Integrating Context-Aware Computing in Decision Support System

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Abstract—**With the rapid development of ambient intelligence and ubiquitous computing technologies, the concept, principle, architecture and technique of decision support system evolve significantly. In this paper, we discuss the challenges to decision support system for providing ubiquitous, personalized, and proactive decision making services. A framework of context-aware intelligent decision support system is illustrated, with the description of the advanced technologies of human computer interaction, context-awareness and context mining.**

Keywords: ambient intelligence, context-aware computing, decision support system, human computer interaction, context mining

1 Introduction

Decision support system (DSS) is a computer-based information system that supports decision-making activities. In the past decades, the applications of DSS have an explosive growth in diverse domains such as business management, marketing, financial analysis, medical diagnosis, agricultural production, enterprise management, etc. There are different taxonomies of decision support system [1]. For example, concerning the assistance mode it can be divided into communication-driven DSS, data-driven DSS, document-driven DSS, knowledge-driven DSS, and model-driven DSS. Alternatively, concerning the relationship between users and applications, it can be divided into passive DSS, active DSS, and cooperative DSS. As the complexity and dynamic of decision making environment increase, computational intelligence is regarded as a vital component of intelligent decision support system (IDSS).

Nowadays with the rapid development of ambient intelligence and ubiquitous computing technologies, the concept, principle, architecture and technique of decision support system evolve significantly. Ambient Intelligence (AmI) indicates the intelligent interfaces which are embedded in all kinds of objects and capable of recognizing and responding to the presence of different individuals in a seamless, unobtrusive and often invisible way[2]. It refers to a digital environment that proactively and sensibly assists people in their daily lives [3]. In this situation, decision making should consider some new challenges.

- In ubiquitous computing environment, the computer may be any embedded computational machine, such as personal digital assistant (PDA), mobile phone, spacecraft cockpit or microwave oven. Accordingly, decision maker becomes 'anytime, anyplace'. As decision supporting is likely required through any device at any workspace, the mobility and portability of decision support system become increasingly important [4]. For example, when a user is on the travel, he would like to use his cell phone to handle stock exchange with the aid of some stock analysis tools.
- Traditional decision making mainly focus on the problem to be solved with little consideration of decision maker. However, present decision is highly depended on the situation of user and environment. In other words, a specialized decision which concerns user personality is more attractive than a general decision. In order to meet the demand of personalized services, personalization and customization is an essential factor to evaluate the capability of present-day decision support systems. For example, users would like to get some advices of appropriate restaurants for lunch to their needs, including location, time, weather, preference, etc.
- Proactive service becomes a promising trend of decision support system in the sense that the needs of users are captured unobtrusively and the desirable services are initialized automatically with the least user intentional interaction [5]. Decision making is expected to perform in an implicit and automatic way rather than the explicit and manual way. For example, when a tourist arrives a new place, he wants to receive some attractive introduction of scenic spots before posing a request manually.

To fulfill these purposes, there is a great need to increase the intelligence of DSS which is able to acquire knowledge in agile ways and provide relevant information actively to decision makers. Context-aware computing is

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the key technique to recognize and utilize the context in an unobtrusive manner for intelligent decision support. Context-aware computing refers to systems that can sense their physical environment and adapt their behavior accordingly. The motivation of this paper is to illustrate how context-aware computing can be integrated into decision support system through advanced technologies of human computer interaction, context awareness and context mining. Firstly, a general framework of context-aware intelligent DSS is described to provide personalized and agile decision making services. Secondly, the role of context-aware computing is discussed in two representative applications.

The subsequent sections are organized as followed. In section 2, the framework of a context-aware intelligent decision support system is outlined and the kernel techniques are discussed. Section 3 discusses two representative applications, namely healthcare systems and personalized recommendation systems, where context-aware computing plays an important role in decision making. Finally, the paper is concluded in section 4.

2 Framework of Context-Aware Decision Support System

Context aware refers to softwares that adapt to the location of use, collection of nearby people and objects, as well as changes to those objects over time [6]. In a recent publication, it is defined as systems that use context to provide relevant information and/or services to the user [7]. In order to deploy context in decision making, a decision support system should have some advanced features such as:

- Sense and collect contextual information autonomously from light and portable wireless devices;
- Represent and manage various types of contextual information;
- Extract context-relevant patterns through context mining;
- Deploy context data and patterns in model selection, formulation and execution for decision making;
- Provide different users with adaptive and customizable decision supporting.

