# A Generalized Model of Cognitive Tasks

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**ABSTRACT**

*A person applies her knowledge when she performs a cognitive task. The representation of a person's knowledge of a task is accessible from a cognitive task analysis. The think-aloud method is useful for carrying out a cognitive task analysis because think-aloud data represent closely a person's knowledge. Various cognitive tasks were analyzed and models of cognitive tasks were developed based on the external and internal environments of tasks. Comparison between models of cognitive tasks shows similarities between the models. Further analysis suggests common features which formed the basis for the construction of a generalized model of cognitive tasks. This study proposed a generalized model which has four major categories referred to as (a) properties, (b) events, (c) essence and (d) rules of a task. These categories represent information and knowledge in the external and internal environments of cognitive tasks.*

**Keywords**

*Cognitive Task Analysis, Think-Aloud Method, External and Internal Environments, Knowledge States*

## 1.0 INTRODUCTION

Cognitive task analysis or CTA involves the modeling of knowledge, mental structures or processes that are required to perform cognitive tasks. Verbal protocol analysis, also referred to as the think-aloud method, is one of the general methods of CTA and is an important technique for studying human intelligence because verbal protocols or think-aloud data represent closely a person's knowledge (Ericsson & Simon, 1993; Gordon, 1994; van Someren, Barnard & Sandberg, 1994). It is one of the few methods that gather data with sufficient temporal density to account for behavior nearly second by second (Simon & Kaplan, 1989). CTA based on the think-aloud method is capable of revealing knowledge, mental model, attention-distributions or meta-cognitive strategies used in cognitive tasks. Often think-aloud data represent explicitly knowledge and information rather than the mental processes of task performance (Redding, Cannon, & Seamster, 1992; Redding, 1995). Therefore, the objectives of most CTA studies are to (i) uncover the representations of knowledge from data, (ii) generate knowledge states which major categories of the representation of knowledge that are uncovered from data and (iii) construct models based on the knowledge states that are generated from data. This study reports models of various cognitive tasks and proposed a generalized model of cognitive tasks.

## 2.0 METHOD AND ANALYSIS

The think-aloud method is the primary method of data collection. Think-aloud data that are collected are subjected to microanalysis, coded and categorized. The categories of knowledge and information are generated from data and reflect the external and internal environments of a task. A model of a cognitive task is constructed from the analysis of knowledge and information in the external and internal environments.

### 2.1 Think-aloud Method

The think aloud method is an important technique for eliciting and analyzing data which represent a person's knowledge of a task. Think-aloud data are "memory trace" of a respondent's knowledge in short-term memory (Ericsson & Simon, 1993; Green, 1998; van Someran, Barnard & Sandberg, 1994). Derrida is of the view that a "memory trace" is a psychological trace of a person's knowledge (Seung, 1982). A major assumption of the think-aloud method is that verbalizations are generated by the same cognitive processes which generate other cognitive responses. Therefore, the verbalization of think-aloud data must comply with the constraints governing all cognitive processes (Ericsson & Simon, 1993). These assumptions have a number of implications (Ericsson & Simon, 1993; Redding, 1995) including (i) information can only be reported if it is attended to, thought about or looked at, (ii) as task performance becomes more automatic, the intermediate steps of a process become unavailable for verbal report because only information that is attended to can be reported, (iii) verbalization of task performance is an added load to mental processing and acts to divide attention so performance may be inhibited and (iv) instructions on what to report have a direct effect on verbalization of task performance.

Typically, the think-aloud procedure involves asking a person to think aloud while performing a task. The think-aloud method is very direct because a person is required to say aloud her knowledge, but it does not require a person to interpret and explain her thinking (Ericsson & Simon, 1993; Green, 1998, van Someran, Barnard & Sandberg, 1994). The process of providing explanation would interfere with a person's knowledge. Think-aloud method is least intrusive to a respondent because a researcher does not pose questions, interrupt or influence a person's thinking when she performs a task. In the think-aloud method, a person just renders her knowledge of a task as they come to mind (Ericsson & Simon, 1993, van Someran, Barnard & Sandberg, 1994).

