

Use Case Scenarios of Dynamically Integrated Devices for Improving Human Experience in Collective Computing

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Abstract. Smart city concept emerged as a technology supported response to challenges posed by growing cities. To provide ambient intelligence smart cities rely on ubiquitous and context-aware computing. Given the ubiquity of computing devices, the ability to connect objects and people into a smart context-aware system is one contemporary challenge. Our early research proposed a novel approach for dynamic integration of devices into a system with context-aware behavior inspired by concepts used in role theory. The idea behind our model is to embed the predefined internal structure of a system given the context into a mobile device to allow it owing a certain role in that system. The objective of the present paper is to prepare the ground for further prototyping of the model. We present ontology-based use-case scenarios utilizing the model to demonstrate the capabilities of the model.

Keywords: Context-aware computing, dynamic integration of devices, role theory, ambient intelligence, collective computing.

1 Introduction

Growing cities pose environmental, economic and social challenges amid attempts to provide sustainable livable conditions. Tackling these challenges require cutting-edge hardware and software solutions and business supported urban development given the social and environmental sustainability. The current urbanization scenario demands efficient solutions for public transportation, land use and high-quality urban services. Over the last two decades the “smart city” concept has emerged as a technology-supported response to challenge these issues at city scale [1]. While the term smart city has been widely used, there is no a “universal” definition. Given the comprehensive review of definitions of smart city [2], we combine the definitions of Bakici et al. [3] and Caragliu et al. [4] to argue that a smart city is a high-tech intensive and advanced city that connects people, information and city elements using new technologies in order to create a sustainable, greener city, competitive and innovative commerce, and an increased life quality with a wise management of natural resources, through participatory governance”.

While industry, education, participation and information technologies infrastructure compose the core four components of a smart city, the key indicators for smart city

assessment are smart people, smart economy, smart governance, smart living and smart environment [2]. Our definition is intentionally resource management and life quality oriented than the one of Washburn and Sindhu [5] who consider the smart city as a collection of the intelligent computing infrastructure, such as a new generation of integrated hardware, software and network technologies that provide a real-time awareness of the real world, and actions that optimize public city services and business processes.

Ambient Intelligence (AmI) is an essential attribute of smart cities providing sensitive and adaptive smart electronic environment. AmI is a multidisciplinary paradigm incorporating several computing areas to bring intelligence to everyday life [6][7], and is believed to change the role of information and communication technologies, and to transform the way people live, work and spend their leisure time [8]. Building upon advances of ubiquitous computing (ubiquitous computing) and context-aware computing, and Internet of Things (IoT), AmI is aimed to provide services to users in an unobtrusive way [9].

Before introducing research objectives of the paper, we draw readers' attention to recent contributions to ubiquitous and context-aware computing. Abowd [10] argues that: (i) ubiquitous computing has spread throughout the most of computing domains and is now indistinguishable from computing itself, and (ii) there was no consideration of interaction between individuals in Weiser's [11] vision of ubiquitous computing but rather user's communication with a computing device. The recently introduced paradigm of collective computing arguably defines "a new era of cooperation between humans and computing that enhances both computational capabilities and the human experience" [12].

Mobile devices gain relevance in providing communication between people and to other devices given the contextual information about surroundings. However, the ability to connect objects and people into a smart context-aware system is one contemporary challenge [13]. The dynamic integration of devices is seen as a contribution towards the achievement of the collective computing vision, thus enhancing context-based cooperation between humans and computing devices.

Santos et al. [14] proposed a novel approach for dynamic integration of devices into a system with context-aware behavior inspired by concepts used in role theory. This is achieved by assigning roles to devices and applying rules and contracts defining the relations between devices. The distinctive feature of their model is the embedment of the predefined internal structure of a system into a mobile device. This gives a device an idea about the system's organization and facilitates an instant "introduction" of the device to a system. However, the model contained numerous flaws and issues [15]. In our early research, we identified its deficiencies and proposed solutions to improve the model [16].

The objective of the present paper is to prepare the ground for further prototyping of the model. We present ontology-based use case scenarios utilizing the model to demonstrate its capabilities and the variety of domains where the model can be applied to. We also provide the aforementioned predefined structure of the system specifying the potential relations between devices in these use case scenarios.

The scenarios utilize the notions and paradigms from sociology and are aimed to facilitate the subsequent prototyping. We also discuss the existing obstacles of the model and provide our vision on how to solve them.

The remainder of the paper is organized as follows. The next section briefly discusses the background concepts. The related work is provided in Section 3. Use case scenarios are highlighted in Section 4. In Section 5 we debate on the current drawbacks of the model. Conclusion and future work are provided in Section 6.

2 Background Concepts

There are numerous papers covering the topic of ubiquitous and context-aware computing in detail. Thus, it is out of scope of this paper to provide a comprehensive review of the domain. We focus only on the milestones and trends in computing resulting in AmI and collective computing.

