Architecting Ambient Intelligence Systems

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ABSTRACT
Ambient Intelligence (AmI) systems refer to ubiquitous computing with focus on human experiences. The AmI ideas are based on the premise that if environment around individuals can be personalized for the current needs of an individual, then the lives can be more productive and enjoyable. New and existing technologies will be used to personalize spaces and experiences in AmI environments. The goal of AmI is to make computing and technology transparent and invisible to the individual. AmI is characterized by unobtrusive and mostly invisible technologies working together, anticipating the needs, and personalizing the environment and experiences for individuals. This paper presents new ideas in developing AmI infrastructure for deploying AmI services. The proposed system architecture is based on characterizing the roles and rights of individuals in the current environment and designing components and services that respond to these roles. The generalized architecture can be used to adapt physical as well as virtual spaces to fit individual preferences. A general architecture is necessary to move AmI from a collection of "cool gadgets" to an ambient and aware service focused on personalization for individuals.

Categories and Subject Descriptors
C.2.4 [**Distributed Systems**]: Distributed applications

General Terms
Design, Experimentation, Human Factors

Keywords
Ambient intelligence, architecture, service composition, personalization.

1. INTRODUCTION
The ubiquitous computing efforts that began in the early 90s were focused primarily on computing [1,2]. The goal was to make computing available everywhere and this led to developments in embedded and mobile computing. The ubiquitous computing efforts did not focus on user interactions perhaps because of the significant increase in complexities involved in dynamic environments and changing roles of users present. Ubiquitous computing efforts have been evolving toward more collaborative environments such as the smart home research efforts [4,5]. The general purpose and user centric AmI paradigm gained prominence with the work of Emilio Aartes at the Philips research labs [3]. Among the well known efforts in AmI research in the US are at MIT Media Lab, the AmI lab at CMU, and the aware home project at Georgia Tech [6,7,8]. The AmI research currently being undertaken is primarily in the form of 'projects' to help understand the underlying research problems and move toward the goal of true AmI. With the challenges posed by this new paradigm, it is expected that true AmI environments will be possible around 2015. Early AmI solutions in closed environments will be possible in the near term.

With Ambient Intelligence the individuals' experiences are at the forefront and technology is pushed into the background. Individuals will interact with the environment naturally and new technologies and interfaces will be intuitive and blend into the user environment. The technologies that will make the dream of AmI a reality are multimedia processing, embedded computing, wireless communications, and complex systems that are configured dynamically with components communicating and collaborating to make user experience better.

The key contributions of this paper include a new AmI framework for generalized AmI services, modeling environments based on individuals' roles and rights, and a generalized model for adapting physical and virtual spaces. This paper presents the ideas we are developing in order to enable personalized environment with limited or no human intervention. Another goal of this paper is to identify the research challenges in enabling generalized AmI services.

2. THE 3Ps OF AmI – PRESENCE, PROCESS, AND PRESENTATION
With the individual experiences and environment personalization at its heart, the AmI framework can be abstracted with three concepts: presence, process, and present.

Presence: Presence information tells which individuals are present in the environment and what objects and services are present in the environment. An individual's presence in space and time provides key insights for personalizing the environments. Individual presence is obtained using means such as video cameras and RFID tags. Objects and services in the

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environment can signal their presence using broadcasts on personal area networks.

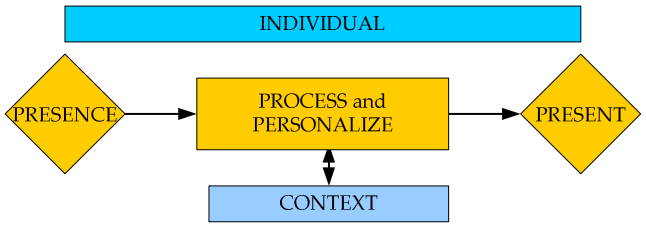

Figure 1. AmI concepts

Process: The process stage is responsible for all the necessary information processing such as media transcoding to suite the right display and sending a message to the sofa to reorganize the room. Process stage can be compute intensive and all processing uses embedded computing hidden from the naked eye. The process stage bridges the gap between the presence information and the presentation environment. Inherent to the process is personalization based on individual preferences and resources available in the environment. The same environment and context may result in different presentation based on individual behavior and preferences. Figure 2 shows the information flow in AmI systems based on this abstraction.

