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Context-Sensitive Visualization for User-Centered Information System and Product Design

E. C. Jung, K. Sato
Institute of Design, Illinois Institute of Technology, Chicago, IL, United States

1. Introduction

One of fundamental objectives in human-centered information system and product design is to provide a user with experiences that fits his or her needs. As a user's interaction environment becomes ubiquitous and pervasive, the way a user experiences the physical and media world through active representation of function and information embodied in the system has become an important issue [Dourish, 2001]. To enhance the quality of the interaction in a user-centered way, the user's mental models on artifacts [Young, 1983], human cognition model for action plans [Norman, 1990], user modeling with knowledge-based architectures [Fischer, 2001], and context-awareness methods [Dey, et al., 1999] have been introduced from several research areas such as cognitive science, HCI, and AI.

However, these approaches have mainly focused on information push to a user with considering user's external contexts rather than internal contexts. Human-imitated agent models that can interpret those external contexts are generally proposed to implement intelligent systems and products from those research areas. For higher standards of interaction design beyond these approaches, the quality of information and delivery methods satisfying user's contexts is critical while a user is interacting with information systems and products. The concept of CSV (Context-Sensitive Visualization) has been proposed by the authors to reflect the dynamic nature of context changes as shown in Figure 1 [Jung & Sato, 2005].

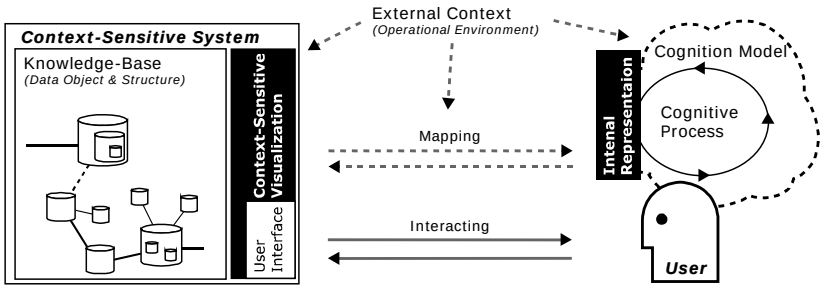

Figure 1. Interaction Model with CSV for User-Centered Design

Figure 1 explains the position and role of CSV in interaction model incorporating the several approaches to enhance quality of interaction. In bridging these approaches, CSV plays an important role to deliver data encoded in information systems and products corresponding to a user's internal representation in cognitive process by the context of use. As theoretical foundations to embed CSV in systems and products, 1) context models - how human cognition is activated and processed with external context and user's knowledge - and 2) visualization schemes with controls that can match with user's internal representation in context of use are examined.

To develop these foundations, a definition of context and a mechanism of context-sensitivity are surveyed by investigating a continuum between the user's cognitive process and information product and system in section 2. A context model with representation scheme is suggested in section 3 to explain how a user can interpret information with his or her internal representation in a context-sensitive way and to develop CVS-based system. Section 4 develops visualization schemes for mapping information into context models to implement the concept of CVS. The conclusions and future works are presented in section 5.

2. Context-Sensitivity

To understand the nature of interaction between a user and systems in a pervasive and ubiquitous environment, context should be considered carefully since a user has a diverse experience with several products in such an environment. The context is associated with the interaction seamlessly; thus, the theoretical foundation for CSV should start with understanding context and its mechanism.

2.1 Definition of Context

The term *context* originated from the field of linguistics as a set of parameters which makes the content of a sentence more understandable. One way to consider context is that it consists of any information that can be used to characterize the situation of an entity [Dey, et al., 1999]. Such explanations can be categorized as externally defined context. *External context* in Figure 1 can be defined as the collection of manifesting or latent sources of influences affecting actions and performances of users, systems, and environments [Swanson, et al., 2003]. These external contexts are considered as conditions in situations in this research. However, these external contexts are only meaningful to a human or machine agent when they are recognized and positioned in relation to the current cognitive state and actions of the agent [Kokinov, 1999]. The current mental state of the cognitive system selects the relevant contexts for cognitive actions. The authors found during the previous research that the context is a mental model or pattern in the agents' knowledge activated by triggering information elements at a certain situation [Jung & Sato, 2004].

2.2 Mechanism of Context-Sensitivity

Human cognition is related with problem-solving activity for achieving goals and intentions through the seven stages of action [Norman, 1990]. Mental models play an important role for problem-solving activity since they provide suitable contents, structures, and views through internal representations for interpretation. The mental models in a certain situation are formed through the interaction among information from outside, knowledge, and interpretation [Kokinov, 1999]. For user-centered interaction design, the phenomenon of

knowledge chunking in mental models should be taken into account. This chunking phenomenon is the mechanism of context-sensitivity and the representation of the mechanism is a context model.

