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# FUTURE CHALLENGES IN CONTEXT-AWARE COMPUTING

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**ABSTRACT**

Context-awareness is the ability of computing systems to acquire and reason about the situational context and adapt application accordingly. Context-aware system start with gathering of raw, low-level contextual data, interpret the raw contextual data into high-level interpreted context, reason the interpreted context to derive implications and adapt the application behaviour on the basis of the implications. This article identifies the research challenges in context-aware computing and elaborates the context-aware process with the issues in each stage. Some of the current application domains of context-aware computing are also listed.

**KEYWORDS**

Context-Awareness, Future Challenges, Technology Strategies.

## 1. CONTEXT AND CONTEXT-AWARENESS

The ability of smart devices and smart applications to identify current operating conditions or context and adapt their behaviour on the basis of the context is termed as context awareness. The context information is a set of parameters defining the surrounding situation that emerge in the moment. The entities involved in a context setting include the persons, the objects and the computing resources present in the environment (Dey, 2001). Humans being a very complex architecture are quite successful at conveying their thoughts to each other in an implicit natural way. This is because humans communicate through rich languages as well as gestures and expressions. Modern ubiquitous computer systems lack an automatic mechanism of inferring information like humans do. By improving the ability of computers to gather context and infer it, the richness of communication in human-computer interaction increases that results in a more powerful and more useful computational environment.

## 2. RELATED RESEARCH

The pioneer context-aware systems like Active Badge (Want, 1992) and Xerox PARC (Schilit, 2002) are call forwarding systems that use only location as their context information. Tour guide systems like GUIDE (Chaverst, 1998) and Cyberguide (Abowd, et al, 1997) evolved the concept of context by adding temporal information in addition to spatial information. These systems are primarily context-aware application designed to provide better and customized services to their users. The Context Toolkit (Dey and Abowd, 2000) provides an Application Programming Interface (API) to develop context-aware applications but is limited to tightly coupled 'Widgets' that access the hardware context sensors.

The recent context-aware systems are context-aware frameworks that facilitate smart service discovery, delivery and adaptation through rich ontology based context representation. This rich context ontology considers all parameters relevant to an interaction as the context. Gaia (Roman, et al, 2002) ( a CORBA based distributed operating system) and CAMUS (Riaz, et al, 2005) a JINI based service oriented framework) provides context-aware service delivery limited only to context-aware applications. CoBrA (Chen, et al, 2003) is a mobile agent based framework that dispatches mobile agents to gather context information from the sensors in the environment. CAPEUS (Samulowitz, et al, 2001) uses a document based approach that exchanges context-aware packets that describe service requests. All these systems are either context-based applications or context-aware frameworks that facilitate context adaptation processes. The context interpretation is carried out as per the requirements of the adaptation process.

# 3. RESEARCH CHALLENGES OF CONTEXT-AWARENESS

Some of the future research challenges (Winograd, 2001) of context-aware computing are listed in Table 1..

Table 1. Research Challenges

| Research Challenge | Description |
|---|---|
| Defining Context | The context is a vast concept that encompasses all possible parameters identifying a situation. The applications and frameworks must define context and identify relevant parameters limited by their scope. |
| Context-Aware Models | The context-aware architectures are still in their infancy. Most of the models and architectures are task specific. Standards and support tools are yet to be developed. |
| Sensing Context Data | Context sensing devices are undergoing development process. Wearable computing is a sub-field of context-aware computing that realizes the design and development of personalized context sensors. |
| Predicting Context Data | Lack of sensors requires prediction of context data on the basis of history. Probabilistic techniques like Bayesian models can be used to predict context. |
| Representing and Storing Context Information | The context representation scheme should facilitate the context interpretation and context sharing processes and follow a standardized structure. |
| Inferring Context and Adapting System Behaviour | The interpretation of context and adaptation of service behaviour is a prime challenge of context-awareness. The interpretation process is adaptation oriented. |
| Evaluation of Context Aware Systems | Evaluation criteria need to be defined for verification of context-aware systems. Measures for quality control and end-user satisfaction of context-aware products need to be outlined. |
| Privacy Control | The contextual data of the participating entities is private information and must be secure from exposure to malicious entities while in transit or at storage device. |

# 4. COMPONENTS OF CONTEXT-AWARE SYSTEM

Figure 1 shows a context-aware system in illustrated form. A context-aware system has the following distinct components that perform specific tasks.

