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Context-aware Technologies and Systems

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Abstract. The move from traditional desktop computing environment to ubiquitous and mobile computing have brought to the front Context-aware applications which are capable of providing appropriate information and services to the user depending upon the computational/user context. This paper attempts to discuss the concept of Context-awareness from functionality perspective. The components and characteristics of Context-aware systems are identified and described in terms of the requirements expected from other applications. The different architectural approaches used in the envisioning of context-aware systems are presented to highlight the functionalities and quality concerns which dictate their choice. Moreover, Context-aware frameworks and middleware which facilitate the efficient development of Context-aware applications are highlighted as instantiations of various architectural styles. Finally, the paper highlights the importance of context-awareness for pervasive computing by discussing sample applications in diverse fields of education, health and tourism.

Keywords: context-awareness; context framework; sensors; context model; Context-aware applications; context-aware systems.

1. Introduction

Context can be defined as any information that characterizes a person, place or object that could impact the application use of a person [1]. Its derivative, the term context-aware, was first used by Schilit and Theimer, [2] and it refers to the ability of an application to use context information to satisfy a dynamic adaptability requirement. One of the first context-aware systems was the Active Badge Location System by [3]. It was typical of the first efforts because most of the first context-aware systems were primarily location aware. Since these first attempts and because of advances in technology (including mobile technology) the capability of context-aware systems to utilize other types of context has increased. Moreover, during the past two decades context-awareness as a functionality has also been a crucial part of nascent IT paradigms of pervasive computing and advanced HCI.

This paper attempts to discuss the concept of Context-awareness in a comprehensive manner. It starts by looking at historical trends and foundational definitions of context. The components and characteristics of Context-aware systems are identified and

described in terms of the requirements expected from other applications. The different architectural approaches used in the envisioning of context-aware systems are presented to highlight the functionalities and quality concerns which dictate their choice. Moreover, Context-aware frameworks and middleware which facilitate the efficient development of Context-aware applications are highlighted as instantiations of various architectural styles. Given, the dominance of layered approach to context-aware systems, an important functionality, Context-modeling is treated in a separate section to gain more insight into the different choices, considerations, and perceived advantages of more common modeling techniques from the literature. Finally, the paper highlights the importance of context-awareness for pervasive computing by discussing sample applications in diverse fields of education, health and tourism.

2. Context Awareness

Several researchers define context in various circumstances and occasions. One possible definition of context was suggested by Schmidt [4] and it states that: "A context describes a situation and the environment a device or user is in. A context is identified by a unique name. For each context, a set of features is relevant. For each relevant feature a range of values is determined by the context". In addition, Dey [1] also defines context as: "Any information that can be used to characterize the current situation of an entity". Another variety of context definition is by specifying instances of contexts. For example, Schilit and Theimer [2] tried to identify four categories of contexts: "Computing context: network connectivity, communication costs, communication bandwidth, nearby resources such as printers, displays, and workstations. User context: the user's profile, location, people nearby, the current social situation. Physical context: lighting, noise levels, traffic conditions, and temperature. Time context: time of a day, week, month, and year."

Concerning Context-aware system, Schilit, Adams and Want [5] initially defined it as: "A system is context-aware if it uses context to provide relevant information or services to the user, where relevancy depends on the user's task".

If a given application is aware of its context, then it can propose the user with a group of services that the user can instantly access. Moreover, the application might also change its procedures so that it matches the contemporary context of the user. Most common context types to scrutinize situational awareness are: User's location, User's working activity by sharing video, User's audio and User's overall activity. Moreover, different researchers consider issues such as: Where you are, who you are with and what resources are nearby as an important attributes of context aware.

Therefore, Context-aware systems represent applications which can read certain contextual elements and reason about such elements. Accordingly, adjust their behavior so that the user needs might be satisfied in relation to the current operational context. Despite, the advantages of context-aware systems; such systems are not yet widely spread. One of the possible causes might be an immense gap between the system behavior and user's expectation and this has been pointed out by Sitou and Spanfelner [6].

3. Evolution of Context-aware Computing

During the initial stage of mobile computing, in the late 80s and 90s, the main target was providing mobility services everywhere, regardless of environmental changes. After the appearance of ubiquitous computing, in the early 90s, there was a move in thinking and mobile computing is extended and the context of use as a resource has been become hot topic for researchers [7].

