Ambient Ecologies and Activity Spheres

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Abstract. The vision of Ambient Intelligence (AmI) has already affected our daily life by changing the nature of almost every human activity. Already computation and networking has been embedded into devices and everyday environments, supporting the collection, processing and exchange of information, thus providing, in an increasingly intelligent way, situation and activity recognition, context representation, proactive behaviour, collaboration and resource management. Our environments have been transformed into Ambient Intelligent Environments (AIEs) populated with smart communicating objects, which are able to perceive the environment, act upon it, process and store data, manage their local state, communicate and exchange data. In this paper, we present two concepts that can assist designers and users of AIEs in adopting the new metaphors and adapting to the new requirements. Ambient Ecologies consist of smart objects, autonomous artifacts, portable devices, mobile robots, plain objects, services and people; they form the infrastructure against which user Activity Spheres can be realized. An activity sphere is deployed over an AE and uses its resources (artifacts, networks, services etc) to serve a specific goal of its owner.

Keywords: pervasive computing, activity modelling, ontologies

I. INTRODUCTION

As Ambient Intelligence technology is finding its way into the market, our environments are being transformed into Ambient Intelligent Environments (AIEs) populated with smart communicating objects (artifacts), which are able to perceive the environment, act upon it, process and store data, manage their local state, communicate and exchange data [4]. An artifact can be independently developed and delivered as a unit and offers interfaces by which it can be connected with other components to compose a larger system. Each artifact possesses a digital representation of its properties, which it makes available to other artifacts, and provides functionality in terms of services via well-defined interfaces. Thanks to their "digital self", artifacts can publicize their abilities in the digital space. These include properties (what the object is), capabilities (what the object knows to do) and services (what the object can offer to others) [5].

Up to now, the ways that an everyday object could be used and the tasks it could participate in have usually been determined by its shape. Smart objects overcome this limitation by producing descriptions of their properties, abilities and services in the digital space, thus becoming able to improve their functionality by participating in compositions, learning from usage, becoming adaptive and context aware. This ability improves object independence, as a smart object that acts as a service consumer may seek a service producer based on a service and not object description. The benefit of this compositional approach is adaptability and evolution: a component-based application can be reconfigured with low cost to meet new requirements. The possibility to reuse devices for several purposes - not all accounted for during their design - opens possibilities for emergent uses of ubiquitous devices, whereby the emergence results from actual use. In this way, people are given 'things' with which they can make 'new things'! [7]

II. AMBIENT ECOLOGIES

We use the "Ambient Ecology" (AE) metaphor to conceptualize a space populated by connected objects and services that are interrelated with each other, the environment and the people, supporting the users' everyday activities in a meaningful way. Everyday appliances, devices and context aware artifacts are part of AEs [3].

An Ambient Ecology consists of smart objects, autonomous artifacts, portable devices, mobile robots, plain objects, services and people. AEs are formed as clusters in a worldwide web of things, usually based on some kind of proximity, i.e. location, usage, brand etc. They can be thought of as distributed application platforms, which support the deployment of ubiquitous computing applications; the latter are developed as orchestrations of available services, features and capabilities in order to support user activity. While smart objects and environments focus on information storage and processing, the main feature of an Ambient Ecology is interaction: Smart Objects interact with each other and with the Smart Environment, people interact with the Ambient Ecology components or the applications these support, etc [8].

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Ambient Ecologies differ from other approaches to ubiquitous computing systems in that they require that their components can interact and interoperate, with each other or the environment, yet they only collaborate for a specific purpose, when such a need arises. In other words, AEs serve as the infrastructure within which human activity can be supported by a ubiquitous computing system in an intelligent way. Ambient Ecologies integrate their, possibly heterogeneous, components, into a coherent whole. They exhibit systemic properties such as adaptation and learning; they may also exhibit emergent properties, as a consequence of the interactions among their components.

