# Context-Aware Cognitive Agent Architecture for Ambient User Interfaces*

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**Abstract.** An ambient user interface is a set of hidden intelligent interfaces that recognize user's presence and provides services to immediate needs. There are several research activities on user interfaces and interactions which combining VR/AR, ubiquitous computing/ambient interfaces, and artificial intelligence. However, real-time and intelligent responses of user interfaces are still challenging problems. In this paper, we introduce the design of Context-aware Cognitive Agent Architecture (CCAA) for real-time and intelligent responses of ambient user interfaces in ubiquitous virtual reality, and discuss possible scenarios for realizing ambient interfaces. CCAA applies a vertically layered two-pass agent architecture with three layers. The three layers are AR (augmented reality) layer, CA (context-aware) layer, and AI layer. The two passes interconnect the layers as an input or output. One of the passes of each layer is an input path from a lower layer or environmental sensors describing a situation. The other pass is an output path and deliveries a set of appropriated actions based on the understanding of the situation. This architecture enables users interact with ambient smart objects through an ambient user interface in various ways of intelligence by exploiting context and AI techniques. Based on the architecture, several possible scenarios about recognition problems and higher level intelligent services for ambient interaction are suggested.

**Keywords:** Ambient user interface, ubiquitous virtual reality, context-awareness, augmented reality.

## 1 Introduction

According to the changing of computing environments, user interfaces and interaction ways have changed radically. Computing paradigms such as ubiquitous virtual reality, ambient intelligence, ubiquitous/pervasive computing are proposed in order to fulfill requirements for the new computing environments [1,2]. An ambient user interface is a set of hidden intelligent interfaces that recognize user's presence and provides services to immediate needs [3]. With an ambient user interface, users are allowed to interact with a whole environment with expecting the highly intelligent responses.

Many researchers expect that lots of novel interfaces and interaction methods would be appeared by combining visualization/user interaction techniques (AR/VR),

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context-awareness, and artificial intelligence (AI). These show that AR/VR can be combined with AI as ambient interfaces in ubiquitous computing environments. AI-BAS (Adaptive Intent-Based Augmentation System) is a framework for improving tracking and display technology in order to minimize registration errors [4]. The idea is that if a system could understand purpose of augmentation, it could reduce registration error. DWARF is a framework for developing augmented reality system with a set of intelligence module [5]. It was designed under the assumption that AR systems are working in ubiquitous computing environments. ARFaçade is an AR storytelling system originated from Façade which is the first working storytelling system [6]. ubiAgent shows several AR agent applications and suggests future research directions in AR, AI, and ubiComp [7]. ARGardening and CAMAR (Context-Aware Mobile Augmented Reality) could be one of representative researches of user interfaces in ubiquitous virtual reality [8,9]. However, real-time and intelligent responses of user interfaces are still challenging problems.

In this paper, we introduce the design of Context-aware Cognitive Agent Architecture (CCAA) for real-time and intelligent responses of user interfaces, and discuss possible scenarios for realizing ambient interfaces. It applies a vertically layered two-pass agent architecture with three layers [10]. The three layers are AR (augmented reality) layer, CA (context-aware) layer, and AI layer. The three layers are classified according to their processing complexity. While higher layers are doing their processing, AR layer produces output in real-time. A higher layer makes up for the weak points of a lower layer. For example, CA layer could give a processing result for improving recognition performance in AR layer.

This architecture enables users interact with ambient smart objects through an ambient user interface in various ways of intelligence by exploiting context and AI techniques. It is designed to guarantee real-time and intelligent responses of the ambient interfaces. Based on the architecture, several possible scenarios about recognition problems and higher level intelligent services for ambient interaction are suggested.

This paper is organized as followings. In Section 2, we briefly introduce background about ambient user interfaces in ubiquitous virtual reality. Context-aware Cognitive Agent Architecture is presented in Section 3, and problems in ambient interfaces and possible scenario is in Section 4. Conclusion and future works are discussed in Section 5.