Schilit and Theimer [2] commence the concept of context-aware computing in 1994 on their paper entitled "Disseminating Active Map Information to Mobile Hosts" which was presented at "the Workshop on Mobile Computing Systems and Applications (WMCSA)" [7, 8]. Nevertheless, according to [9], the development of Olivetti Active Badge in 1992 could be considered as the first attempt and research exploration of context-aware computing. In Schilit and Theimer's work [2], context is robustly associated with location of machines and devices in which mobile devices can provide variety services in different locations. Starting from that time onwards, there have been many efforts in the areas of context-aware computing. Currently context-aware computing is widely used not only through mobile phones but also through different devices, machines, infrastructures and in diverse areas [9] such as in the area of robotics, wearable computing, adaptive and intelligent user interfaces, augmented reality, adaptive computing, intelligent environments, and context-sensitive interfaces . Also the usage of context is expand and it is very useful in many fields encompassing e-commerce personalization, information retrieval, ubiquitous and mobile computing, data mining, marketing, and management [10].

4. Context-awareness and Ubicomp

Context awareness is fundamental feature of ubiquitous computing devices which helps them to give adaptive services for users and applications based on the inclusive context [11]. Context-aware ubiquitous computing systems are crucial applications which are able to respond and interact to their physical environment dynamically by the help of sensor technologies. They perceive, respond and interact according to the user's environment, needs and desires to take smart decisions about when, where and what service to provide to the users. Nevertheless, such ability of systems is determined by the developer of them. Designers of context-aware ubiquitous computing systems have to include the ability to dynamically add, change and select the appropriate needed functionality or services [12].There have been many instances of these; context-aware messenger [13], context-aware communication service provider [14], office assistant [15] , context-aware applications which are used in the areas of Internet of Things (IoT) [8], and many ambient intelligent context-aware systems and applications [16, 17] can be considered as potential applications of context-aware systems.

5. Evolution of Context-aware Computing

Context-aware systems can be characterized by the satisfaction of requirements for 5 R's [18]: "the 'Right' Information, at the 'Right' Time, in the 'Right' Place, in the 'Right' Way to the 'Right' Person". The word 'right' is put into quotes because in most cases there is no simple 'right' or 'wrong'.

- The 'right' information involves task modeling; and maps and makes inference about habitual user behavior and activity pattern even if the sensory data is incomplete;
- The 'right' time concerns with choosing the right moment to deliver information which can distract the user. It may involve prioritizing between interruptions and user discretion [19];
- The 'right' place makes use of location based context information [20];
- The 'right' way requires choosing appropriately between multiple ways of service providing. E.g. choosing font sizes for people with eye sight problem [21];
- The 'right' person refers to developing accurate profile of users so to as to differentiate services according to user model [22].

It is also noteworthy that there might be overlapping within the requirements, for example a geographical context might be associated with a corresponding time zone or season. Consequently, to satisfy the above requirements, context-aware system gathers raw data through the sensors [23]. Sensor drivers are hardwired into the system. The system also interacts with other systems through API. After data is gathered, preprocessing phase will be conducted. In this phase tasks such as reasoning, interpreting, extraction and aggregation are done. The next phase is storage which consist public interface to the client and synchronization of data. Finally, the applications component is used to facilitate actual reactions on various events and context instances are implemented in order to provide desired services.

6. Context-aware Systems Architecture

Architecture refers to how the components of a system are organized and how the components are related to each other [24]. A comprehensive architecture for context-aware systems can facilitate the envisioning, designing and implementation of context-aware systems. There are a number of factors which affect the architecture of Context-aware systems. The nature of sensors and their intended location, scale of the intended system, the type of target applications, mobility concerns and the limits of computing and communicating resources are some of the factors [25]. Moreover, the methods of context acquisition and representation have also a considerable effect on the design and architectural layout of the components.

A number of architectural approaches [26, 27, 28] prefer to apply a layered view of Context-aware systems. Knappmeyer et al. [25] observe that: "Context-aware systems are usually designed as middleware adopting a layered design – each functional layer hiding the details of the underlying layers."