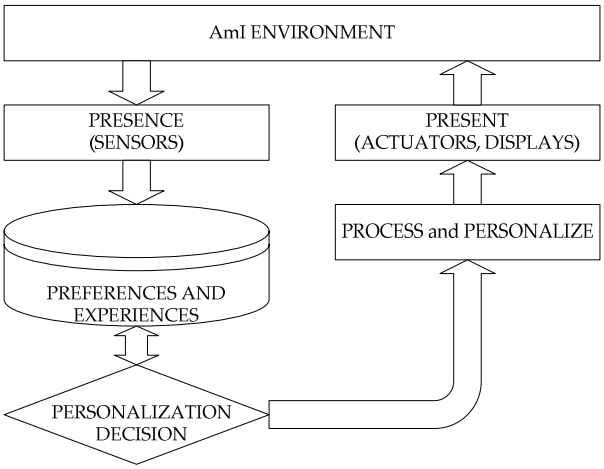

Figure 2. Process flow in AmI

Present: Presentation represents the personalization of the environment based on the presence information and the current context. The context is determined by the space and time the individual is in (home vs. work; business meeting vs. a play date), the preferences of the individual, and the individual behavior learned from past experiences. For example, a video conference call will be displayed on a mobile device when a user is away from the office and the call will use a larger and better quality display when the individual is at the desk. The AmI framework makes the decision seamlessly without user interference. Presentation can affect virtual as well as physical environment; for example, automatically reorganizing furniture (e.g., a motorized sofa) in a room anticipating the open space necessary for a play date with neighbor's children. Since physical reorganization can have serious safety implications, the systems and services have to be consistent and reliable. Consistency is defined as an attribute that does not violate the defined normal behavior for an object.

3. MODELING AmI

The AmI environments require collaborating objects and environments that anticipate individual needs and learn from past experiences. Not all objects in an environment have to collaborate in a given context and the "system" has to determine the objects that are necessary to personalize the experience. Existing work in AmI is primarily early development projects intended to understand the barriers to the AmI promise. Our approach to overcoming the barriers to the AmI is based on the following key elements: 1) modeling the roles and rights of individuals 2) dynamic modeling of presentation spaces and 3) software architecture for dynamic configuration of AmI systems. We are developing a family of related projects that are based on these elements and are designed to enable a deeper understanding and develop a solid foundation for AmI. Formal modeling of AmI environments can enable faster development of AmI systems and software. As we develop AmI projects and begin to model systems, we will gain a better understanding of the systems. It may not be possible to have a simple model of a framework that can be applied to all AmI scenarios. One of the objectives of our work is to be able to understand how generic AmI models are and what domain specific models are necessary are.

3.1 Modeling Roles and Rights

This model is based on the observation that individual behavior and expectations are strongly dependent on the location or where the individual is and the role of the individual. The nature of the environment an individual in, as it pertains to the AmI, can be characterized as either public or private. A public environment implies that the elements (objects and services) of the AmI environment are usually not available for private use and influences the presentation decisions. For example, an individual traveling in a train cannot use the public video displays for his/her personal use. A private environment implies that the environment is likely to have AmI elements that can be trusted and used to personalize the environment better. The presentation decisions are also informed by individual roles: observer or participant. The observer and participant status of an individual grants certain rights to the environment. Usually a participant will have more rights than an observer and hence better personalization. An observer is usually transient in the environment while a participant is persistent for a certain amount of time. The roles and rights can be inferred automatically based on the presence information (e.g., calendar entries and previous history).

3.2 Presentation Spaces

Presentation is the end product of AmI and represents personalization of physical and/or virtual spaces. Spaces also represent natural interfaces individuals will use to interact with AmI services. Our model of the presentation spaces is based on characterizing the presentation spaces as either exclusive or shared. Exclusive spaces can be used to present personal information and shared spaces have to be used only for shared information. For example, AmI enabled meeting rooms allow participants to receive background details of the meeting/participants in exclusive spaces. A mobile phone display is an example of exclusive space and so is the space on the wall

that is not visible to other participants. Presentation spaces change dynamically as individuals move in the environment and realtime characterization of spaces is a challenging problem. The presence information gathered from cameras and sensors becomes essential to such characterization.