### 2.2 Data Analysis

Think-aloud data represent explicitly the knowledge and information that are used during a task (Redding, Cannon, & Seamster, 1992; Redding, 1995). However, the representation of mental processes are less explicit and often, it is necessary to infer mental processes rather than attempting to code the processes directly (Simon & Kaplan, 1989). Therefore, data analysis focused on uncovering and coding of data which represent knowledge and information that are used during a task rather than identifying the mental processes of task performance.

Data which represent knowledge and information are uncovered, coded and categorized. The uncovering and coding of data are based on the interpretation of the meaning of data. Data with similar intended meaning are coded and categorized. The categories of knowledge and information that have similar core features are categorized together to form bigger major categories. An important element to consider about major categories is the idea of the external and internal environments of a task. The external environment relates to perceptual information and the internal environment relates to conceptual knowledge of a task (Hassebrock & Prietula, 1992; van Someran, Barnard & Sandberg, 1994). Therefore, a major category relates to either an external or internal environment of a task. The major categories are also referred to as knowledge states (Hassebrock & Prietula, 1992) and formed the components of a model that represents a cognitive task.

## 3.0 VARIOUS CTA MODELS

Think-aloud data for various cognitive tasks were collected and analyzed. In this study, think-aloud data consisted of verbal communications and explanations. Think-aloud data were coded in order to uncover protocol representations of knowledge and information. These were used to generate categories of knowledge and information of a task. The categories were analyzed further and categorized under major categories or knowledge states. Knowledge states are used to construct the basic structure of models of cognitive tasks. The following sub-sections reports three models of CTA constructed from data.

### 3.1 Air Traffic Control

A study on air traffic control by Anding and Songan (1998, 2000) analyse on-the-job tasks of approach air traffic controllers. Data was analyzed based on knowledge states and conceptual operators.

Figure 1 shows two main categories of protocol representations, that is, knowledge states and conceptual operators that are needed to handle the air traffic situations. Conceptual operators are cognitive operators or mental processes that act on the relevant knowledge or information in short-term memory and often, conceptual operators had to be inferred from data (Simon & Kaplan, 1989). Conceptual operators are not the focus of this report because the main features of a generalized model are concerned with knowledge states which are representations of knowledge and information in short-term memory.