They also outlined the advantages of these approaches where varied sources of sensory data and different requirements of applications is served well by a layered approach which encapsulates the complexities and organize the functionalities of each layer. This architectural view is also analogous with the life cycle of context data. Context data usually goes through the stages of acquisition, formatting, aggregation, organization and communication [25]. A sensory data access oriented view of architecture is provided by Balduaf et al. [23]. They identify between context-aware designs: which allow a direct access to sensory data, which use a middle-ware to acquire a managed sensory data, and finally approaches, as a further decoupling of the middle-ware tactic, which employ a context server to provide sensory data. In a more holistic view of architecture as a design, Hong et al. [29] recognize: (1) Network Infrastructure Layer, (2) Middleware Layer, (3) Application Layer and (4) User Infrastructure Layer.

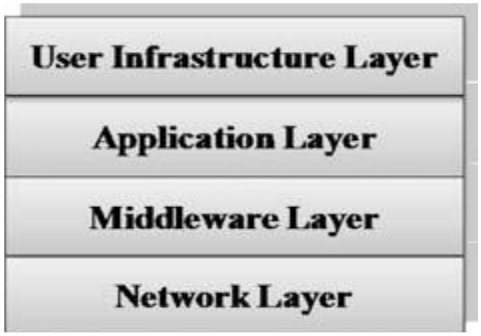

Fig. 1. Abstract layer architecture of context-aware systems. Hong et al., 2009

Context-aware systems and frameworks have also been characterized by design and deployment based architectures. Object-oriented approaches to context-awareness employ object to encapsulate Context-awareness functions and share information by communication between objects. These approaches also make use of inheritance and polymorphism to facilitate the required extensibility of context-aware systems. Event-driven approaches like SOA have also been chosen for their propensity to mirror the stimuli-response world of context-aware applications [30]. Components designated as context consumers can register to be notified, when events which happen in the environment are captured by context producers. SOA based architecture is well positioned to be the dominant approach for context-aware systems because of the increasing pervasiveness of cloud computing infrastructure. Other types of architectural styles like, blackboard based architecture are used in a manner which a central repository of context can be updated by different sensors. It can also provide an access point for components which use context information. In some cases, the distributed nature of context-aware systems is one of the reasons where, a distributed clients with a centralized server, type of architecture is used by some frameworks to circumvent the communicational /computational limitations of distributed sensors. Other more specialized types of architectures can be observed in some of the Context-

aware frameworks; for example Gaia [26] uses an extended MVC pattern, and The Context Toolkit [31] employs a widget based style. In conclusion, even though there are numerous architectural approaches, the most common theme in the architectures and frameworks is the separation between context acquisition and storage, and the application which provides service to the user by accessing the context information.

7. Context-aware Systems Frameworks and Design

Frameworks offer support for the building of Context-aware systems by providing reusable design resources which facilitate the rapid development of Context-aware application [32]. Moreover, a context-awareness framework supports context-aware applications by giving guidance and provisions for: context representation and storage, access of context, context source identification, etc. [33]. Lie in [32], pointed out that Context-aware frameworks should support the requirements of: being lightweight, extensibility, robustness, Meta-Information and context sharing. There have been a number of Context-aware frameworks provided by researchers since the early days of Context-aware computing. Early efforts like Context Toolkit framework by Dey et al. [31] used widgets to access sensors, and attribute value tuples supported by XML schema for context modeling. Gaia [26], another framework for smart spaces applies concepts from operating system like I/O access and operations to facilitate communication between objects which correspond to active spaces. Another framework for intelligent space which is based on distributed agents is exemplified by CoBra [34]. A central broker maintains common context representation for agents which can be devices, services or web services. A context-aware framework tailored for mobile devices is provided by the Hydrogen project [27]. It provides a layered framework with the capacity to differentiate between local (information a device knows) and remote context (information from another device); and enables sharing of information through peer-peer communication. CORTEX [35] is also a mobile based approach albeit using object oriented principles for its architecture. It is primarily based on Sentient Object Model; which encapsulates; Sensory capture, Context hierarchy and Inference engine. More recently, there have also been frameworks which advocate Service Oriented based implementations for context-aware systems like CoWSAMI [36] that give provision for dynamic service discovery through communication protocols such as SOAP and WDSL.

8. Context Modeling Approaches

Context-aware applications need to interpolate information that are gathered from different sources with varying quality in order to adapt to changes. This feature of context-aware applications inevitably makes development process complex [37]. To simplify and introduce greater structure into the task of developing context-aware applications a number of context models have been introduced.

