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Context-sensitive Approach for Interactive Systems Design: Modular Scenario-based Methods for Context Representation

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Abstract As information technology becomes more ubiquitous in our work and daily life environments, understanding contexts of activities becomes critical to enhance a foundation for human-centered design practice. This research introduces a conceptual framework for defining, representing and incorporating contexts as core information for interactive systems design. Modular Scenario Composition Method was developed as a mechanism for linking descriptive field study information and analytical aspect models representing many viewpoints involved in the system development and use processes. Design Information Framework (DIF) previously developed by the author was used as a common information platform to bridge different information representation formats including scenarios and aspect models. By combining modular scenarios and aspect models representing contexts, chains of relations between contexts, their triggering factors, and their influences on user actions can explicitly be described. *J Physiol Anthropol Appl Human Sci 23(6): 277–281, 2004* http://www.jstage.jst.go.jp/browse/jpa

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Introduction

New technologies such as wireless networking and ubiquitous computing can provide seamless technological environments that support our work and daily life. While such technologies pervade into our activity space and attempt to deliver functional and informational services where and when they are needed, understanding contexts of use becomes increasingly important in order to predict how new systems can be accepted, understood, incorporated, used, and valued in people's life. In order to effectively use new technologies to enhance the quality of people's experience, the nature of services provided by the system needs to be finely tuned to users' needs and the context of use.

In order to effectively incorporate the concept of context into the design information for enhancing the foundation of human-centered design practice, it is necessary to introduce a more rigorous and applicable form of its conceptual framework. The performance of interactive systems is determined in relation to the context in which the system performs its intended roles. The system that performs well in one context may not perform well in other contexts. While the context dynamically changes, systems are usually designed to remain the same and to be operated within a very limited context. In order to maximize the system performance particularly from users' viewpoints, therefore, the system needs to be sensitive to the change and range of the context. In order to ensure the quality of users experience with the system, use contexts from users' viewpoints need to be well understood and incorporated into design consideration as the core information for human-centered design practice.

There are two primary approaches to context-sensitive design: context-aware and context-conscious. On the one hand, context-aware design is often defined in AI and Robotics (Swanson et al., 2003). In the context-aware approach, a system uses sensors to detect changes of contexts and adjusts its behavior to optimize the performance in new contexts. The conscious approach, on the otherhand, tries to identify relevant contextual information and incorporate it into design decisions to produce a system that can perform well in a wide range of contexts.

This research intends to introduce a representation framework for contextual information critical for developing a methodological foundation for user-centered design practice. There are three threads in this research: 1) Introduction of a conceptual framework for understanding and representing the concept of context, 2) Development of structured scenario composition methods to bridge descriptive and analytical representations of contexts, and 3) Application of the Design Information Framework (DIF) as a unified information platform to bridge different views and representation of contexts.

Concept of Context

Much diversity can be found among definitions of contexts from different interests such as context aware computing, usability analysis, urban planning, and linguistics. In context aware computing, some descriptors of the domain such as location, identity, and time, describe conditions and environments of the system operation and are considered to be parameters of context (Dey et al., 2001; Selker and Burleson, 2000). In urban planning, community history is a part of context. In the area of office space planning, contexts of work include social, cultural and organizational aspects. An office worker's task level, information flow, project history, and daily activity patterns become important aspects of the context. Such mechanism of defining contexts with factors external to human or machine agents can be categorized as *external definition*.

External conditions and states become 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. Another mechanism of defining context, therefore, can be considered *internal definition*; context is developed internally in the cognitive system as a model or pattern of knowledge that is associated by the recognition of a current situation. Some contexts emerge as personal knowledge that is hard to communicate or unsharable by others. Some contexts emerge as socially shared knowledge through common experience among people in the community. Context is a mental model or a pattern of one's memory activated by "trigger" elements in the situation.

These different disciplinary viewpoints suggest some characteristics of the concept of contexts: 1) Multiple aspects of context manifest based on the emergent relevance to the nature of actions and conditions, 2) The granularity of description varies depends on the focus of the viewpoints, 3) Contextual changes are evoked by triggers from different constituent elements of the domain, 4) Context evolves over time but some aspects change fast and others change slow. In order to understand the concept of context, it is useful to also define related concepts such as conditions, states, environments and situations.

Conditions are commonly defined as individual variables in the domain of concern where the interaction is situated. They include environmental states, system states, and user states that include variables such as location, temperature, sound, and user emotion and attention level.