Figure 2 shows the mechanism in order to illustrate where contexts exist and how contexts work in human cognitive systems. Information forms condition and situation. If a user has goals or tasks in a situation, the user's cognitive system will select appropriate information from outside to achieve the goals with selecting knowledge frames. That is, the information triggers to select proper knowledge frames for interpreting the information in the situation. These selected frames are context models which are types of mental models from a user's knowledge. The context models contain knowledge frames to describe how people interpret information in situations. After a proper context model is selected from knowledge, the information from outside is mapped into the context model. The activated context model is contextualized knowledge for internal interpretation. This process is the core mechanism of contexts. Once the interpretation is evaluated, it will be stored as knowledge. That storing process is called learning. A context-sensitive information system is a system that can visualize information based on proper context models to deliver right information with right format at right time for facilitating the user's better decision-making in situation changes.

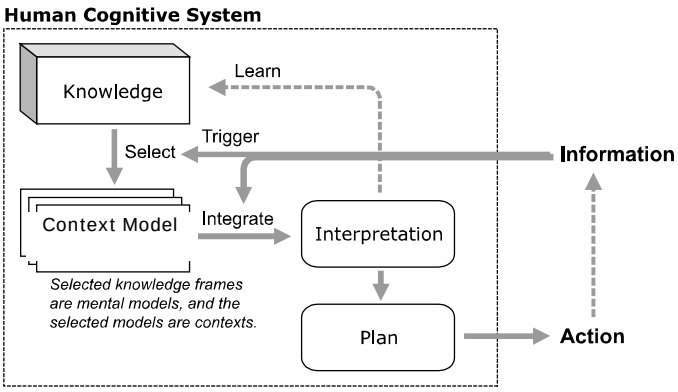

Figure 2. Mechanism of Context-Sensitivity in Human Cognitive System

3. Context Model

Context model is dynamically formed by receiving information from outside, selecting appropriate knowledge frames, and mapping the information into the selected frames for interpretation. Context model is the place where internal knowledge processing happens. Thus, a user can make a next action plan through interpretation with context model. This section will develop representation scheme of context model by examining the generating mechanism of context models in interaction. The purpose of representation is to understand the structure and mechanism of context model for implementing context-sensitive systems and products.

3.1 Simulating Context Model

To develop the authors' argument more effectively, a case scenario about a mobile and car information products and systems is presented. A scenario is a good method to simulate a situation [Carroll, et al., 2000]. With this case scenario, concepts of context models and CSV will be explained.

Chris is about to leave home for his office at 9:00 AM. Suddenly, he receives a phone call from his client and is asked to attend a project meeting in the client's office at 9:30 AM. To accept the request, Chris should reorganize today's schedule. Once his schedule is reorganized, Chris notices that he does not have enough time to reach his client's office in time. He should find the fastest route, so that he may arrive as soon as possible.

This scenario looks simple, but it contains enough information to explain context models. By breaking this short scenario down with, the mechanism of context-sensitivity is modeled as depicted in Figure 3. This model shows 1) the relations among knowledge, information, goal, and condition, and 2) the emerging mechanism of context models dynamically and iteratively.

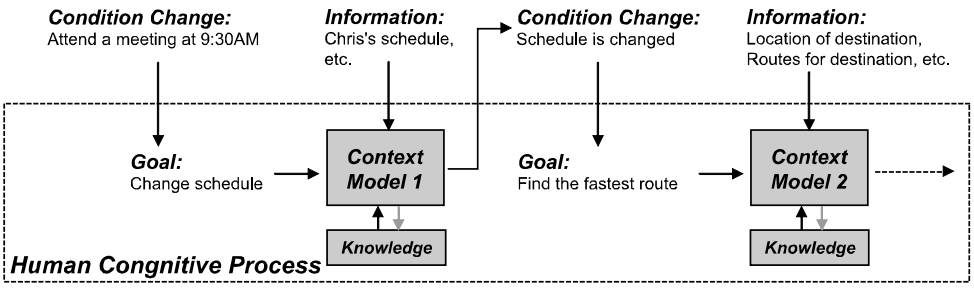

Figure 3. Instances of Context Model in Human Cognitive Process

The condition change of attending a meeting at 9:30 AM forms a new user goal, i. e. changing a user's schedule. The goal triggers a context model to make a decision with selecting appropriate knowledge frames and information. In Figure 3, the first context model should provide knowledge frames for a user to modify his or her schedule adapting to a new situation. By manipulating the context model, a user can make a new schedule for the changed situation. For the second context model, knowledge frames for route selection with the location of a destination and routes for the destination are required.