As described in Figure 1, the system is composed of the following components as complements of conventional DSS. The core capability is the acquisition, exploration, and deployment of context to provide appropriate decisions to particular user. Context acquisition module acquires various contextual information from user, environment and other external services. From the primitive context data, composite and task-relevant data are obtained through context reasoning and modeling. These context data are reserved in the context repository. Afterwards, the relevant data are fed into the context mining module, in which different data mining tools, e.g., association rule mining, classification, clustering and sequence mining, are performed to extract context-relevant patterns. These patterns are used as parts of knowledge to solve the problem in context decision making module through model selection, model formulation, model execution and model interpretation [8]. Finally, the decisions are presented to users in an adaptive way.

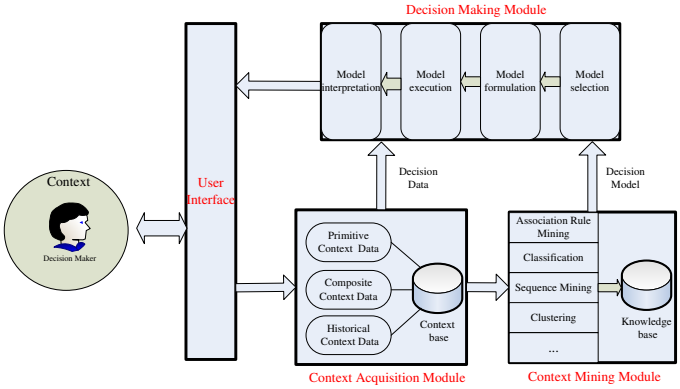

Figure 1: Framework of context-aware intelligent DSS

In order to satisfy the expectation of decision makers for complicated and specialized problem solving, the development of decision support system needs a shift towards ubiquitous, personalized, and proactive services. It can be implemented through recent advanced technologies in non-invasive and wearable sensors, wireless communication, context awareness, ubiquitous computing and data mining. We introduce the concept and technique of some important issues from the presentative of decision making assistance.

2.1 Human Computer Interaction

Human computer interaction (HCI) is an inter-discipline covering computer vision, machine learning, network security, database, artificial intelligence, multimedia technology, embedded computation, ergonomics, cognitive psychology. It studies the design, evaluation and implementation of interactive computing systems for human use [9]. The main motivation of HCI is to achieve a natural interaction between human and computer similar to the way between human and human. Besides the explicit interaction through command or dialog, some implicit elements are encompassed into the communication, which capture implicit input from users and present implicit output to users [10]. Implicit input could be the action and behavior of users in various forms of human sense, such as vision (e.g., body movement, hand gesture, gaze, emotion, face), audio (e.g., speech, voice), smell, haptic and taste. Implicit output is not directly presented to

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the user, but seamlessly integrated with the environment and the task of the user. Through the implicit interaction, users are capable to concentrate on their task rather than the computer itself.

The core of HCI is the accurate understanding of user intention under specific context. For example, when a person enters a smart room, the air condition turns on and adjusts to the desired temperature automatically. To invoke such action, the system first acquires the surrounding context information, and then makes the decision according to the inner models concerning the relationship between context and temperature. Contributed to the advanced technologies of context awareness and context mining, the acquisition and analysis of context information is not problematic at present.

2.2 Context-Awareness

Ubiquitous computing gains great importance in many applications to make full use of all resources. It has rich potential to get well understanding of contextual information from augmented environment. As ubiquitous computing provides 'anywhere, anytime' service through network and communication technologies, the context could be identified automatically. Context can be any information relevant to the interaction between user and applications, including user-relevant context (e.g., identity, activity, preference, emotion), environment-relevant context (e.g., temperature, climate, time, location), and device-relevant context (e.g., type, resolution, screen size, memory, connection speed). Alternatively, in [11] context is classified into four categories: physical context, computing context, user context and time context.

Due to the fact that context implies implicit knowledge of users and their environment relevant to particular user and decision task, users do not have to specify the required information manually. As context is regarded as an integral part of computer, context-awareness becomes a fundamental enabling technology for ubiquitous computing. A context-aware decision support system utilizes contextual information in the problem solving task to provide personalized service and eliminate the explicit interaction between human and computer.

2.3 Context Mining

Data mining is an analytical technique to discover hidden knowledge from database. It has been demonstrated as a promising approach to enhance the intelligence of decision making system. A variety of data mining techniques are integrated in the intelligent module which provides decision makers with domain knowledge, problem understanding and skills. Asides from regular functionalities of data mining for decision aiding, the great development of ubiquitous technologies brings innovative opportunities and challenges to knowledge-based decision supporting. As was mentioned, context is valuable information to decision making. Besides current context, context information can be historical, i.e., the past context and user actions are collected along a time span. Historical context information can be very useful to establish context-relevant patterns and predict some of the possible user's actions. By integrating implicit contexts into data mining process, the prediction output changes from the similar set of inputs under varied context factors, thereby improves the adaptive capacity of decision-making [12].