## 2 Ambient User Interfaces in Ubiquitous Virtual Reality

Ubiquitous Virtual Reality (Ubiquitous VR) has been researched in order to apply the concept of virtual reality and its technology into ubiquitous computing environments [1,2]. The idea comes that the limitations of virtual reality could be improved through the new computing paradigm, on the other hands, the problems when we realize ubiquitous computing (ubiComp) or ambient intelligence (AmI) could be solved by conventional virtual reality technology. Kim et al. discussed how VR and ubiComp help each other to overcome the limitations [11]. VR is still far from users in Real world and it has no killer applications in our daily lives. UbiComp is novel paradigm and many technical problems are raised currently such as user interfaces, context-awareness with artificial intelligence, collaborative networking, resource sharing, and others. Those problems has been researched and discussed in VR research field.

Lee et al. presented three key characteristics of Ubiquitous VR based on reality, context, and human activity [2]. Reality-virtuality continuum was introduced by Milgram. According to Milgram's idea, real world is 'any environment consisting solely of real objects, and includes whatever might be observed when viewing a real-world scene either directly in person' [12]. Context is defined as 'any information that can be used to characterize the situation of an entity, where an entity can be a person, place, or physical or computational object' [13]. Context can be represented as static-dynamic continuum. We call static context if it describes information such as user profile. On the other hand, if it describes wisdom obtained by intelligent analysis, it is called dynamic context. Human activity could be classified into personal, group, community and social activity. It can be represented a personal-social continuum. Ubiquitous VR supports human social connections with highest-level user context (wisdom) in mixed reality. Hence, Ubiquitous VR was described as *socially wise mediated reality*.

An ambient user interface is a set of hidden intelligent interfaces that recognize user's presence and provide services to their immediate needs [3]. It assumes that things necessary for daily life embed micro processors, and they are connected over wired/wireless network. It also assumes that user interfaces control environmental conditions and support user interaction in a natural and personal way. Hence, an ambient user interface is a user interface technology which supports natural and personalized interaction with a set of hidden intelligent interfaces.

An ambient user interface in Ubiquitous VR has different features from other user interfaces. It has to cover real and virtual space (mixed reality). Hidden intelligent interfaces are not easy for human to be aware of their existences. Augmented reality technology could help solve this problem [9]. It should have not only simple input/output functions, but it should also support more abstract levels of computation and representation. Thus on the highest level of abstraction, the ambient user interface could understand user-centric contexts so as to show intelligent responses [14]. Ambient user interfaces in Ubiquitous VR should help users adapt the application to their personal needs intuitively and personalized way without interrupting their tasks. Without considering a user's situation, applications always provide the same interfaces to all users.

## 3 Context-Aware Cognitive Agent Architecture for Ambient User Interfaces in Ubiquitous Virtual Reality

### 3.1 Requirements

In order to develop an ambient user interface in Ubiquitous VR, we need to combine augmented reality user interfaces, context-aware middleware, and artificial intelligence technology. The followings are requirements.

1. Processing Time
   - It is necessary that augmented reality user interfaces should display its contents and allow user interaction in real time. It requires at least 30 f/s.
   - It requires at least one second for acquiring, integrating, and processing context [18].
   - AI algorithm requires enough time for reasoning and planning.

2. Complementary cooperation
   - It requires context-awareness to enhance augmented reality user interface and its contents.
   - It requires artificial intelligence technology for effective and accurate context-awareness.
   - It requires user profile for providing personalized services.

### 3.2 Context-Aware Cognitive Agent Architecture for Ambient User Interfaces

Cognitive Agent Architecture for virtual and smart environment was proposed for realizing seamless interaction in ubiquitous virtual reality [10]. It is a cognitively motivated vertically layered two-pass agent architecture for realizing responsiveness, reactivity, and pro-activeness of smart objects, smart environments, virtual characters, and virtual place controllers. Direct responsiveness is bounded to time frame of visual continuity (about 40 msec). Immediate reaction is requested from user's command and it could take more than 40msec, with a second. Pro-activity is schedule events and it could take any amount of time, five sec, a min., or a day.