## 4.1 Context Acquisition

Any context aware system starts with the sensing of contextual data and subsequent gathering of the contextual data. Both of these phases may include the exchange of identities of the participating entities and establishing of secret keys for future communication. The context is sensed through the sensors that are locally built into the mobile devices as well as present in the environment and is gathered by the acquisition modules of the context-aware systems. The data generated by the sensors is dynamic and is generated in high quantity.

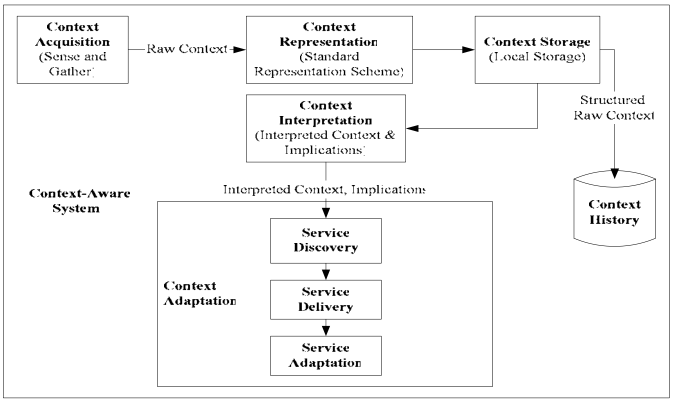


Figure 1. Components of context-aware system

## 4.2 Context Representation

The gathered contextual data requires a representation scheme that provides efficient structuring and retrieval. This gathered data is represented in a standard format so that it assists the sharing process. The structure of the shared context must be the same across the smart space although it can have different internal structure. The *context space* is a hyper space of context data where a single point in the context space is a set of all attributes of the context data that identifies a situation. The issues in context representation are discussed is Table 2.

Table 2. Context Representation Issues

| Issue | Description |
|---|---|
| Standard Representation Schemes | The representation scheme should preferably be an industry standard, all-across the smart space so that it can easily be shared among context-aware systems. Extensible Markup language (XML), Resource Description Framework (RDF) and Web Ontology Language (OWL) are tag-based accepted standard formats for representing contextual data. |
| Context Transformation | In case of absence of a standard representation scheme context transformation mechanisms should be designed to translate contextual data between the standard formats. |
| Authentication | Identities of the context-aware systems involved in inter-communication need to be authenticated before starting exchange of data. |
| Confidentiality | Exchange of data needs to be secure from the malicious objects requiring confidentiality. Communication can be established using either public or private cryptosystems. |
| Fuzzy Variables | The contextual parameters are a set of fuzzy variables and require the use of fuzzy logic. |

## 4.3 Context Storage

The gathered and represented context data is stored on local storage. The storage process allows the system to maintain a history of context that is used to identify preferences of the entities. The constraints in storage processes are discussed in Table 3.

Table 3. Constraints in Storage Processes

| Constraint | Description |
|---|---|
| Storage Requirements | The context data is large and requires a sufficient memory and fast retrieval mechanisms to achieve memory related efficiency. The dynamic nature of context requires that the context data be consistent throughout the smart space. |
| Purging Outdated Context Data | The outdated and old context data must be purged but its effect should be maintained e.g., a month long history of food preference of Alice should not be completely stored although the |

| | |
|---|---|
| | preference should be stored as most recent to beyond a fortnight. Artificial Neural Networks (ANN) provides a smart way to preserve the preferences as weights. |
| Predicting Context | In the absence of sensor data the context data is predicted through history. Probabilistic techniques are used to approximate the contextual data of the missing variables. |
| Encrypted Data | Contextual data is stored in encrypted form at local storage areas to avoid exposure to unauthorized and malicious entities. Encrypted data is shared amongst the participants in areas of high risk. |