4. SOFTWARE ARCHITECTURE

Prior work on software architectures for pervasive computing was reported in [9, 10, 11]. Developing general purpose AmI systems requires component based architecture with support for service composition. Such architecture would allow dynamic configuration of services with available components.

4.1 AmI component (AiC)

AiC (pronounced ice) is an atomic entity in the AmI environment. An AmI component performs one well defined task. A component is analogous to a process and multiple components may be supported on the same hardware device (e.g,. multiple video decoders on the same device). A component falls into one of the three major types: presence, process, presentation. Components communicate over well defined interfaces using know protocols. Two components can be connected if they have compatible interfaces: the output of one component must be compatible with the input of the connected component. A component can support multiple channels, with exactly one input and one output per channel. The type of a component is an inherent attribute of a component and unambiguously identifies the functionality supported by components. Components connect to other physically separate components using wireless networks.

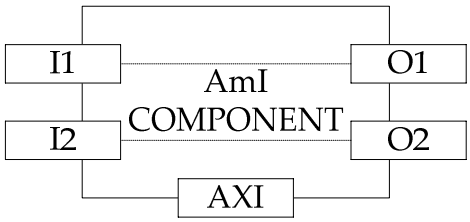

Figure 3. A Generic AmI component

Each component supports a default discovery protocol that allows capability exchange and negotiation among components. Components cannot connect to other components directly and require the services of the AmI ConteXt Manager (AXM). The AXM, with the knowledge of component compatibility, can force connections between components that are not able to automatically determine compatibility.

4.2 Ami Context Manager

AXM is the equivalent of a personal manager and is responsible for communicating with components and establishing communication among components. Each component has a standardized AXM interface to talk to an AXM service. A user can have multiple AXM instances operating in each of the users' persistent environments. A mobile, home, and office instances of the AXM are synchronized and personalize the user environment. With AXM managing component connections, AmI environments can be configured dynamically to perform the desired personalization tasks. An AXM service can be supported on a device such as a mobile device that users carry or it can be available on home or work PCs. Multiple AXMs of an individual coordinate and one AXM takes up the leadership role to coordinate AmI environments for the individual.

4.3 Service Composition

Service composition stage integrates the services offered by a set of components into a coherent service to meet the current presentation needs. All services adapt the environment with goal of improving the user experience. While there has been significant work in the area of service composition, the work on components with realtime constraints and concurrency has been limited. The concurrency aspects of the problem are critical as multiple services are usually run on same hardware to take advantage of the multi-core architectures of the processors. Most of the work on Service Oriented Architectures has been in configuring application distributed environments and some of the models can be adapted for AmI. A scripting language such as a web service orchestration (WSO) script can be used to dynamically configure a service. A set of preferred service configurations can be mapped to a set of commonly occurring contexts and dynamic service configuration can be used if the context's presentation goals are not met by pre-configured services.

5. SCENARIOS FOR AmI DEVELOPMENT

AmI systems are designed to be experienced by individuals and part of developing AmI services is experiencing the AmI environment and feedback the experiences to continue the development. This approach allows for an evolutionary development that gradually overcomes the barriers to AmI services.

Figure 4. AmI development cycle

With AmI promising to make lives better and individuals more productive, the proposed set of projects are designed to demonstrate the use of AmI in our daily lives and understand the challenges in delivering the AmI promise. The projects are based on a Day in the life of Alice and Bob. These scenarios were designed to exercise various aspects of the AmI service design and development.

Alice: Alice is a museum curator at the Metropolitan Museum of Art in New York City. Her day starts by taking a combination of bus and subway to work. After arriving at work, she acts in part as museum administrator and in part as a museum educator. As part of her job, Alice commonly interacts with a variety of objects as she catalogs museum pieces, examines incoming pieces and assists in the creation of new displays, and guides students and tour groups through the museums various showings. Alice finds herself in highly social roles, interacting with both new and familiar people on a daily basis, both in her work as an educator and administrator, and as part of her public commute.