III. Activity Spheres

As we move from physical to digitized spaces, some of the existing real world components, concepts or metaphors will have to be adapted. The notion of "bubble" has been used to describe a temporary defined space that can be used to limit the information coming into and leaving the digital domain [1]. Based on this notion, we have defined the concept of an "Activity Sphere" (AS), to be both the model and the realization of the set of information, knowledge, services and other resources required to achieve an individual goal within an AmI environment. Inspired by object-oriented approaches, an AS expands the bubble notion to contain not only the data and models, but also the associated processes and other resources that create, use or otherwise affect this data, leading to the specification of autonomous and coherent entities, which can adaptively execute on changing infrastructure. Thus, an activity sphere has a dual hypostasis: firstly, it is a semantically rich model of an entity's specific goal and its associated tasks and a specification of the realization of this model; secondly, it is the orchestration of specific services, data and knowledge that realize this specification within the context of a specific ambient ecology [11].

An activity sphere is deployed over an AE and uses its resources (artifacts, networks, services etc) to serve a specific goal of its owner. It usually consists of a set of interrelated tasks; the sphere contains models of these tasks and their interaction. The sphere instantiates the task models within the specific context composed by the capabilities and services of the infrastructure and its contained artifacts. In this way, it supports the realization of concrete tasks [3].

Thus, any AE is used as the platform, the virtual machine that can realize an activity sphere. However, AEs are highly dynamic structures, the configuration of which may change, for example, because a new device may enter the ecology, or some other may cease functioning. While successful execution of tasks will depend on the quality of interactions among artifacts and among people and artifacts, it is important that task execution will still be possible, despite changes in the Ambient Ecology. Thus, the realization of mechanisms that achieve adaptation of system to changing context is necessary [10].

By including mechanisms that maintain its internal structure, and at the same time support adaptation, the sphere can deal to a certain extent with internal and external changes by adapting its structure and functionality. At the AE level, the system can support the realization of the same activity sphere in different AEs. At the same time, the system can adapt to changes in the configuration of the ecology (i.e., a new device joining, a device going out of service, etc.). At the task level, the system realizes the tasks that lead to the achievement of user goals using the resources of the activity sphere. The artifacts can also adapt to the uncertainties associated with the changes in the artifacts characteristics, context as well as changes in the user(s) preferences regarding these artifacts and their operation [9].

The deployment of an activity sphere over an ambient ecology requires the orchestration of available services and the inclusion of available resources. Because we expect that these will be heterogeneous and in order to ensure the user centric operation of the sphere, we compose a sphere ontology. This encodes the information and knowledge necessary for sphere operation; it also provides context representation for the components of the sphere. We assume that several (but not all) of the ambient ecology components will contain their proprietary ontology, or set of meta-data, which describe properties, services, constraints and even state information of the component. Information about the user is contained in the user profile ontology, which contains instances such as personal data, location, preferences, and even goals and tasks. The AE ontology may contain policy ontologies, which constrain the interactions or the use of services; examples of policy ontologies are privacy policy ontology, interaction ontology, conflict resolution policy ontology etc [9][11].

A. *Example: Feel Comfortable Activity Sphere*

The above can be illustrated with an example (adapted from [5] – refer to Figure 1).

Suki has been living in this new adaptive home for the past 10 months. Suki's living room has embedded in the walls and ceiling a number of sensors reading inside temperature and brightness; some more sensors of these types are embedded in the outside wall of the house. A touch screen mounted near the room entrance together with a microphone and speaker is used as the main control point. The touch screen can display the situation of the house, the settings and the commands Suki has given.

Suki uses an air-conditioning as the main heating / cooling device. The windows are equipped with automated blinds, which can be turned in order to dim or brighten the room. Also, the windows can open or close in order to adjust the room temperature. For the same purpose Suki can use two sets of lights in the living room. Finally, Suki has two TV sets in the house, one in the living room and one in the kitchen. The latter also contains a smart fridge, which can keep track of its contents, and an oven, which also stores an inventory of recipes and can display them in the fridge screen or the TV set. Each of these devices of the Ambient Ecology