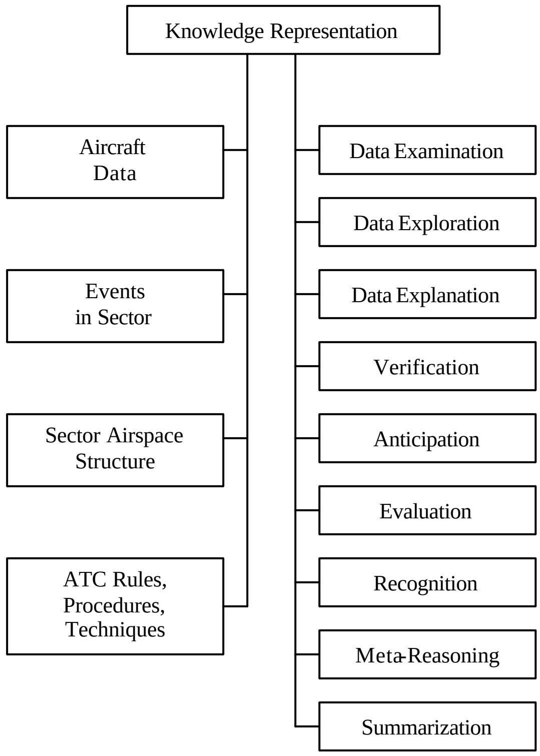


*Figure 1: Model of air traffic control task*

The knowledge state *Aircraft Data* relates to information and knowledge associated with aircraft. *Events in Sector* concerns air traffic events, situations and factors occurring in a sector. Information on *Aircraft Data* and *Events in Sector* are sensory and perceptual in nature. The knowledge state *Sector Airspace Structure* concerns air traffic controllers' conceptual knowledge of the physical characteristics of a particular sector. *ATC Rules, Procedures and Techniques* concerned the rules, procedures, techniques, methods or strategies that approach air traffic controllers used to manage air traffic. *Sector Airspace Structure* and *ATC Rules, Procedures and Techniques* relate to air traffic controllers' knowledge that is committed into long-term memory. *Sector Airspace Structure* and *ATC Rules, Procedures and Techniques* are conceptual, semantic and structured. Knowledge about *Sector Airspace Structure* and *ATC Rules, Procedures and Techniques* are retrieved into working or short-term memory during task performance. Sub-categories of the knowledge states are as follows.

*Aircraft Data*: Flight number, Position, Heading, Altitude, Location, Route, Time estimate, Aircraft type, Speed, Aircraft on-board instrument.

*Events in Sector*: Events near completion, Aircraft entering sector, Traffic situation, On-going events, Potential conflicts, Requests, Weather or other factors.

*Sector Airspace Structure*: Special Areas, Topography, En route structure, Geography.

*ATC Rules, Procedures and Techniques*: Vectoring, Separation, Prioritization, Visual approach, ILS approach, Sequencing, Alternative plans, ATC procedures and rules.

### 3.2 Tour-guiding

The task of tour-guiding is highly information driven because a tourist guide manages and conducts tours. A CTA on tour-guiding by Anding and James (2000) developed the model as shown in Figure 2 which represents the types of knowledge and information used in tour guiding.

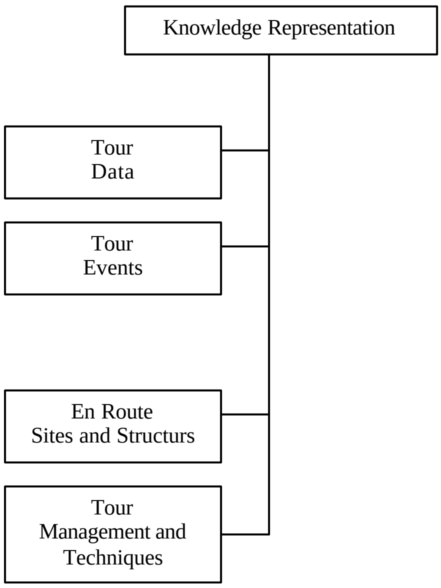


*Figure 2: Four knowledge states in tour-guiding*

This study identified four knowledge states which are referred to as *Tour Data*, *Tour Events*, *En Route Sites and Structures* and *Tour Management Knowledge and Techniques*. Sub-categories of these knowledge states are as follows.

*Tour Data*: Route and distance, Accommodation, Departure time, Departure point, Transit point(s), Destination, Duration, Schedule, Transport type and condition, Client(s), Tour group size, Group characteristics, Interests.

*Tour Events*: Interaction with clients, Tour starts, Traffic, road and river Situations, Weather factors and conditions, Briefings before events, Welcoming, Festive and religious events, Meal-breaks, Resting and stops, Visit to Iban longhouse, Handicraft-making activities, Cultural show and activities, Photo-taking activities, Forest-trail walk, Flora and fauna identification activities, Hands-on activities, Experience preparing food in the jungle, Tasting local or forest food, Harvesting activities, Visit to farm, Purchasing souvenirs, Bargaining and using cash.

*En Route Sites and Structures*: Farms, Residential areas and villages, National Parks, Wild-Life Centres and Sanctuaries, Geographical areas and sites, Historical sites, Museum, Markets, Schools and government departments, Other structures such as bridges, General sites en route, People en route, Flora and fauna en route, Primary and secondary forest, Road system, Longhouse location and facilities, Longhouse physical structures and layout, Longhouse social structure, Statuette and motifs, Forest-trail terrain.