If information such as the user's schedule and route for the destination is delivered to user's cognition with appropriate formats and timing, a user can reduce his or her cognition load and extend the boundary of knowledge. This is the core feature of CSV. Through this observation, it is suggested that the generic context model can be used to examine types of knowledge and information, and to describe its triggering mechanism.

3.2 Representing Context Model

Context model consists of working memory and information interpreter. Working memory is a temporal space to store information from outside. By mapping the stored information into selected knowledge frames, information interpreter will process the information for problem-solving and decision-making.

There are two types of user knowledge: domain knowledge and system knowledge. Domain knowledge is the knowledge about the content of systems and system knowledge is the knowledge about the usage of systems. In each knowledge type, there are different layered knowledge types, which are propositional

knowledge and procedural knowledge [Anderson, 1983]. Propositional knowledge is the knowledge about what a user know and procedural knowledge is the knowledge about how a use to achieve something. In context model, propositional and procedural domain knowledge, and procedural system knowledge are important rather than propositional system knowledge since propositional system knowledge is more system designer-oriented view in terms of contents of the knowledge. Generally, a user doesn't have an interest in how system functions are organized and designed.

Context model plays an important role for the problem-solving activity since it provides suitable contents, structure, and view for internal interpretation with some internal representation formats. Human's internal representations can be incomplete by some limitations of human's cognition ability. To extend the incomplete user's ability, CSV is suggested for facilitating user's interaction.

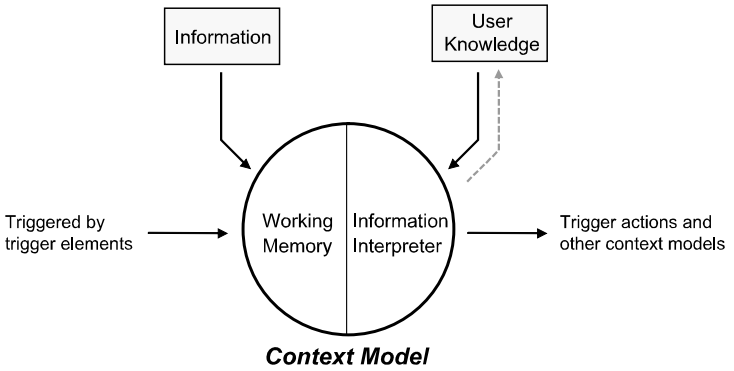

Figure 4. Structure of Context Model

4. Context-Sensitive Visualization (CSV)

The meaning of understanding is that a large amount of data is simplified and reduced to the small number of categories of information that a user is capable of taking into account in dealing with a given problem [Bertin, 1983]. The context model can be used to focus the relevant information from huge data in terms of data selection, and visualization methods can be used to amplify user's cognition in terms of data delivery.

Visualization is essentially a mapping process by using computer-supported, interactive, visual representations of data to amplify cognition [Card, et al., 1999], and the purpose of visualization is to get insight for discovery, decision making, and explanation from complex multi-dimensional data sets [Hamming, 1973]. Information visualization is the term for visualization schemes and methods which have been developed to reveal patterns and structures of huge data sets from science, statistics, physics, etc.

The definition of CSV is a user-centered knowledge representation reflecting user's context models for context-sensitive information delivery. The main differences between information visualization and CSV lie in the quality of target users and the interests for visualization. There is no 'typical' user for system and product design. If the user classification scheme based on stereotypes is introduced [Rich, 1989], the target users of

information visualization are expert users on each domain. However, target users of CSV could be novice, intermediate, and expert users. Thus, the scope and view of information is more critical in CSV since target users for CSV do not have the complete domain and system knowledge.

Information visualization has more interests in the nature of data sets and the whole structure of the data. Thus, it has developed visualization schemes and methods that can represent whole data set and structure transparently without loosing any data. It is not necessary for information visualization to consider user's context rigorously. On the other hand, CSV has more interest in the information mapping process with context models for the visualization schemes and methods since a user wants to get right information on right format at right moment.

