Cognitive Mapping	data
	Problem Decomposition	data
Alternative Generation	Subproblem Session	data and evaluation
	Subproblem Integration	opinion and argument
Selection	Team Decision	judgment and team decision

transferred among members for helping the problem decomposition. They might be used for being made aware of a member's goal and constructing a problem space for the goal in a member's mental model.

Phase 3. Subproblem Session

This phase corresponds to the alternative generation stage of the team-level view.

- Mental Model Perspective:

In this phase, each member tries to achieve his/her own member goal as identified through goal decomposition. By applying expertise, or by getting the required information from other members, the member tries to achieve his/her member goal. This activity can be conceptualized as selecting and applying appropriate operators successively in the member's problem space to reach the member goal. This phase continues until all members achieve their member goals.

- Information-Oriented Perspective:

To achieve individual members' goals, members look for the information required from other members and provide available information to the others through interaction. Generally, data and evaluations are transferred at this phase. The information transfer is a function of the nature of the participating members and their respective knowledge [Prietula et al., 1990].

Phase 4. Subproblem Integration

This phase also corresponds to the alternative generation stage of the team-level view.

- Mental Model Perspective:

Solutions of the subproblems should be synthesized into a team-level solution when all members solve their subproblems, that is, when all of them achieve their member goals. This process is called problem integration, in contrast to the process of problem decomposition. In this phase, members present their opinions for certain topics based on their current mental models, which have been built through their subproblem-solving experience.

Conflict among members can arise when they hold different mental models[Levesque et al., 2001]. In fact, conflict is an important facilitator for cognitive change, and conflict can produce intellectual development[Levine et al., 1993]. When conflict occurs, members try to support their opinions by providing arguments. The exchange of opinions and arguments leads to the evolution of the members' mental models andthe resolution of the conflict. Often new opinions are drawn from revised mental models. The exchange also contributes to the increase in the shared portion among the mental models of individual members[Levesque et al., 2001]. This problem integration process continues until all members have solid opinions or until the time limit is reached.

- Information-Oriented Perspective:

In general, two information types, opinion and argument, are actively transferred in this phase. Individual members come to have their own opinions about various aspects of the team problem due to their roles, expertise, and experience. Such personalized views of the team problem often conflict with each other and contribute to generating alternatives. Conflict arises because each member has only a limited local view of the team problem, yet has to solve the problem globally[Davis and Smith, 1983]. The exchange of opinions and arguments can compensate for the imperfection of individual expertise by allowing a variety of viewpoints on the subject and by considering different approaches to the problem. Through listening to other members clarify ideas and provide rationales for their opinions, members may proceed from understanding the different perspectives of others to accepting the legitimacy of alternative points of view [Mohammed and Ringseis, 2001].

Phase 5. Team Decision

This phase corresponds to the selection stage of the team-level view.

- Mental Model Perspective:

When all members' opinions remain stable or when the time available to the team closes to zero, the final phase that makes the team decision begins. At this phase, members are believed to have a larger portion of the shared mental model than before, due to the interaction during previous phases. The shared mental model has hidden effects on team decisions.

- Information-Oriented Perspective:

Judgment and team decision are the two types of information thattransfer through interaction for this phase. At the end of the problem integration phase, each member comes up with a judgment, which can serve as an alternative to the team decision. Members prefer information that supports their favored or chosen judgment alternative compared to information that opposes it[Frey, 1986]. In the team decision phase, a team decision mechanism that uses member judgments as inputs is activated to make a team decision. The decision mechanism reflects a particular decision rule, such as "majority judgment win" or "average judgment win." For a team that has a leader, the team leader collects all member judgments and makes a team decision by using an appropriate decision mechanism. Then the team decision is announced to the other members.

Ⅳ. An Example of Using the Dual-Level Model

Actually, the conceptual framework introduced so far in this paper has already used to build a computational model of decision making team, called Team-Soar.

4.1 Soar

In this study, a computational model called Soar[Laird et al., 1993], is used to model individual team members. The main reason for using Soar is that it reflects a comparatively complete general architecture for reasoning and problem solving. Soar, an exemplar of Newell's "Unified Theories of Cognition," has a sufficiently detailed cognitive architecture and is believed to closely resemble that of a human's [Laird et al., 1993]. Employing a single set of mechanisms that covers all cognition, Soar is capable of goal-oriented problem-solving, learning, and interacting with external environments [Laird et al., 1993].