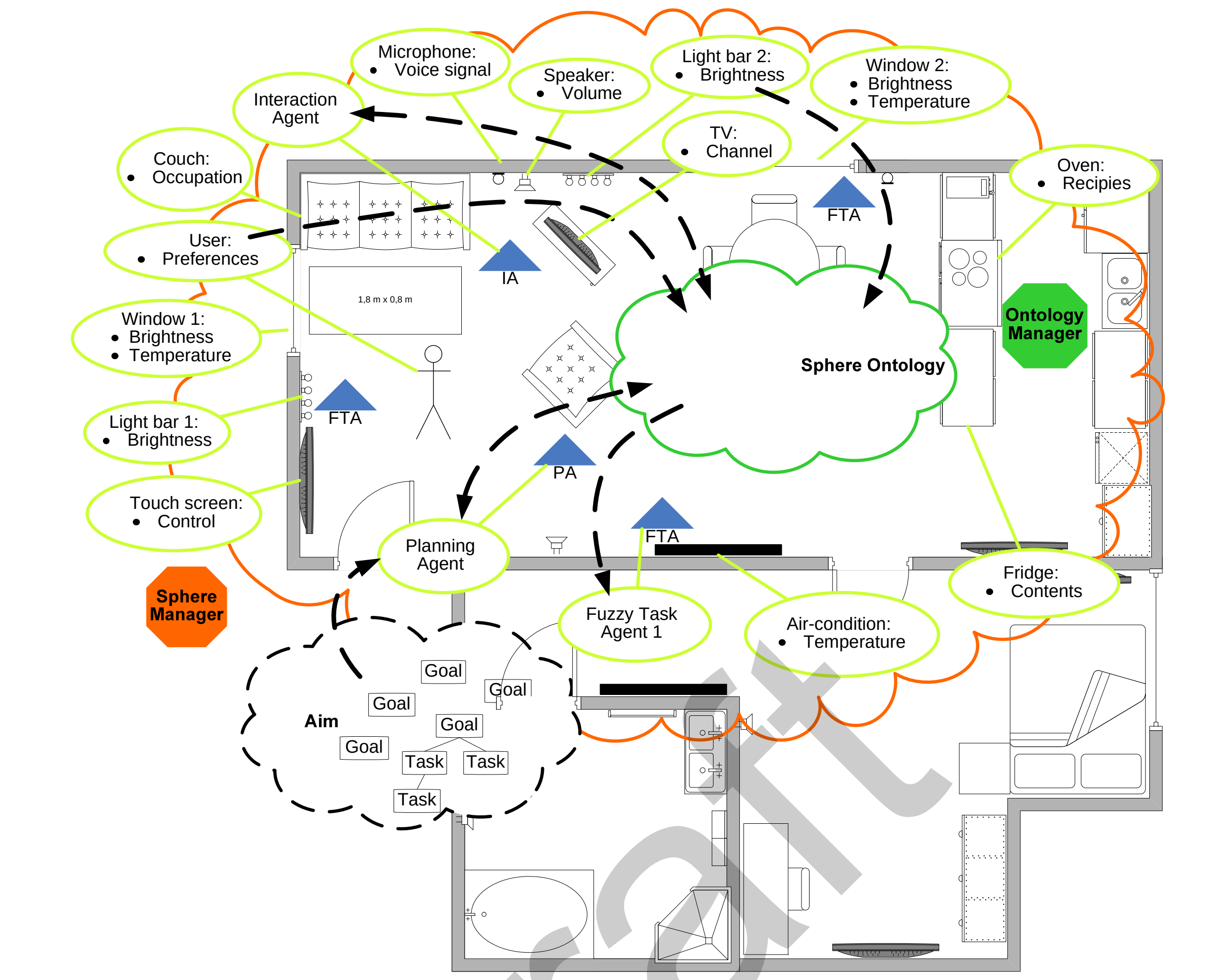

Figure 1. The "feel comfortable" example activity sphere

contains its own local ontology, which describes the device physical properties and digital services. For example, the lamp ontology stores the brand, the material, the size, as well as the location, the state (on/off) and the luminosity level. Similarly, the TV set ontology stores the set and screen dimensions, location, state, available TV channels, currently playing TV channel, statistics about channel usage, as well as viewing parameters (brightness, volume, contrast etc). The local ontologies will be used to form the sphere ontology.