4.1 CSV-Based Information Processing Model

Figure 5 is a unified model to explain the whole information flow and interaction channels of CSV-based systems and products containing a user, environment, and a system. By introducing this model, specifications for a CSV middleware is revealed more clearly. The CSV middleware provides three features of 1) appropriate resolution, format, and timing of information delivery for effective use in changing context with interaction methods to control and monitor information, 2) generic and domain-dependant contextual reasoning that enables to understand user's context model in give situation, and 3) data accumulation to record the history of user's interactions that makes the system adaptable to a user. To simulate and evaluating the CSV concept, the basic CSV architecture was developed to implement a software tool [Jung & Sato, 2005].

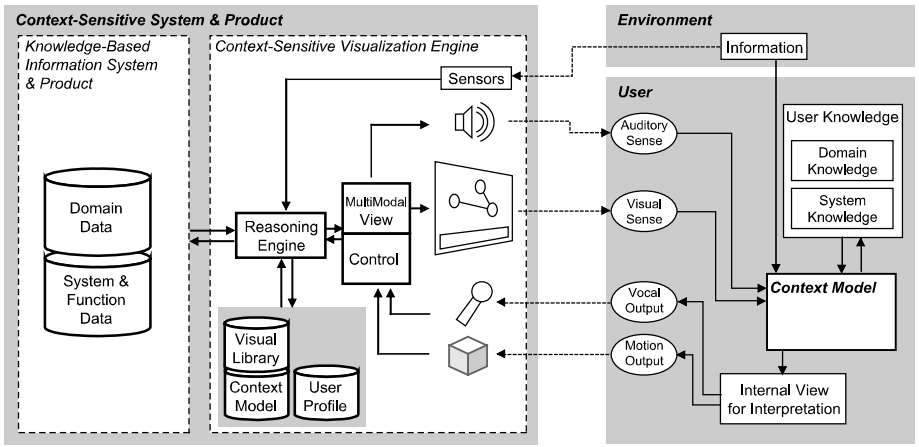

Figure 5. Interaction Model between CSV and a User

In this paper, visualization issues such as view, control, and visual problem-solving are mainly discussed. Multimodal view in CSV provides the basic topological space considering user's knowledge frame in a given situation. The view is activated by triggering elements and information through the reasoning engine. The view always comes with controls that can navigate inside the view, select information, and change mode. CSV makes knowledge structures transparent for user's easy access and problem-solving activity by providing

interactive control of the mapping from context models to internal and external representation in a separate user interface or integrated with the representation structure.

Data and knowledge encoded in information systems and products are visualized by integrating and mapping dynamically with two-layered visualization schemes: knowledge visualization and context model visualization. The main benefits of CSV are 1) improvement of information delivery and interaction quality by positioning information in user's context model, and 2) development of a common design framework to incorporate context-sensitivity into information system and product design for intelligent home, office, car, and mobile environment.

4.2 Multimodal View and Navigation

Multimodal view and navigation is the basic visual structure in CSV which is generated when user's knowledge and information are mapped into a visual space. User's mental model and mental image are considered carefully for the view. There are four criteria for a mental model: performance, reasoning, design, and learning [Young, 1983]. Selecting a common metaphor for the mental model that can be shared among people for the view is important for performance issue. A user can predict the response of the system and product, and make a right decision making in a given situation. That is, the view should provide controls with the view for contextual reasoning. This view and control can be used as a guideline for a user-centered interaction design. Finally, the view provides the whole structure of knowledge to extend user's knowledge, which is the learning process.

Figure 6 depicts some examples of multimodal view and navigation for domain and system knowledge. In the case scenario, there are three information devices: a map navigator, a scheduler, and a phone book. To provide the views of domain knowledge for the devices, mental models that a user has are used. For map data, the survey view with a camera-imitated control can be suggested. Page view is used for scheduler and phone device. System knowledge visualization has a little different story since system knowledge is about how the system is implemented and encoded by system developer.

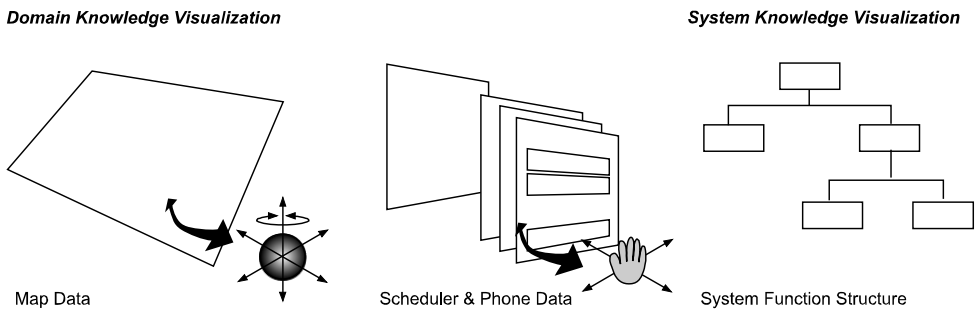

Figure 6. Visualization Scheme of Information and Knowledge

Generally, a user has more interest in usage of the system rather than function structure of the system. Thus, these whole structures of knowledge should be focused and condensed to delivery information context-sensitive way by mapping information into context models.