Context mining is the process to exploit knowledge from context data. These patterns represent the preference or behavior of users and can be used to predict the future action. By making use of contextual information it makes possible to provide decision makers with more accurate and feasible decisions. Differently from the general data mining, context mining mainly focuses on utilizing contextual information related to the actual moment or historical events, usually performs in an automatic manner with implicit input and output, and extracts context-relevant patterns.

3 Representative Applications

Some studies have been carried out in developing decision support system in ubiquitous computing environment. For example, a ubiquitous computing technology-based framework "ubiDSS" [4] integrates decision making methodology and context-awareness computing to reinforce tradition DSS with proactive and personalized service. With the help of Web service and multi-agent technologies, the system recognizes context automatically and adapts the decision making on the user's behalf accordingly. Due to the fact that context becomes inevitable in decision making, there is a growing interest in realizing context-aware systems, such as context-aware comparative shopping for mobile commerce to increase the satisfactory of customers [13]. In this section, we introduce two representative applications in which the context is used to facilitate the interactive computing and decision making.

3.1 Ambulatory Healthcare System

The traditional healthcare systems rely on infrequent and expensive patient visit and diagnosis. In the world of increasing elder population, they do not meet the nowadays requirements any more. Proactive healthcare technologies become more and more urgent for prevention and detection of diseases. The current healthcare systems develop towards continuous, long-time, ubiquitous and ambulatory service. Through the continuous and ambulatory monitoring, the physiologic signals of patients are acquired at any time and any place and used for healthcare service. It is particularly useful for chronically ill patient, elder and handicapped to whom the frequent visit to hospital is non-realistic. The long-term monitoring

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offers a large amount of physiologic data for better understanding of patient physiology and behavior as well as the evolution of disease. Compared with traditional healthcare system, the ambulatory healthcare system is superior to reduce the cost of healthcare service, facilitate patients and elders, simply disease monitoring and treatment, extend healthcare service from clinical setting to any environment, obtain fine granularity of physiologic data, fast respond to emergence case, recognize early signals of diseases and give preventive health recommendation [14].

Context mining plays an important role in medical data analysis for clinical decision support, biomedicine, drug discovery, and healthcare applications. A large amount of quantitative data are acquired during the continuous and long-term monitoring and stored in a personal health profile of patients. Based on the analysis of patient-specific information and sequencing physiologic data, the medical diagnosis becomes more accurate and customized than traditional diagnosis. Context mining have achieved promising performance to provide good diagnostic opinion by learning patterns from the past clinical data. For example, classification classifies the signals into different categories relating to clinical history. Clustering analysis identifies gene groups of similar expression. Association rule discovers the relationship between different symptoms or diseases. Sequence mining predicts the occurrence of diseases sequentially. In general, context mining in medical data analysis is responsible of the following tasks:

- Recognize the abnormal signs based on a number of physiologic features;
- Analyze the signals and relationships with particular disease;
- Predict the evolution of diseases from time series physiologic data;
- Evaluate the treatment relating to the disease evolution to adjust prescription accordingly;
- Discover routine patterns and provide personal recommendation concerning the current status.

In a hospital information system (HIS) [15], the contextual information of patients is considered as a factor of prescription. However, the system is not real context-aware without the ability of acquiring context information directly. Ubiquitous healthcare is of increasing importance to provide healthcare service anywhere and anytime. LiveNet [14] is a flexible wearable platform for long-term ambulatory health monitoring with real-time data streaming and context-awareness applications. It combines commodity hardware, sensor interconnection bus, light-weight distributed sensing and software to process the multimodal and context-aware data. LiveNet is applied in health and clinical classification, critical soldier monitoring, parkinson disease monitoring, epilepsy seizure detection, depression therapy treating and general activity classification. Based on a general wearable wireless personal area network (WWBAN), a prototype [16] composed of inexpensive, lightweight and miniature sensors is developed for heart activity and motion monitoring with real-time feedback about the current health status. In this field, some commercial products have been developed for either real-time or post analysis, such as LifeShirt System [17], SenseWear WMS [18] and Actiwatch monitoring system [19].