Bob: Bob is a project director at a corporate marketing research firm. Also living in New York, Bob has a house in the Long Island suburbs and is able to enjoy a private commute to work in his car. Once at work, Bob deals largely with a small group of

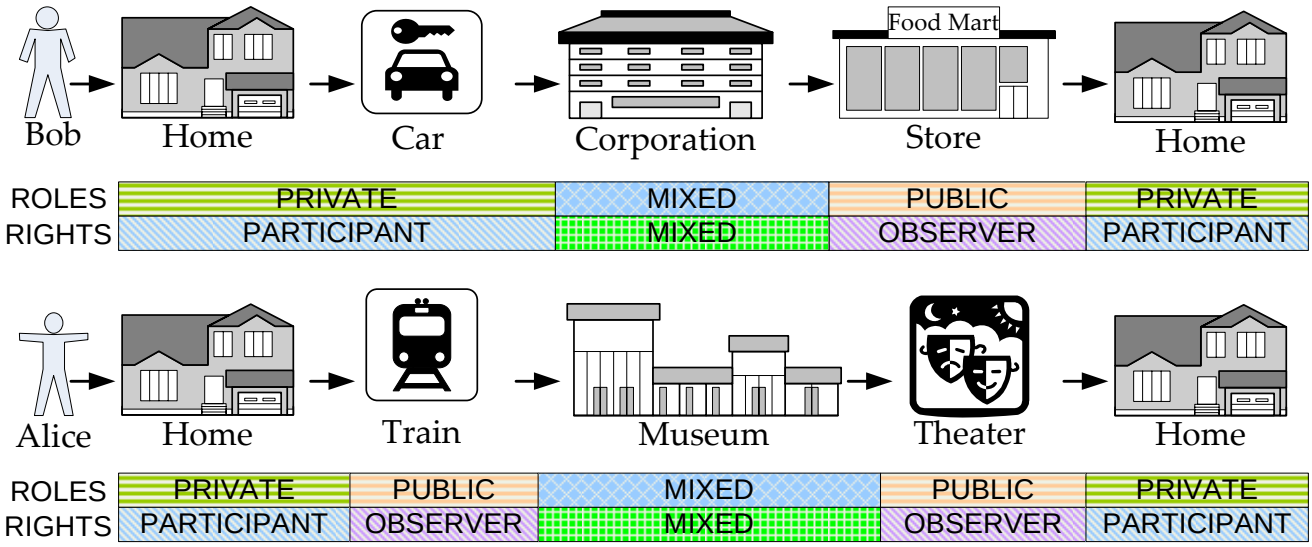

Figure 5. Day in the life of Alice and Bob

analysts and client representatives. The analysts meet once a week in a corporate conference room and Bob often meets with representatives on a personal basis. As a project director, it is Bob's responsibility to respond to proposal requests for research contracts as well, both from new and existing clients. Bob finds himself in a highly private social role, both in his personal dealings with clients and analysts, and in his daily commute from his suburban home.

Both Alice and Bob represent two polar aspects of the private and public relationship with our environment. Because of their work, as well as their personal preferences, they take on very different roles in often very similar types of environments. The default roles and rights that Alice and Bob have are shown in the figure 5. The roles and rights change as they move between environments. Roles default to observer in public spaces and to participant in private spaces. Some of the participant rights can be constrained in confined spaces. By exploring emerging technologies and better leveraging existing ones through the use of AmI, we examine how different roles of behavior within our private and shared environments may be explored and how computing resources may be used in a more intelligent fashion for greater benefit.

6. CONCLUSIONS

In this paper we present a new approach to modeling AmI systems. The proposed is model based on characterizing an individual's roles and rights as the individual moves between environments. These roles and rights change in space and time and an individual's context manager is responsible for coordinating these transitions. The model presented allows personalization of physical as well as personal spaces with in the AmI context. The goal of this work is to develop AmI models that can be used to develop and deploy a large range of services instead of one-off gadgets. This paper is intended to encourage the research community to develop generalizable models and architectures.

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