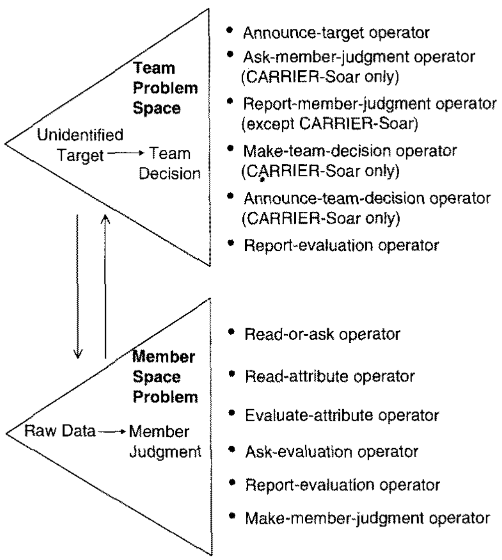
Soar is an excellent tool for modeling individual humans who engage in decision-making tasks. Like humans, Soar casts all its behavior as a search through problem spaces in service of satisfying goals[Prietula and Carley, 1994; Newell, 1990]. Soar achieves its task by selecting and applying a number of operators (i.e., a sequence of actions) that transform the current state into the goal state through intermediate states[Laird et al., 1993]. Soar, as a symbol system, has explicit symbolic representations of the problem spaces and manipulates these representations by symbolic processes [Newell, 1990].

4.2 Team-Soar

"Team-Soar" is an artificial intelligence(AI) model of a naval command and control team consisting of four members who have different expertise and cooperate interactively to accomplish aircraft identification tasks(i.e., identifying the threat level of aircraft). For the team model, four AI agents(i.e., Soar agents) are realized on a SUN machine by using a multi-agent Soar technique developed for distributed problem solving[Laird et al., 1993]. In Team-Soar, the four individual AI agents are interconnected to represent a communication channel between team members.

The team being modeled by Team-Soar consists of Commanding Officers(CO) of four units in a naval carrier group. The leader is the CO of the Aircraft Carrier(modeled by CARRIER-Soar). The other members are the CO of a Coastal Air Defense unit(modeled by CAD-Soar), the CO of an AWACs air reconnaissance plane(modeled by AWAC-Soar), and the CO of an Aegis Cruiser(modeled by CRUISER-Soar). The team's task is to monitor the airspace surrounding the carrier. Aircrafts are tracked by radar and evaluated in terms of nine attributes: angle, direction, size, speed, altitude, corridor status, IFF, range, and radar type.

Modeled by a group of Soar agents, Team-Soar can be described in terms of goals, problem spaces, states, and operators. During the team decision making, each member in Team-Soar develops two problem spaces: a team problem space and a member problem space (see <Figure 2>). In the team problem space, the member tries to achieve the team goal, that is, to make the team decision correctly; in member problem space, the member tries to achieve the member goal, that is, to make a good recommendation to the leader. The team and member goals are achieved by applying appropriate operators to states in the corresponding problem spaces.



<Figure 2> Team and Member Problem Spaces with Operators in Team-Soar

As modeled by Soar, each member also maintains both long-term memory and working memory. All knowledge, including expertise, is stored in each member's long-term memory in the form of a production, that is, an "if-then" rule. Working memory, on the other hand, keeps only the knowledge that is relevant to the current cognitive activity of the member. The content of working memory is decided by a decision mechanism using the preference concept and is selected from the knowledge in long-term memory. The preference concept is part of the Soar architecture[Laird et al., 1993].

4.3 Team-Soar and the Dual-Level Model

Team-Soar implements the DL model, a conceptual model of team decision making. This section will explain the DL model implemented in Team-Soar, with respect to the member-level view. Sincethe three stages of team-level view in the DL model are considered to be phenomena emerging from the activities in the member-level view of the model, Team-Soar represents the team-level view implicitly when it implements the member-level view explicitly. In other words, while passing through certain phase of a member-level view, Team-Soar automatically goes through the team-level stage corresponding to the member-level phase. Therefore, explanation of the DL model will be focused on the member-level view.