Context is often understood as a pattern of behavior or the relation among variables that are outside of the subjects of design manipulation but potentially affect user behavior and system performance. Is context different from environmental conditions or users' states? In activity theory, context is referred as the specific transformative relationship between people and artifacts that both internally and externally exist (Nardi, 1996). There are many different aspects that emerge in different actions and situations affecting system performance in different ways. For example, aspects of context for driving are a chronological development of the user's activities for the day—a destination and purposes of driving, and a plan for intermediate activities before arriving at the destination. These are aspect models of contexts that all influence driving behavior. Often simple terms such as "driving freeway" and "teenager" are also considered as contexts. These are examples of ostensive or indexical use of words implying particular contexts represented by typical patterns of conditions or characteristics associated with them instead of pointing to their immediate meanings. Some aspects of context take significant roles in forming situations for the current action; some aspects become irrelevant to the current action. We call the former *manifesting aspects of context* and the later *latent aspects of context* (Sato, 2003). Figure 1 shows how the manifesting aspects of context and conditions form the situation of the action. As a result of the action, some of the aspects of context change and evolve over time.

Situation is a collective condition at the scene of the interaction that is composed of relations among variables of conditions such as environmental states, contexts, system's and user's states. Therefore the representation of situations needs to include description of relations as well as the set of descriptors as listed above. In some cases, actions in the situation consequentially become a part of the situation. In Fig. 1, *m* state variables and *n* aspects of context are indicated, and a small number of states and aspects of context manifest relevance to the action by imposing direct or collective effects. Figure 2 depicts the mechanism of context manifestation as mental models in a cognitive system based on the internal definition of context.

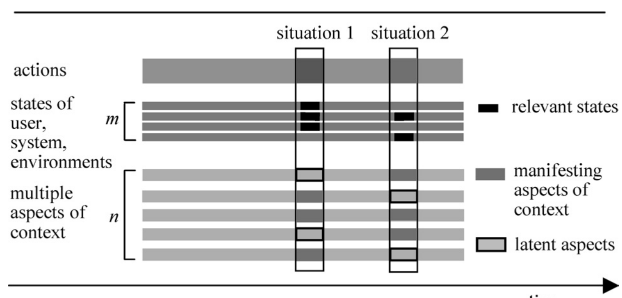

Fig. 1 Formation of situations with actions, states and contexts.

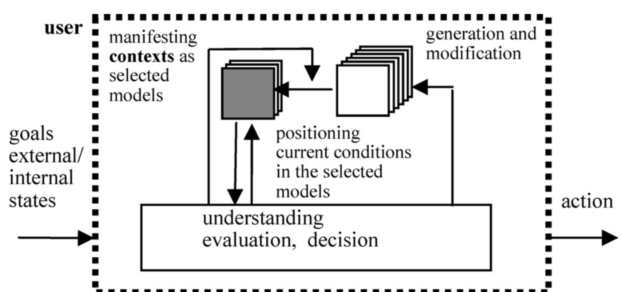

Fig. 2 Mechanism of context formation with mental models.

Representation of Contexts in Design Information

The development of scenario representation methods and formal aspect models to describe different types of context will be explained. The Design Information Framework (DIF) as a unified information platform as shown in Figure 3 is applied to bridge different views and representation formats of contexts.

Case studies were first conducted to understand how contexts influence the quality of user interactions and system performance, and to identify taxonomy of contexts and mechanisms of imposing influences over user interactions. Automotive information and navigation systems and office system were among cases investigated. Different definitions and uses of the concept of context in different disciplines such as AI, HCI and design are also analyzed and compared. Through these studies, a conceptual framework was developed to explain what composes contexts, how contexts are structured, and how they can be described. In order to bridge the gaps among different disciplinary viewpoints, and between rich narratives of instances and the accuracy of formal representation, all essentials to incorporate the concept of context into the scope of design practice, scenario-based representation methods and aspect model representation methods are developed using the DIF previously developed by the author's research group.

Since context is defined as mental models which people use as resources for inferential actions, they can be represented in various forms of model representation. For example, some social contexts can be represented as causal models or sets of rules that tell us how we should behave to be appropriate in a particular situation. The Design Information Framework (DIF) has been developed to provide a unified information platform to multidisciplinary design activities and viewpoints (Lim and Sato, 2001, 2003). DIF can be effectively applied to represent a wide range of mental models composing complex contexts.

DIF is composed of two concepts of information units, Design Information Primitives (DIP) and Design Information Elements (DIL). DIP represents the most fundamental units of information, which cannot be further decomposed. However, DIL are higher concepts of information that are composed of the DIP's and the other DIL's information elements. Figure 1 depicts how the DIL's information elements that are specific to a domain of concern for a particular project are defined. DIF only provides a general structure of information units. Since every project domain addresses a specific concern and viewpoints, it needs to identify its unique set of DIL's elements called P-DIF that defines a structure of relationship beween the DIP's and DIL's information elements. In other words, P-DIF defines the ontology of the domain of concern for a specific project.