Two main types of tasks have to be handled in cognitive agent architecture. Context integration is the task of deriving aggregated and abstracted information about a situation from sets of singular data, particularly, sensory data and facts. Context management is the task of invoking services/actions appropriate in a context with appropriate contextual information.

Context-aware Cognitive Agent Architecture (CCAA) is designed for real-time and intelligent responses of ambient user interfaces based on context-aware agent architecture in Ubiquitous VR. The three layers are AR (augmented reality) layer, CA (context-aware) layer, and AI layer. This architecture enables ambient smart objects to interact with users in various ways of intelligence by exploiting context and AI techniques.

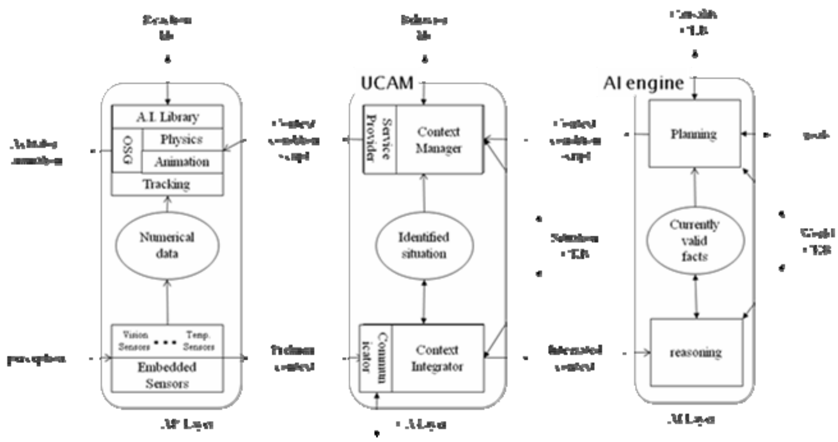


**Fig. 1.** Context-aware cognitive agent architecture for ambient user interfaces in ubiquitous virtual reality

AR (augmented reality) layer is composed of several embedded sensors such as camera, light emission sensors, and temperature sensors, and libraries for augmentation such as graphic rendering, tracking, and physical simulation module as shown in figure 1. It is similar to conventional augmentation reality applications. CA (context-aware) layer is applied to unified context-aware application model (UCAM) [15]. It is a representative context-aware middleware in Ubiquitous VR. Context integrator gathers data and information form embedded sensors and environment through network. Context manager process those information and provide AR layer with final context. AI layer is in charge of planning and reasoning.

The CCAA is designed to guarantee real-time and intelligent responses of the ambient interfaces. The three layers are classified according to their processing complexity. Its two passes interconnect the layers as an input or output. One of the passes of each layer is an input path from a lower layer or environmental sensors describing a situation. The other pass is an output path and deliveries a set of appropriated actions based on the understanding of the situation. While higher layers are doing their processing, AR layer produces output in every 40 msec. A higher layer makes up for the weak points of a lower layer. For example, CA layer could give a processing result for improving recognition performance in AR layer.

## 4 Possible Application Scenarios

Based on the CCAA, several possible scenarios about recognition problems and higher level intelligent services for ambient user interfaces and user interaction are described here.

### 4.1 Recognition of the Large Number of Patterns

As a possible scenario, CCAA can apply to recognize large number of patterns with natural feature tracking algorithm. Let's assume that we need to recognize the thousands of patterns of Digilog Book [8,16] with natural feature tracking algorithm. It means the patterns follows dictionary order. We must face a problem that natural feature tracking algorithm is hard to match current observed pattern with the thousands of patterns in a database. One possible solution is that if we know exact pattern number or possible set of patterns, it might be easier and faster.

Before the first layer detects patterns in a page, the CA layer could find out exact page number of the pattern or possible set of pages from user's reading history. The page layout of Digilog Book can be a clue to find out the exact page number. If we can read the page number at the bottom or top of a page directly, it reduces computational complexity dramatically. On other way, if we know current page, then we can expect that the next pattern will be in the previous or next page. It could not happen that the next pattern is the next several pages.