4.3.2 Individual Cognitive Mapping Phase of Team-Soar

In this phase, several activities occur in a problem space called team problem space. The activities of identifying a team problem and understanding a team goal happen in the problem space through individual cognitive mapping. When Team-Soar agents perceive a task, each agent develops its own version of the problem space for the team task in its working memory. Each agent's team problem space has an initial state and a goal state. The activity of retrieving meta-knowledge about other agents(e.g., their position and expertise) from an agent's long-term memory occurs in the problem space. The initial state is refined with the meta-knowledge. It is not necessary to exchange data among agents to help them understand the team problem because each agent is familiar to the team task and knows what to do for such routine job.

The agent who first spotted the unidentified target announces the appearance of that target to the other agents(announce-target operator). After receiving this announcement, the other agents follow the same problem space development process as the announcing agent, except for the announcing activity.

4.3.2 Problem Decomposition Phase of Team-Soar

After constructing and refining its team problem space, each agentdevelops an individual member goal as a subgoal of the team goal in accordance with its position on the team, and then develops its member problem space. In Team-Soar, developments of individual member goals are designed to be done automatically without requiring special communication among agents because all agents already have predefined roles for the routine team task.

4.3.3 Subproblem Session Phase of Team-Soar

Within the member problem space, each agent tries to achieve its member goal, which is to make a correct judgmentfrom its local view and information of the task, by successively applying the relevant operators to the current states in the member problem space. During pursuit of their own member goals, agents exchange evaluations, which are expert interpretations of attribute data.

To make a judgment, an agent first reads the values of attribute data the agent can access (read-attribute operator) and evaluates each attribute on a scale of zero to two(evaluate-attribute operator). Here, the scale represents threatening level of the attribute. The agent also may ask other agents for evaluations of certain attributes(ask-evaluation operator). The decision whether to evaluate the attributes by itself or to ask other agents for the evaluations is made randomly(read-or-ask operator). The agent may voice its evaluations to other agents upon request (report-evaluation operator). When the agent has made all the required evaluations, it then makes a judgment about which of seven possible courses of action (make-member-judgment operator) and then returns to the team problem space. The seven possible courses of action varied in degree of aggressiveness from Ignore, which has a value of zero, to Defend, which has a value of six. Intermediate actions on this scale are Review(1), Monitor(2), Warn(3), Ready(4), and Lock- on(6).

4.3.4 Subproblem Integration Phase of Team-Soar

Owing to thatit is a limited implementation of the DL model, the current version of Team-Soar model does not incorporate the activities corresponding to the subproblem integration phase. But, the omission of this phase is not inappropriate when any two subproblems have no intersection and each memberhas exclusive expertise on a subproblem assigned to the member, or when the time available to the decision-making team is not enough to go over the phase. In the current version of Team-Soar, the subproblem integration phase is skipped because individual agents play distinctive roles and have different expertise. Note that, due to the omission of this phase, the agents' judgments made from the previous phase remain unchanged and information types of opinion and argument are not used here.

4.3.5 Team Decision Phase of Team-Soar

As soon as the leader agent(i.e., CARRIER-Soar) returns to its team problem space, it asks the other agents for their judgments(ask-member-judgment operator), and the other agents recommend their judgments to the leader(report-member-judgment operator). When all other agents report their judgments to the leader agent, the leader combines the judgments of all agents including itself in a decision mechanism and makes a team decision(make-team-decision operator). Two examples of the decision mechanism used in Team-Soar are "majority judgment win" and "average judgment win." After making a team decision, the leader agent will announce the decision to the other agents(announce-team-decision operator). Then all agents close their team problem spaces and wait for a new task.

4.4 Simulation Examples of Team-Soar

Team-Soar was designed in terms of three domains team-level, member-level, and task/environment by considering the DL model[Kang, 2001]. The team-level factors include team size (number of members), team structure(the level of tam hierarchy), resource allocation(who can access which and how many attributes of the aircraft), communication method(one-to-one or broadcasting), and team decision scheme(majority win or average win). The member-level factors include expertise(accessibility of attributes, ability to evaluate the attributes, and knowledge about interrelations between attributes), meta-knowledge (knowledge about other members' expertise), member judgment scheme(how to combine evaluations of attributes into a judgment), and agent type(selfish or cooperative; passive or active). Modeling of the task and its environmental factors considers target distribution (distribution of threat levels of the targets), task complexity(relational complication among target attributes), and task uncertainty(unpredictability or unknown nature of tasks).