Suki's goal is to feel comfortable in his living room, no matter what the season or the outside weather conditions are. After careful thinking, he concluded that for him comfort involved the adjustment of temperature and brightness, the selection of his favorite TV channel and the adjustment of volume level, depending on the TV programme.

Regarding the latter, the smart home system had observed Suki's choices over the past months and has drawn the conclusion that he tends to increase the volume when music or English speaking movies are shown, except when it's late at night; he keeps the volume low when movies have subtitles, or when guests are around. This has been possible with the help of the Task agent. Nevertheless, the system does not have enough data to deduce Suki's favorite lighting and temperature conditions as the seasons change. Initially, the system will combine information in Suki's personal profile, the environmental conditions, the weather forecast and anything else that may matter, in order to tacitly adapt to the values that Suki might want. In case of a doubt, it will engage in dialogue with Suki about specific conditions, with the help of the Interaction agent. Of course, Suki can always set directly the values he desires by manipulating the devices that affect them; the system will monitor such activity and tacitly will adjust its rules.

B. Example: Prepare for School Activity Sphere

Alexis is a 5th grade student in a Greek high school. This is what goes on each day in the morning, as he is preparing to go to school. Before he gets up, Dick, his digital personal assistant, has already checked the daily schedule and has selected the books and equipment that Alexis has to carry with him today. All this material has been automatically highlighted in the cases where Alexis keeps them, so that he can locate them easily. All necessary digital material has been uploaded by Dick to his personal digital cloud, so that Alexis will be able to access it while not at home. Today Alexis is also going