8.1. Key-Value models

Key value models are one of the earliest and simplest approaches which use simple data structure for context modeling [23, 37]. In this approach context information is modeled as key-value pairs and the values are provided to application environment variables. This mechanism allows matching algorithm for easier lookup [23, 25]. Such an approach can be observed in [5, 38]. Even though Key-Value models are easier to manage they are not suitable for efficient context retrieval and complex contexts [25].

8.2. Markup scheme models

Markup scheme models represent contexts by markup schemas such as XML [37]. These models incorporate a hierarchical approach comprising of markup tags with attributes and content [23]. Profiles based on serialization of a derivative of Standard Generic Markup Language (SGML) are considered as a typical representative for markup scheme models [39]. User Agent Profile (UAProf) (Open Mobile Alliance) [40] and Capabilities/Preferences Profile (CC/PP) [41], which are based on Resource Description Framework Schema (RDF-S) syntax, are the most popular examples of markup scheme modeling.

Markup scheme models are good for handling heterogeneity and incompleteness. However, these models lack expressive structure and have weak formalism. In addition, they are Insufficient for capturing context information, relationships, dependencies, timeliness, and quality of context information [37].

8.3. Graphical Models

In this approach contextual information is expressed using graph data structures and richer data types. Unified Modeling Language (UML) [42], a well-known general purpose modeling instrument, is used to model context [43, 44]. This is shown for instance by Gámez et al. in [45], where the context information for wireless sensor networks is modeled using the UML. Another example of graphical modeling approaches is a context extension of Object-Role Model (ORM) [46] introduced by Henricksen et al. [47].

Graphical Models are more expressive than key-value and markup scheme models as they allow relationships to be captured into the context model. Furthermore, as graphical modeling is well-known it is easy to learn and use. However, lack of formalism for on-line automated access and support for distributed context model poses a challenge [44].

8.4. Object oriented models

Object oriented context models employ object oriented approach (encapsulation, inheritance, reusability) into context [23, 25]. In this approach, details of context

processing and representation are hidden to other components. Consequently, contextual information can only be accessed through well-defined interfaces [23, 39]. Modeling context using object oriented models offers the powerful capabilities of object orientation. However, the complexity of the models requires high computation power which might not be supported by low-end hand-held device [43]. Such an approach can be observed in [48, 49].

8.5. Logic based models

In logic based models context information is represented as facts, expressions and rules [39]. A logic based system made it flexible to add, update and delete contextual information in terms of facts and a reasoning process is applied to drive new facts based on existing rules in the system [23]. A variety of applications have adopted this model for instance in Ranganathan et al. [50] used first-order predicate logic to model context for their context-aware chat program. Logic based context models have a strong formality and expressive structure. However, handling heterogeneity and incompleteness are still lacking [44].

8.6. Ontology based models

In ontology based models context is organized into ontologies using semantic technologies like RDF and Web Ontology Language (OWL) [25, 43]. Ontologies are descriptions of concepts and their relationships [23]. There are several ontology based approaches available for context modeling among them CONON [51], ULCO [52] and COBRA-ONT [53] use OWL as the base language. Other approaches can be seen in [37, 39].

Due to their formal expressiveness, the ability to handle heterogeneity and the ability of applying ontology reasoning techniques ontology based models are regarded as the most promising methods to model context [23, 44]. However, it can computationally intensive and time consuming when searching and processing context in large volume of data, in particular in low resource embedded environments. Moreover, their capability is limited in handling uncertainty and unavailable data [25, 44].

9. Using MS Word

Context-Aware applications in tandem with UbiComp systems are being advanced to solve many real world problems. In the health sector, specifically in ambient assisted living (AAL), there have been various efforts to improve the lives of people with disabilities and chronic medical conditions. Forkan et al. [16] developed a generic scalable framework, known as “CoCaMAAL”. CoCaMAAL supports body sensor networks integrated with AAL environments, by using cloud computing and service oriented architectures with context management system. These components help the model to provide “assisted living service” and “unified context generation”, to

aggregate raw sensor data and to select services appropriately. CoCaMAAL provides medical support and monitoring services effectively and efficiently for vulnerable groups of the community. It helps users, patients and healthcare professionals, to gather, access, process, envisage, record, distribute and look for large quantity of data from various AAL systems and service providers without any difficulty. It also functions as decision support systems.

Location based context-aware applications for mobile users are one of the dominant applications for context-awareness [44]. Examples of such projects include smart health (s-Health) application [54] and iConAwa project [55].