The consideration of different levels of modeling factors allows researchers to study different aspects of team decision making by varying the setting of the modeling factors. Actually, Team-Soarhas been used for examining various team factors on team performance and testing a theory of team decision making by performing simulation experiments. Here are some examples:

A simulation experiment using Team-Soar mimics a human team experiment that was performed to test a theory of team decision making called "multilevel theory[Hollenbeck, 1995]." The results supported the major propositions of the multilevel theory in the same fashion as the ones of the human team experiment[Kang, 2001].Another Team-Soar simulation has performed to examine the relationship of team decision scheme and the amount of information available to teams with the measures of team effectiveness[Kang et al., 1998]. The results reveal that majority win schemes do not seem to be good team decision strategies for the aircraft identification task. Another Team-Soar simulation has done to explore the relationship of meta-knowledge and the amount of communicated information with how long it took the team to reach a decision[Kang et al., 1998]. From the results, we find that the degree of expertise redundancy can affect team efficiency by constraining the number of possible responders. Another Team-Soar simulation examines the relationships of team decision scheme and member incompetence with team performance [Kang, 2000a]. The results indicate the interrelation of team decision scheme with member competence and suggest that the choice of the right team decision scheme becomes more critical when team contains more incompetent members. Another Team-Soar simulation examines the effect of agent activeness on the efficiency of decision-making teams that access different amount of information[Kang, 2000b]. The simulation results reveal that having more active agents did not always enhance team efficiency. Another Team-Soar simulation examines the relationships of cooperativeness with team performance at different levels of information redundancy[Kang, 2002]. The results uncover that the impact of agent cooperativeness depends on the amount of information need to be processed during the decision making process.

The use of Soar agents adds more simulation power to the Team-Soar. For example, Team-Soar can measure team performance in terms of team efficiency as well as team effectivenessdue to the use of Soar. In Team-Soar, team effectiveness is measured by two external standards: decision deviation and disaster rate. Decision deviation refers to the deviation of the decision that the team made from the correct decisions, which are predetermined by the Team-Soar mechanism. Disaster rate was a function of the frequency of decisions that were off by four or more points from correct decisions[Hollenbeck et al., 1995].In contrast with team effectiveness, team efficiency is measured by two internal standards: team wait time and team decision cycles. These internal measures shed light on what are normally hidden cognitive processes. These internal measures can be used because Team-Soar was built from Soar agents displaying the power of cognitive computational models. Team wait time and team decision cycles are variables that are related to the amount of time it takes a team to reach a decision. In the Soar model a decision cycle is a cognitive measure, an elementary deliberation unit that consists of an information processing step and a decision step[Carley, 1989]. In Team-Soar, the variable team decision cycles is the sum of the number of decision cycles that each member goes through to complete a task. The other variable, team wait time, is simply the sum of the idle times of all the members; idle time is counted in terms of decision cycles.

Another example of the benefits of using Soar agents can be found in the modeling of agent types. Within an organizational context, an agent type reflects the behavioral tendency that a member might employ across tasks. Team-Soarrepresents agent types in two dimensions: agent activeness and cooperativeness.

First, Team-Soar considers two different levels of agent activeness: passive and active. Passive agents participate in team activities passively, that is, only upon request, whereas active agents involve themselves voluntarily. For instance, an active agent voluntarily passes information to other agents whenever new information is available. Generally speaking, an agent's activeness is generic attribute that comes from the personal characteristic of the agent. For this reason, in Team-Soar, agent activeness is embedded into the operators. For example, whenever new information is available, an operator of reporting the information to other agents(i.e., report-evaluation operator) is proposed for the case of active agents. On the other hand, for the case of passive agents, the report-evaluation operator is proposed only if someone has requested the information. Remind that like humans, Soar achieves its task by applying a number of operators(i.e., a sequence of actions) that transform the current state into the goal state through intermediate states[Laird et al., 1993].

Team-Soar considers three different degrees of agent cooperativeness: selfishness, cooperation, and neutrality. In Team-Soar, agent cooperativeness comes into play as agents make judgments and provide information to other member agents. When receiving a request from other member, selfish agents disregard the request until they have nothing to do but the answer the request. On the other hand, co-operative agents suspendtheir current activities and help the requesting member, then resume the suspended activities. Neutral agents assign equal priorities between the two categories of activities and randomly choose their next activity from both categories. In Team-Soar, agent cooperativeness is modeled by the handling preferences of operators. The Preference mechanism, which determines the contents of the problem spaces used by Soar agents, is part of the Soar architecture[Laird et al., 1993]. Setting preferences is a way of characterizing the personality types of the agents, and also a way of imposing social, cultural, and group norms on the agents [Prietula and Carley, 1994]. In Team-Soar, cooperative agents have a higher preference for reporting evaluations over reading attributes, evaluating attributes, asking for an evaluation, and so on. Therefore, whenever operators compete with each other to be applied next, the report operator will always be selected over the others. Conversely, selfish agents in Team-Soar have a lower preference for reporting evaluations compared to the other operators.