*Tour Management Knowledge and Techniques*: Hospitality management, Safety, Equipment and provisions for a trip, Socio-cultural and arts, Economy, Education, Eco-tourism, Manage local-site-transportation.

*Tour Data* refers to basic information about a tour route. *Tour Events* are the set of events that may occur along a tour route. *Tour Data* and *Tour Events* are classified as knowledge states in the external environment of the tour-guiding task because *Tour Data* and *Tour Events* relate to information that is external and perceptual in nature. *En Route Sites and Structures* are knowledge about sites, physical structures and conceptual structures along a tour route. *Tour Management Knowledge and Techniques* refers to knowledge and techniques of managing a tour. *En Route Sites and Structures* and *Tour Management Knowledge and Techniques* are classified as knowledge states in the internal environment of the tour-guiding task because these knowledge states are conceptual in nature.

### 3.3 Problem Solving in Engineering

Anding, Mai Sumiyati Ishak and Mohd Razali Othman (2001) conducted a CTA about the collapse of a river bank retaining wall. The think-aloud method was used to analyze problem solving in engineering. The verbal protocols consist of verbal communications and related explanation given by the two practicing engineers with ten years experience and four final year engineering students as they attempt to solve an engineering problem on the collapse of a rumble wall that served as a river bank retaining wall. This study identified that respondents approached this engineering problem in stages. Nevertheless, the focus of this paper is about knowledge states and in this study, seven knowledge states as shown in Figure 3 were generated from data.

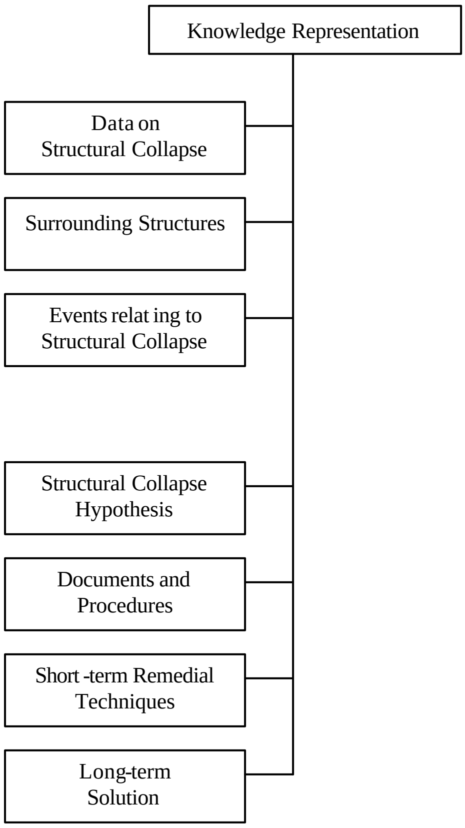


*Figure 3: Knowledge states associated with problem solving of the collapse of a riverbank retaining wall*

Knowledge and information which are categorized under these knowledge states are as follows.

*Structural Collapse Data*: Type of retaining wall, Location, Date and time occurred, Strength of foundation, Quality of material used, Nature of piling, Design.

*Events*: Weather - raining: Date and time raining, Tide - high tide: Date and time of tide, Constructions nearby.

*Surrounding Structures*: Flow of river, Soil type, Drainage, Features of buildings, Area surrounding.

*Structural Collapse Hypothesis*: Erosion, Soil type, Quality of material, Strength of foundation, Effect from surrounding area, Goal.

*Document and Procedures*: Structural plans, Foundation plans, Hydrological data, Local piling procedures, Piling tests, Visit to site, Safety procedures.

*Short-Term Remedial Techniques*: Temporary wall, Temporary support, Fill earth or gravel or sand bags, Pile type, Improve drainage, Prevent water entering, Raise ground level.