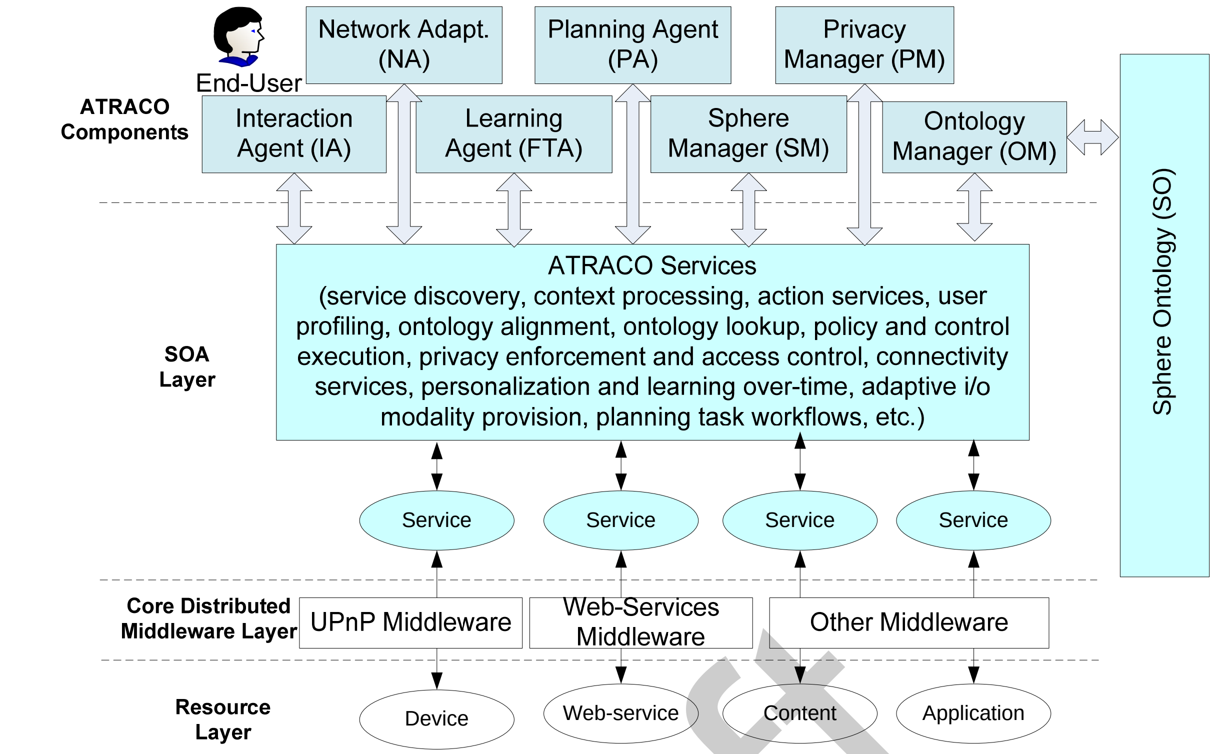

Figure 2. The ATRACO architecture

to rehearse with the school bandmates; thus Dick has also informed the guitar, which in turn is emitting an optical signal to draw his attention.

As Alexis is going to attend a class in Physics, Dick has gone through last week's assignments and discovered that he has not answered the review test. Dick plans to help Alexis go through the test as he will be walking to school. Dick informs Alexis about today's schedule by projecting it on the bathroom mirror, as it has noticed that Alexis is currently washing his teeth.

As he is walking to school, Dick asks Alexis to go through the Physics test, by speaking to him via the headphones of his mobile phone. Dick gives Alexis a synopsis of the theory, then Alexis replies to the questions, which are stored in the schools Learning Management System.

IV. The ATRACO Approach

In ATRACO [5] an Activity Sphere (AS) is formed to support a user's specific goal and is modelled as an abstract workflow that can be instantiated with the appropriate AE resources that are available and functional at runtime. An abstract workflow contains a sequence of abstract services that are ontological descriptions of service operations that cannot be directly invoked, but will be resolved during runtime. This is supported by a semantic-based discovery mechanism that is applied to discover suitable services or devices from ontologies that contain the relevant descriptions. Thus an abstract workflow that is defined at design time can be instantiated with the services/devices which exist in a specific AE at runtime. In this way an AS is dynamic and thus robust to some of the AE uncertainties, but does require mechanisms that achieve AS adaptation in response to changing context.

In ATRACO we used a combination of the SOA model with Agents and Ontologies (see **Error! Reference source not found.**). The ATRACO architecture consists of active entities (agents and managers), services, passive entities and ontologies.

Active entities are managers and agents. The managers (Sphere Manager (SM) and Ontology Manager (OM)) are responsible for the formation of the AS and for keeping the Sphere Ontology up-to-date. The agents (Planning Agent (PA), Fuzzy logic based Task Agent (FTA) and Interaction Agent (IA)) are responsible for task planning, automated adaptation, resolving conflicts, interacting with the user, and in general supporting the users achieving their goals.

Passive entities are devices such as interaction devices (touch screens, speakers, microphones, etc.), actuators and sensors (including televisions, radio receivers and HVACs, etc.), services such as remote or external web-services (i.e., online banking) and local or internal services (i.e., personal calendar). They are usually triggered by agents and therefore behave passively.

Ontologies are used to provide semantic modelling by expressing the basic terms and their relations in a domain, task or service. Thus, they constitute an extensible and flexible way of tackling the semantic heterogeneity that arises in AEs by providing agents a common repository of system knowledge, policies and state. Moreover, through the semantics they convey, ontologies are used in order to address two important goals of NGAIE design, namely the increase of the amount of knowledge available to the system and the minimization of the inaccuracy of knowledge as well as the ambiguity regarding the interpretation of the shared information. Hence, despite their heterogeneous representations of the world, AE components are able to interact successfully through a common communication channel.

There are two main kinds of ontologies: (i) local ontologies provided by both active and passive entities whose state, properties, capabilities, and services are encoded in, and (ii) the Sphere Ontology (SO), which serves as the core of an AS by representing the combined knowledge of all entities. In our approach, we assume that each ATRACO entity (user, agent, device, or service) maintains locally and manages an ontology, which describes its properties, capabilities and current state. In other words, the local ontology of an entity represents the complete set of knowledge associated with this entity.