A conceptual framework for defining and representing contexts in design is developed and a mechanism for effectively incorporating the concept and information of contexts in the design process is introduced. This research also demonstrates that the concept of context, which has been considered as soft and peripheral information in design, can and must become a critical resource for user-centered design practice. Particularly, the use of context sensitivity in many different application domains opens a vast new space for research and system development including topics in re-configurable system architecture for the physical and media objects, and mechanisms for capturing, identifying and managing contexts.

<P-DIF Formated Data>

DIL: ACTION (C)	DIPs: TIME	USER	ACT	OBJECT	TOOL
explaining a procedure (c_{15})	t_{15}	phlebotomist (e^{u}_{1})	explains the procedure (a_{15})	patient (e^{o}_{2})	
tying patient's arm with a tourniquet (c_{16})		phlebotomist (e^{u}_{1})	binds (a_{16})	patient's arm (e^{o}_{3})	a tourniquet (e^{tl}_{7})
finding a vein (c_{17})	t_{16}	phlebotomist (e^{u}_{1})	finds (a_{17})	a vein (e^{o}_{8})	phlebotomist's eyes (e^{tl}_{16}) and hands (e^{tl}_{17})
telling possible problems (c_{18})		phlebotomist (e^{u}_{1})	tells possible problems (a_{18})	patient (e^{o}_{2})	
palpating a vein (c_{19})	t_{17}	phlebotomist (e^{u}_{1})	palpates (a_{19})	a vein (e^{o}_{8})	phlebotomist's hands (e^{tl}_{17})
tracing a vein (c_{20})	t_{18}	phlebotomist (e^{u}_{1})	traces (a_{20})	a vein (e^{o}_{8})	phlebotomist's hands (e^{tl}_{17})
cleaning a site (c_{21})	t_{19}	phlebotomist (e^{u}_{1})	cleans (a_{21})	patient's arm (e^{o}_{3})	gauze (e^{tl}_{15})
performing a venifuncture (c_{22})	t_{20}	phlebotomist (e^{u}_{1})	performs (a_{22})	a venipuncture (e^{o}_{12})	a syringe (e^{tl}_{14})

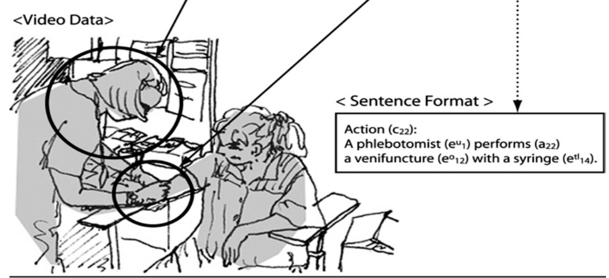

Fig. 3 Transcription of video data to formal data format.

Scenario Representation of Contexts

Scenario description is used for many different purposes such as the documentation of specific cases, exploration of possible cases, and presentation and evaluation of proposed concepts. Its story-based description can communicate well to a wide range of audiences and carry rich information including context description for the subject of concern. In spite of these significant advantages, narrative format of conventional scenarios limits its effective uses in system development because of a lack of consistency, incompleteness and difficulty of translating into analytical model representations. These disadvantages arise because of its dependence on arbitrary writing styles based on the preferences and capabilities of the writer. Scenario-based methods have been adopted for interactive systems development in order to accommodate richer and deeper insights into human experience and task situation (Carrol, 2000; Johnson et al., 1995]. Use case scenarios have been used in object-oriented system development as a starting point of system analysis. Object relation diagrams are developed by parsing scenarios to

users	actions	objects	intention	sources	user state	external cond.	contexts
activity: looking for a restaurant for lunch on the way to a resort area for a weekend overnight fishing							
John 35 male, mech. eng, married with two children (7yr girl and 4yr boy)	John decides to stop at a restaurant in a small shopping mall he vaguely remembers around the area. He checks the navigation system.	Driving system Navigation system	John wants to feed children to keep them happy and be ready for action when they arrive at their destination	Car navigation system shows a small familiar village and his watch/car clock indicates 1:35pm.	They are hungry. John is eager to arrive destination. Children became bored during the long trip	Traffic conditions/ Commercial signage/ Road conditions/ Weather	Model 1: geographical relationship, model 2: event plan for the trip, model 3: causal relation of meal, driving and children's conditions