*Long-Term Solution*: Improve Foundation, Improve Surrounding Area: Soil, Improve Material Quality, Purpose: Prevent Water Entering

During the early stage of identifying and interpreting the problem, the knowledge states used are concerned with *Structural Collapse Data*, *Events*, and *Surrounding Structures*. Respondents examined data or information in order to identify the problem, which is perceptual in nature. The stage whereby respondents identified and hypothesized on the cause of the problem involves knowledge about *Structural Collapse Hypothesis* and *Document and Procedures*. For the final stage of problem solving, respondents considered *Short-Term Remedial Techniques* and *Long-Term Solution* which involved meta-reasoning processes whereby respondents evaluated or reasoned about the knowledge they used in a problem-solving task. These are conceptual in nature.

## 4.0 GENERALIZED MODEL OF CTA

Think-aloud method was also used to explore on a smaller scale other tasks which students conducted as their assignment on cognitive modeling. These tasks, which are not reported here, include planning tour packages, doing facial treatment, 'trouble-shooting' computers, designing invitation cards, determining salary scheme for sales promoters, exploring effective counseling and many others. Although the analyses of these tasks are not reported here, initial cognitive task analyses on these tasks and detailed studies of air traffic control, tour-guiding and problem solving tasks indicate that a generalized model may be constructed for cognitive tasks.

Central ideas about the construction of models of cognitive tasks are the external and internal environments and interpretation about perceptual information and conceptual knowledge. The "dimension" of a major category or knowledge state as perceptual or conceptual was used to establish the position of a category in the external-internal environments. Comparison between models for air traffic control, tour-guiding, problem solving in engineering and other cognitive tasks suggests that there are similarities between knowledge states generated from data for different cognitive tasks. Similarities between knowledge states for different cognitive tasks imply that knowledge states can be generalized. The generalized knowledge states are used to construct a generalized model of cognitive tasks. The generalized model of cognitive tasks proposed in this report is based on knowledge states or major categories of knowledge representations in the external and internal environments.

## 5.0 MAJOR CATEGORIES

A generalized model of cognitive tasks was constructed by comparing knowledge states of different of cognitive tasks. A generalized model of cognitive tasks consisted of four generalized knowledge states or major categories which represent knowledge and information that are used to perform cognitive tasks. These major categories are as follows.

### 5.1 Properties of a task

The first major category of a generalized model relates to the physical components, information or data about a cognitive task. Physical components, information or data are basic properties which relate to the external environment of a task because they are often data given about a task. Therefore, a major category refers to the external characteristics of a cognitive task. This major category is referred to as “Properties”.

**5.2 Events of a task**

A second major category of a generalized model of cognitive tasks is about events, situations or conditions. The term “Events” is used to generalize events, situations and conditions. “Events” are due to factors in the external environment.

**5.3 Essence of a task**

A third major category is concerned with the basic structure or knowledge of a task, that is, the essence of a task. The essence of a task is internal to a task. The term “Essence” is used to represent this major category in order to reflect the inner features such as knowledge and structure of a task.

**5.4 Rules of a task**

The final major category of the proposed generalized model of cognitive tasks concerns the steps, procedures, techniques or rules of a task. The term “Rules” is used to represent this major category which is part of a task and internal to a task.

## 6.0 DISCUSSION

This study argues that the think-aloud method or verbal protocol analysis is an extremely useful technique for investigating human information processing including analyzing and modeling of cognitive tasks. A generalized model of cognitive tasks was discovered from comparing and generalizing various models of cognitive tasks. The four major categories or knowledge states of a generalized model are (a) Properties, (b) Events, (c) Essence and (d) Rules of a task. As such, the acronym of the proposed generalized model of cognitive tasks is the PEER model. The PEER model of cognitive tasks is discovered from data and is a simple to remember. The PEER model serves as a simple framework for analyzing cognitive tasks and this study proposed the PEER model of cognitive tasks as a framework for analyzing and modeling cognitive tasks.

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