Team-Soar simulations show several advantages of simulation experiments over human experiments. First of all, simulation experiments can save experimentation costs. The Team-Soar simulations spent nothing but the cpu time of a main frame computer by using Soar agents as experiment subjects. Team-Soar experiments can also save time for researchers as well as experiment subjects. Team-Soar simulations give researchers more freedom in experiment design because of the flexibility of the simulation models. If researchers find something is wrong after an experiment is done, then they can easily fix the problem and re-do the experiment with considerably small cost and time when compared to human experiments. Also, Team-Soar permitsad-hoc experiments with little modification of the simulation models for certain research variables.

V. Conclusion

In this paper, we have reviewed a conceptual model that explains the team decision-making process in terms of team level, individual member level, and the relationship between those levels. The team-level view divides the team process into three stages, while the member-level view splits the process into five phases. Each member-level phase belongs to a team-level stage, which is thought of as a phenomenon emerging from the activities in the member-level phases belonging to that stage.

Team decision making can be viewed as a distributed problem solving activity, which is a macro-level phenomenon emerged from micro-level interactions. Thus, the macro-level phenomenon(i.e., team decision making) can be explained from modeling the micro-level processes(i.e., interactions between team members). Accordingly, in order to build a model of a decision-making team to study the team's decision making behaviors, researchers need to build models of individual team members and their relationships. Considering both member and team levels together, the DL model provides a theoretical framework to explore team decision making by using a set of computational models of team design and team members.

Decision making involves cognitive activities, and cognition is information processing by humans. Therefore we need to consider cognitive aspects when modeling team decision making. Viewing a team decision-making process from both mental model and information-oriented perspectives, the conceptual model can guide modeling of the cognitive activities embedded in team decision making.

The present study has some limitations. First, the DL model is only suitable for the team problems that are decomposable. Nevertheless the DL model can be applicable to many team problems due to that in general team members are composed in order to take in charge of a portion of the team task in which they have special expertise. Second, in order to focus on the topics covered so far, the study cannot address the nature of problem in detail that the team of the DL model can resolve. For example, issues like task complexity, duration of problem solving, overlapping interests among team members, contradictory interests of team members are not discussed. Future studies are necessary. Addressing such issues will improve the usability or adoption of the DL model. Third, although the DL model is embedded into the Team-Soar model, the current version of Team-Soar cannot fully implement it. Future work is necessary to extend the Team-Soar model to have the subproblem integration phase. Fourth, although teams are different with groups strictly speaking, the present-study used the literature on groups as well as teams indiscriminately because teams are special type of groups and literature does not differentiate them. Fifth, the present description of the information-oriented perspective of the DL model is not sufficient due to the lack of related studies in the literature as pointed out in section 3.2. In particular, the information-oriented perspective does not cover all types of information that might be exchanged during decision making processes for different kinds of teams. Therefore, further studies are necessary that examine the possible types of information other than the ones described in this paper in order to complement the information-oriented perspective.

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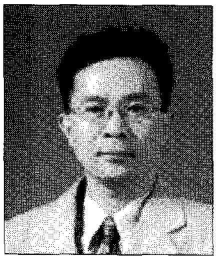
◆ 저자소개 ◆



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현재 아주대학교 경영대학 e-비즈니스학부에 조교수로 재직 중이다. 한국항공대학교 항공전자공학과에서 학사(1984), 미국 뉴욕주립대(SUNY at Albany)에서 전산학 석사(1989), 미국 Rensselaer Polytechnic Institute(RPI)에서 공학박사(1996) 학위를 취득하였다. 삼보컴퓨터에서 연구원, 삼성SDS에서 경영컨설턴트, 그리고 계명대학교경영학부 경영정보학 전공의 조교수로 근무한 바 있으며, 주요 연구 분야는 e-Business, Multi-Agents, Computational Organization Theory 등 이다.

◈ 이 논문은 2003년 2월 21일 접수하여 1차 수정을 거쳐 2003년 11월 22일 게재확정되었습니다.