### 4.2 Recognition of the Same Pattern with Different Meaning

CCAA can apply to reducing search spaces for recognizing objects of ambient interfaces. Let's assume that a mobile device with a camera needs to recognize a specific appliance with company logo to find out its name in a smart home [17]. In a smart home, there are lots of appliances and some of them could be products from the same company with the same logo. In this case, it is a difficult problem to distinguish different appliances with the same logo.

CCAA can give the solution of logo recognition problem. When the first layer detects company logo, it finds several possible candidates from appliances in the room. The second layer of CCAA acquires preliminary context from smart sensors and detects or predicts user's position and orientation from user's behavior pattern. The result goes back to the first layer and it helps the first layer get a correct appliance.

### 4.3 Animated Characters in Ubiquitous Vr

CCAA can apply to animated AR characters which are able to perceive environmental conditions and to select behavior autonomously. Let's assume that we need dancing AR robot in our ambient user interface. We expect that it listens to current music in a room and finds a path to avoid obstacles while dancing in real time. AR Layer performs superimpose a robot character on real world. It puts the robot at a proper position by analyzing coordinates system from video images, and it play animation sequences using animation libraries. The second layer, CA layer, receives music signal from a microphone and analyzes the signal to get the tempo of music. Then it selects a proper animation sequence according to music. The third layer performs planning process based on robot's personality and goal. The results could be translated into values about personality or emotional statues and it could influence the behavior selection mechanism of the dancing robot. Hence the AR robot in an ambient user interface dances according to music tempo and its personality. Figure 2 illustrates how the dancing robot shows intelligent responses being aware of context in real time.

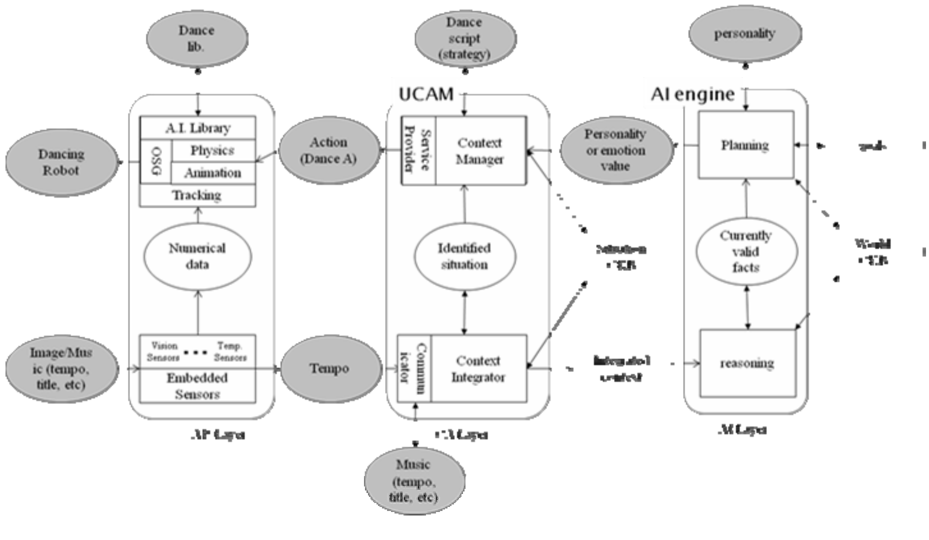


**Fig. 2.** Dancing robot scenario with CCAA

## 5 Conclusion and Future Works

In this paper, we introduced our design of Context-aware Cognitive Agent Architecture and discussed possible scenarios for realizing ambient user interfaces in ubiquitous virtual reality. An ambient user interface in ubiquitous virtual reality has to visualize hidden interfaces in environment and to be aware of a user's and environment context. It also has to process high-level intelligent responses. With the possible scenario, we expect that the context-aware cognitive agent architecture will be applied to ambient user interfaces in future computing environments. For the future works, we have plans to realize this architecture with concrete techniques and application scenarios in ubiquitous virtual reality.

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