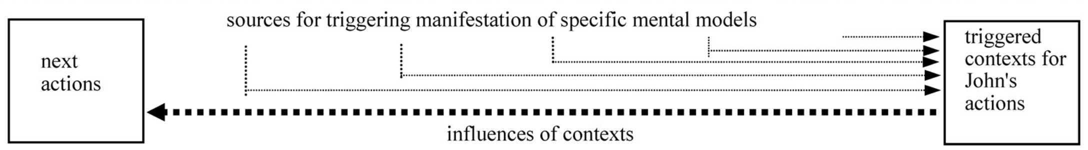

Fig. 4 Example of modular multi-thread scenario format.

identify key objects represented as nouns and key relations as verbs (Robertson, 1995). DIF based scenario analysis provides more structured and formal mechanisms to translate scenarios to other formats for more analytical model representation (Lim and Sato, 2001). Script uses a similar ontology for event scene description using a stage metaphor (Schank and Ableson, 1986). Its representation method with Conceptual Dependency allows the effective formal description of causality and other relations between actions. But neither method particularly focuses on the context description.

In order to construct a generic scenario format for the context description, example ontology with fundamental information elements was developed through case studies in several application areas using the DIF concept. Activity Theory (Nardi, 1996) and Distributed Cognition Theory (Hollan et al., 2000) also introduce similar information elements to describe the human–computer interaction. The scenario description format to be used for this purpose also needs to have the following features: 1) control over the granularity of the description for different levels of concerns, 2) easy manipulation of description to allow "what if" exploration for alternative conditions and solutions, and 3) reflection of the ontology set for the domain of concern in order to embed sufficient and consistent information for interpretation to more analytical representations. Figure 3 shows an example of the formatted documentation method as an intermediate mechanism for formal data representation (Lim and Sato, 2003). The Modular Scenario Composition method has been introduced using the same mechanism particularly to represent contexts in scenarios. The following are definitions of the example of the information elements used in the format indicated in Fig. 4. These definitions are critical to the description of contexts.

User profile leads to some general types of contexts shared among users of the category such as culture-based contexts. Since the sharing of particular experiences, environments and resources are likely to generate similar mental models of particular aspects of a relevant subject matter, some parameters of the user profile can be used as indices for identifying some classes of contexts. Performance models, preference models, and behavioral models are examples of this type of information.

Goals and intention sets conditions for selecting methods and courses of actions. The structure with lower level goals and intentions can be considered as a context.

Appropriate *actions* and *objects* are chosen according to the plan based on the triggered contexts. Execution of actions and use of objects also reciprocally activate contexts, for example, by triggering specific mental models formed through user's experience with this recursive cycle of actions and context formation.

Objects are incorporated in an action as subjects of manipulation, tools and/or environmental elements. They often perform critical roles for setting a course of actions or for triggering a particular association of mental models that set the contexts of the action.

When appropriate *mental models* are selected, in another word, when particular *contexts* manifest, they become a mechanism to produce the rationale for particular actions. The selected models or contexts are used for various mental activities such as understanding, interpreting, deciding and planning by supplementing information, setting a hypothesis, imposing criteria, or setting conditions.

Sources of information to make decisions and actions are often neglected but every action requires information for activating or controlling its process.

User states and external conditions indicate the current status of users, objects and environments. They affect the users' decision, the users' and objects' performance, and the overall system performance.

Causality is a commonly used description of patterns of events. It can be indicated by the detected links between the description modules or pointers with referencing numbers.

With the Modular Scenario Composition Method shown in Fig. 4, it becomes possible to translate a narrative scenario into a formal model description of a specific aspect of the scene as shown in Figure 3. The translation mechanism originally developed to convert user study data to aspect models using DIF can be applied to derive formal models from scenarios in this format or vise versa (Lim and Sato, 2003). The arrows in the lower section of Fig. 4 indicate how particular mental models or contexts are activated by various factors involved in the scene. The analysis of the causal structure among information elements can further reveal mechanisms of the emergence of the contexts and predict their influences to the behavior of the interactive systems according to the model of the context formation in Fig. 2. Figure 5 shows the overall scheme of the translation mechanism with DIF.

Conclusion and Perspectives

This paper firstly introduced the definition of context, which has been considered as soft and peripheral information in design, and positioned context as core information for a foundation for human-centered design methodology. Secondly, a general framework for representing and incorporating it in design information as forms of models was constructed using DIF as an underlying mechanism. Thirdly, scenario-based methods were demonstrated to identify various contexts and their relations to other information elements. Although a general approach to the development of the representational mechanisms for contextual information was explained, further formal and empirical research is needed. Use of context sensitivity in many different application domains opens a huge new space for research and system development including architectural issues of physical and media spaces, interaction, and re-configurable interfaces.

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