In order to achieve dynamic task-based coupling between AS and AE, one has also to deal with heterogeneity of resources, while at the same time achieving independence between a task description and its respective realization within a specific AE. Ontologies can be used to tackle the semantic heterogeneity that arises in AEs and provide a common repository of system knowledge, policies and states. By combining the above, the system can take user goals and contextual information into account to adapt and reconfigure itself in a policy-sensitive manner.

An AS contains a set of goals. Each of the goals is modelled with an abstract task model. User, devices, services and the AE itself provide and maintain its own local ontology within the AS. Two main software modules, the Sphere Manager (SM) and the Ontology Manager (OM) provide foundational functionalities within the AS such as service discovery, data access, and event handling. Several Agents (IA, Planning Agent (PA), and Task Agent (TA)) utilize the AS and offer user-centred services. Like the other entities they also provide their own local ontology.

The SM is responsible for creating, managing and dissolving spheres. It instantiates the various agents, which are responsible for resolving conflicts, supporting adaptation, interacting with the user and monitoring the realization of the concrete tasks. Each goal is decomposed in a hierarchy of abstract tasks. After initialization, the PA is responsible for resolving the abstract tasks into concrete tasks, based on the resources of the ambient ecology. Based on the concrete task description, the SM discovers the necessary ambient ecology entities to be included in the AS and orchestrates their services in order to realize the tasks in the task model. Then, each entity tries to realize this task model within the context of the specific AS. The TA is responsible for realizing one or more concrete tasks in an adaptive way. The IA serves as direct connection between user and system and provides adaptive multimodal dialogue.

The SO ensures the transparent and user centred operation of a sphere composed of heterogeneous dynamically changing resources. It encodes the information and knowledge necessary for sphere operation and provides context representation for the components of the sphere. The SO is formed by matching the local ontologies of the AS resources (to deal with heterogeneity), the pertinent policy ontologies (to ensure correct sphere operation) and the user profile ontology (to ensure that the sphere will serve a specific user goal (and its associated tasks) and take into account the user preferences and experience). Establishing semantic links, that is, alignments, between these ontologies is a necessary precondition to achieve interoperability between agents, services, or applications using different individual ontologies. These alignments can then be used in order to translate requests and data between ontologies, to evolve the ontologies, or to merge the ontologies.

The approach in implementing our alignment solution uses a combination of terminological approaches, which exploit string similarity between labels of ontologies with structural approaches, which rely on the structure of the ontologies. However, the approach for the alignment has its limitations. Satisfactory results are obtained when the input ontologies are in the same domain, and furthermore, when non taxonomic relationships (i.e., restrictions) between concepts are not taken into account. In the ATRACO architecture the component that provides ontology management and aligning services is the Ontology Manager (OM). OM has been developed as a wrapper around the Jena Framework, and its interface supports querying the ontology using SPARQL.

V. Conclusions

In this paper, we approached the issue of adopting novel AmI environments with the use of two new metaphors: Ambient Ecologies and Activity Spheres. The former describe the dynamic infrastructure that is made available by Ambient Intelligence Environments; the latter describe the need to consistently support the ever changing user activities.

After developing small to medium scale systems, which operate efficiently in controlled environments, we are now in a position to consider how we can engineer the new generation of large scale Ambient Ecologies. I anticipate the development of methodologies, processes and tools to engineer self-evolving pervasive systems composed of a large number of interacting autonomous individual artifacts, including robots, which can form societies, either long term or in opportunistic interest-based ad hoc manner, and can collaborate with humans to deal with the realization of Activity Spheres. The latter will be engineered to intrinsically exhibit systemic properties, that is, to develop identity and mechanisms to preserve it, develop a sense of self in contrast to the “others”, perceive the environment and pursue mutual adaptation, optimize their performance and deal with their shortcomings. Moreover, they are engineered to form societies, interact and compete with other ecologies, collaborate with humans and develop their own methods of conception and social norms. In the long term, I would expect such digital systems to exhibit properties of artificial life, and ultimately draw their own evolutionary path.

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