In an automatic healthcare data mining system [20], the daily time series health and lifestyle data is input through mobile phone and transferred to Web server via internet. Afterwards, the personal patterns relating to lifestyle and health condition are extracted using a generalized rule induction algorithm. Similarly, the routine patterns [21] are mined from continuous activity data stream collected from sensors. The routine patterns are important to understand the general behavior of human and detect the life-threatening episode usually marked as the changes of behavior patterns. In [22], a real-time classification system for human movement is implemented based on the data acquired from a single, waist-mounted triaxial accelerometer. The data processing is performed online in wearable units with constrained memory and processing resources.

3.2 Personalized Recommendation System

Recommendation systems are widely used in a variety of domains, such as tourist guild, multimedia e-service, e-shopping, and e-learning, to provide personal service according to users location, preference and surrounding environment. Through modeling and reasoning of domain, task and user, the system is able to adapt the interface to a special user, give feedback about the user's knowledge, and predict user's future behavior.

Location is one of the most contextual information regarding the recommendation system. Traditional recommendation systems mostly utilize user profiles for analysis, but neglect user location and movement. The awareness of mobile user's location is essential to provide quick and necessary information to location-related decision problems. Location is considered as a crucial factor in service recommendation, such as restaurant selection, tourist guidance, special place (e.g., no-smoking place, library, hospital) reminder. Owing to the advanced location and positioning technologies, a mobile device as PDA or GPS is able to provide location information in such applications.

Location-based service (LBS) provides information based on location of mobile users. Most LBSs use the current location of mobile user to determine the services required

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by users. With the support of location prediction technique, the system earns more time to prepare the desired services probably needed in future and consequently improve the reliability of system. Location prediction is a task to estimate the forthcoming location of mobile user based on the movement model. It has been recognized as an important issue in many proactive applications related to location, such as traffic planning, early-reminder system, tourist service, personal communication system, and quality-of service (QoS) wireless ATM network. The regularity in movement is characterized by predictive models through data mining technologies and used in the future location prediction for advance resource reservation and optimal route establishment. The efficiency of location management is highly depends on the accuracy of location prediction to deliver only desired services. In addition, location awareness and prediction help to implement implicit human computer interaction instead of explicit request by users.

Preference is another crucial component of context, and usually learned from the personal resources including the profile, history and context of users. An agent-based prototype residing in portable device [23] finds the nearby restaurant satisfying user preferences from the registered list. Users are required to input their preferences manually including money constraint, food type, atmosphere and no-smoking. A more agile and automatic way is to predict user preferences based on personal model of rules, decision trees or numerical values learnt from the past experiences during the interaction between user and system and updated periodically to adapt to the most recent preferences. The learning of user preference is usually regarded as a classification task. Hidden Markov Model is applied to learn user habits for providing services in a context-aware platform [24]. In a multimedia channel selection system [25], the most recent selected multimedia items are recorded as a training data set to build decision tree classifiers representing the relationship between user preference and multimedia content, and consequently used to recommend the priority list of channels.

An advisor system [26] recommends appropriate restaurants satisfying user preference and location. The location context, user context and environment context are considered as factors of restaurant evaluation. Two decision tree models are created representing the relationship between restaurant selection and user preference, as well as environment context. As a result, the restaurant list is recommended by integrating the output of classification models and location context through predefined weight values. In the most recent work [27], users' preferences are retrieved from context history and deployed in personalized services recommendation. The patterns between user profile and selected services are inferred using decision tree modeling and association rule mining so that the desired service can be predicted for a specific user.

GUIDE project [28] of Lancaster University uses personal and environmental context in a mobile information system for guiding tourists to Lancaster. Personal contexts such as user location and preference are related to a particular user and environmental contexts such as weather and climate are generic information available on Web. The system uses knowledge about physical location and user preference to display information and perform services.

4 Conclusions

The great development of ubiquitous computing technologies brings novel requirements and innovations to traditional decision support systems. Based on advanced technologies of human computer interaction, context-awareness and context mining, we give a framework of context-aware intelligent decision support system which is capable to make decisions proactively and intelligently. The acquisition and utilization of contextual information is performed in an automated manner instead of an intentional interference such as explicit commands or dialogues. The applications in ubiquitous healthcare systems and personalized recommendation systems are discussed.

The research on context-aware decision support system is still in the beginning stage, many challenges remain in this area. Under ubiquitous conditions, mining knowledge from data is limited with time and space constraints, hence the light-weight data mining algorithm is of potential importance especially on crisis and emergency in which real-time data processing and analysis are needed. Along with the advanced human computer interaction technologies, the remarkable progress of many new input and output devices leads to novel ways of interaction, such as gesture, speech, haptics, eye blinks, gaze and motion. How to discover the patterns from the combination of multimodal data is worthy of further investigation.

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