## 4.4 Context Interpretation

Interpreting raw, low-level gathered context to meaningful, high-level interpreted context is the first phase of the interpretation process. The interpreted context provides us a high-level view of the context data and is used for adaptation process. The interpreted context consists of subsets of the gathered low-level context data. Each entity has a number of subsets that identify the context of that entity. The set of interpreted contexts of all entities in an interaction identify the context of the interaction. In the second phase implications are then reasoned from the interpreted context. These implications provide instructions for adaptation process and applications. The interpreted contexts are categorized as ‘What’, ‘Who’, ‘Where’ and ‘When’ contexts. These contexts are the subsets of the gathered contextual data and provide identification, activity, spatial and temporal information. Some of the research issues in interpretation process are: approximate interpretation of context; multiple context hypotheses; searching in context space.

The extent of adaptation provides a guideline for the type of interpretation we are interested in. For example, if the task is to search for the best service available then the interpreted context must be based on identifying the contexts of the services and the user present in the smart space while it is not feasible to gather and interpret the context of the entities present in adjacent environments. On the other hand, if the task is to identify a best route then the context of the intermediate environments on the route should be interpreted. The issues in interpretation process are discussed in Table 4.

Table 4. Issues in Interpretation Process

| Issue | Description |
|---|---|
| User Intention and Biases | The user intention and biases can modify the interpretation mechanism. The interpretation should take into account the user mood and preferences before adaptation. The intention and preference is predicted through history. |
| Scope | The context-aware systems interpret the context on the basis of their scope. A context-aware phone needs not to interpret the context of irrelevant parties like all people walking down the street. Whereas, a context-aware laboratory needs to gather contexts of all people working on different experiments. |
| Context Reasoning Context | Interpreted context describes the situation at a high-level of interpretation. This interpretation can be reasoned to infer implications. For example, if the context of a scholar engaged in research activities is busy for the past two hours then it may imply that the scholar needs a break and would like to have some coffee with sandwiches. This reasoning provides a basis for the discovery and the consequent adaptation of services. |

## 4.5 Context Adaptation

The adaptation process starts as soon as the interpretation and reasoning of the contextual data is completed. The adaptation facilitates the users in different everyday tasks by employing decision making techniques. Context adaptation can be categorized into the following directions:

### 4.5.1 Service Discovery

The contextual data is used to discover services for the user. The interpreted context provides the basis for selecting the appropriate service among available services. The selection process also selects the most appropriate service in case multiple services of the same type are present in an environment. Services requiring other services for information, etc. discover the appropriate service on the basis of load and cost as part of their context preference.

### 4.5.2 Service Delivery

The selected service is then delivered to the user. The mobile devices mediate directly with the service and negotiate parameters that include session, cost, paths, protocols, policies and lease times. The delivery process selects a uniform interface that is compatible with the participating devices.

### 4.5.3 Service Adaptation

The contextual data is used to adapt the service behaviour as well as the device behaviour. Context adaptation can be event-based or event-less. Event-based adaptation is carried out when an external event occurs. Event-less adaptation is carried out in the absence of external event when internal reasoning suggests access and adaptation of services.

## 5. CONTEXT AWARE APPLICATION DOMAINS

Context-Aware computing promises to provide a better future in everyday computation. The application areas are primarily smart spaces where users can interact with each other and traditional systems using their mobile devices. Some of the context-aware application domains are homes, offices, hotels, community areas, healthcare, campuses and military applications.

## 6. CONCLUSION

Context-awareness is an emerging field in the realm of pervasive computing. Potential beneficiaries of context-awareness range from homes to workplaces and from civil domains to military domains. Context-aware systems sense, gather, represent and interpret situational context. The interpreted context is used to provide smart service discovery and delivery and to adapt application behaviour. Context-aware systems utilize the implicit perception of context found in humans and will revolutionize the way entities interact with each other.

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