4.3 Mapping information into Context Models

Context models contain selected information with knowledge frame for interpretation. Context model is a meta-frame for reasoning and analyzing knowledge by focusing relevant information in context of use. Some examples of context model representation are depicted in Figure 7.

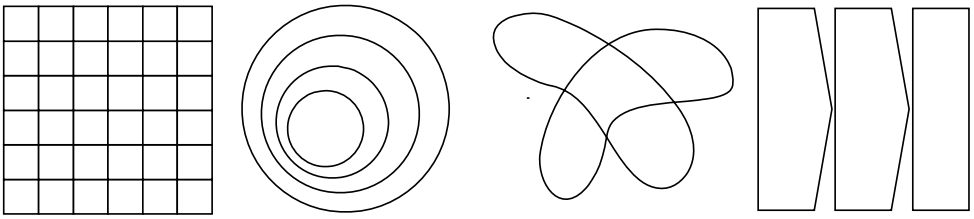

Figure 7. Visualization Scheme of Context Models

By applying the grid model to the map knowledge visualization, the distance relations among landmark on the map can be delivered easily. If the circular grid represent time scale and it is overlaid on the map, the location where a user can reach in time dimension can be displayed, so a user can decide the route to the destination. This can be used for the case scenarios when Chris decides the right route to attend the meeting at 9:30 AM. Categorization can be used for scheduler and phone data when a user gets knowledge by category. For example, if Chris wants to call to attendee for the meeting for leaving a message, this scheme will be applied to phone data in a mobile phone. If a user gets lost inside the system, the procedural scheme works to explain how to use a system with system function structure knowledge visualization.

5. Conclusions

The goal of this paper is to propose theoretical foundations to implement the concept of CSV by examining context models and revealing relations among context models and visualization schemes. Through argument through this paper, context model is defined as dynamically and temporally formed mental models by integrating information into knowledge frames. CSV is essentially the mapping process with two-layered visualization schemes: knowledge visualization and context model visualization.

Figure 8 show whole scope and roles of CSV in ubiquitous and pervasive environment. With CSV, the quality of information delivery and interaction by positioning information in user's context model is enhanced. The CSV-based system can be effectively implemented for diverse applications for intelligent home, office, car, and mobile environment where contexts take critical roles in user interactions with knowledge-based systems and products. In order to develop CSV middleware applicable to diverse interactive system, further studies such as building knowledge class libraries for context models, and the mapping and visualization libraries including data and visual objects must be conducted.

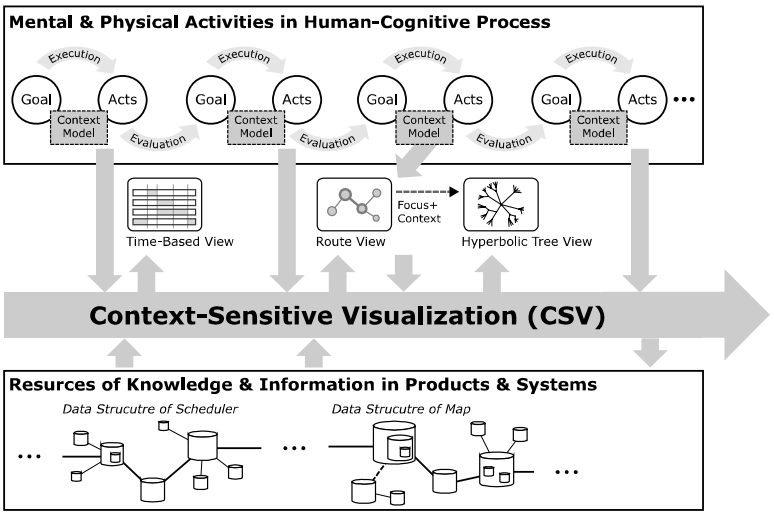

Figure 8. Sequential Interaction Flows of CSV

6. Acknowledgement

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