Patsakis et al. [54], applied the concept of s-Health coined by Solanas et al. [56] to develop a mobile application that leverages smart cities' infrastructure for personalized medical services. The mobile application aims at minimizing health related risks for patients with respiratory related conditions by determining the best route while they are travelling. The application takes user's current location and destination, possible routes for the user's destination determined by Google Directions API, user input for type of measurement he/she is interested in and data collected from sensors between the user's current location and destination as inputs and calculates the best route.

Another location based context-aware application (but tailored to tourism) iConAwa, is given by Yılmaz and Erdur [55]. iConAwa is an intelligent context-aware multi-agent system which provides users with context-aware information that are acquired through ontologies using rule-based reasoning. iConAwa combines the user's current location information and user's personal information stored in context ontology to determine a list of points of interest and nearby users which are suitable for the user's context. Points of interest which can be an activity place, museum, historical/cultural place, restaurant, Movie Theater, shopping store, etc. are displayed for the user on a map after they sorted according to the match degrees of the user's interest. The system also allows users to send messages to nearby users with same interests.

There have also been a number of recent context-aware applications in education. One recent work on this issue is described by Gómez et al. [57]. Context-aware adaptive mobile learning based systems usually integrate wireless, mobile, and sensor technologies to adapt their operations to the current context of a learner without explicit intervention by the learner. Hence, such system can sense, track, detect and monitor the real-world situation of the learner using sensing technologies and then with communication capabilities present the learner with learning guidance, supplementary materials, feedback and advice through a mobile devices. Context-Aware mobile role playing game (CAM-RPG) is designed to encourage pupils to use mobile educational systems [58]. It uses role playing and story generation based on location awareness to engage students in their quest to complete tasks. The system is based on multi-agent architecture. According to the developers the reason for the choice is because of agents' ability to complete different self-sufficient tasks on different devices. Context information is stored in Personal Experience and Knowledge structure database; a database access agent makes interaction with this module possible by servicing requests from other agents like Map holder and Story teller. The other significant agent, player agent, is the only one responsible for the interaction between the user and other agents. A student chooses a role and the game generates learning activities applicable to the role; the student then can proceed by registering objects necessary for the session using

a camera. The game tracks the progress of the student and progressively presents learning materials.

10. Conclusion

In this paper we have attempted to discuss Context-aware systems by examining different notions and definitions of Context and Context-awareness in the literature. Different characteristics of Context-aware systems are identified; and particularly the 5Rs requirements for context-aware systems: the 'Right' Information, at the 'Right' Time, in the 'Right' Place, in the 'Right' Way to the 'Right' Person, was found to be a helpful framework in illuminating the features of context-aware systems. In light of these requirements, we identified the components and functions which enable typical context-aware system to satisfy them. Physical, logical and virtual sensors are used to monitor relevant changes in the computational or/and physical environment of the user. The information from diverse set of sensors is filtered or transformed and stored formats which facilitate efficient retrieval. This is done by a context-modeling component of the system. Key-Value models, ontology based models, Graphical based models, logic-based models, Multi-disciplinary models are some of the Context modeling approaches employed. The stored context can be aggregated to form a higher level context which can be shared across applications.

The number and choice of components which could make up context-aware systems drives architectural considerations. Depending on the requirements of the systems, the platform on which they are to be deployed and quality requirements, numerous architectures for Context-aware systems are proposed and implemented. Many approaches chose a layered view of architecture because of its suitability to encapsulate diverse devices and functionalities. Agent based, object oriented and service oriented architectures are some of the more common approaches identified by this study. We think the new paradigm shift to cloud computing can provide a sustainable infrastructure to SOA based context-aware systems because of equivalences in both (Context-awareness and SOA) event driven paradigms. Moreover, several Context-aware frameworks and middleware which are based on these architectures are realized to facilitate the implementation of context-aware applications.

Context-awareness constitutes an important part of ubiquitous computing and modern HCI designs. Many applications from these fields have applied the functionalities of context-awareness. Particularly, Ubicomp systems for education, manufacture, health, agriculture, tourism etc., sampled in this paper use context modeling and reasoning techniques, often with provided frameworks. Hence, context-aware applications can be readily applied in Ethiopia's Tourism industry which is characterized by scarcity of information which can direct Tourists to appropriate destinations and service providers.

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