Being a core component of urban strategies, ubiquitous information technology provides the intelligent environment in smart cities computing [17][18]. Ubiquitous computing (ubicom) is a third wave in computing, as introduced by Weiser [11], and is characterized by the computing capability embedded into the social framework of daily life [19]. Mainframe computers shared by many users and personal desktop computers are seen as the first and the second waves respectively. Ubiomp, also known as pervasive computing [20], is a software engineering concept when computing is available everywhere and anytime. Ubiquitous access to information, communication, and computing is enabled through context-awareness [21]. Context-aware behavior, in turn, refers to an ability of a system to adapt its operations to certain context without explicit intervention, and to provide relevant services to the user given the information about the environment [22][23]. Context is defined as any information characterizing the environment of an entity [24].

AmI builds upon the concepts of ubicom, context-awareness and Internet of Things, and is designed to sense context and enhance users' experience accordingly [25]. We adopt the definition of Cook et al. [6] who refer to AmI as a digital environment which supports people in their daily lives in a proactively but sensible way. There are five key domains contributing to AmI: sensing, reasoning, acting, human-computer interaction, and privacy and security. AmI is an integral component of smart cities facilitated by ubiquity of mobile computing devices and Internet connection. Enhancing interaction of individuals with computing devices is an ultimate goal of AmI [26].

While there is an obvious progress in ubicom, Abowd [10] argues that the intellectual agenda of ubicom has become broader making it challenging to keep it as standalone well-scoped niche. Moreover, he adds that ubicom has now become an integral aspect of computing itself. Abowd [12] also develops the idea and advocates the emergence of a new phenomenon – collective computing which “blurs the distinction between what is human and what is computational”. It builds on the cloud services, the Internet of Things, wearable computing and human computation through social computing platforms. The ultimate goal of collective computing is to enhance the human experience with computing.

In this paper, we contribute to debate on AmI by demonstrating how concepts from sociology can facilitate the dynamic integration of mobile devices. The scenarios presented in this paper are also aimed to demonstrate the flexibility of the earlier proposed

model and to make the users' experience with mobile devices go far beyond using them for phone calls and trivial apps.

3 Related Work

In this section, we provide a short review of related work. This is explained by the fact that this is a continuation of our previous work.

Bartelt et al. [27] developed a system supporting a dynamic integration of mobile devices but without consideration of the context-aware behavior. Jini, a Java-based framework, was used to make a communication between devices possible. Authors distinguished static, at development time, and dynamic, at run time, integration of devices. This approach does not consider the dynamic integration of heterogeneous mobile devices due to the hardware restriction. Additionally, the proposed platform requires devices to be Java compliant. Computing power constraint of mobile devices, as well as safety and security in the system are not considered.

Strohbach et al. [28] proposed an architecture and system for integrating cooperative artefacts which are defined as autonomous entities equipped with sensors to model all relevant aspects of a physical environment and are able to communicate to each other. Artefacts' reasoning mechanism is facilitated by the static and dynamic knowledge, such as facts and rules to infer further knowledge based on them. The distinctive feature of cooperative artefacts is that they are independent from the supporting infrastructure. The authors developed a prototype demonstrating cooperative artefacts in a use-case scenario to assist handling and storage of chemicals in the industrial environment. The same approach and the model were applied to analyze human activity [29]. Similar to [30], cooperative artefacts, such as glasses and jugs, were built for the domestic setting in order to discover a valuable information about users' activity. Similar to the aforementioned research, this approach is built on the existing platform. Artefacts are essentially electronic boards with connected sensors, and can be attached to various objects that need to be sensed. Artefacts also have inferencing capability to process sensed knowledge. There is no dynamic integration of mobile devices supported.

Sinha and Couderc [31] utilized a similar idea and proposed a framework to represent context for collection of physical objects. Their approach is based on attaching RFID tags with stored information to physical objects. The framework encodes the knowledge into those objects to later decode in a resource-limited distributed environment. Privacy and security is not considered due to insensitivity of the information encoded.

4 Use Case Scenarios

The present paper is the development of our theoretical ontology-based model to enable context-aware behavior in mobile computing devices [14][16]. Our early research identified the model's limitations preventing it from prototyping [15].

Our model allows a mobile device to join a system and execute certain tasks as a component of that system. The core idea behind the model is to use concepts from

sociology to assign a role to a device. This results in the devices being associated with relevant responsibilities for executing tasks and communicating with other devices in the system. The dynamic integration is facilitated by embedding a particular information about the organization of the system into the device. A device is expected to meet the requirements to own a role from both software and hardware perspective.

Before discussing the knowledge representation and relations in the model, we introduce a competency principle of a device which refers to its ability to execute all required functions to accomplish the tasks imposed by the role it owns. In this research, the essential assumption is that when a device owns a role, the competency principle is approved. The competency principle with regard to the first scenario is defined as follows:

- $\text{CapacExec}(\text{Device1}, \text{FunctionX})$ – the Capacity of Traffic lights device to execute the FunctionX.
- $\text{Execution}(\text{Role}, \text{Task})$ – the Responsibility for the execution of the task Change the light switch time associated with the role Manage the light switch time.
- Given $\text{Owner}(\text{Device}, \text{Role})$ and the ability of the FunctionX to meet the requirements of the Task, we assume that the Device is competent to execute the Task.

The ontology model and the relations of the introduced notions is demonstrated through two use-case scenarios: (i) people with special needs crossing a street intersection regulated by traffic lights, and (ii) vehicles passing a toll station. The two following subsections will introduce the aforementioned scenarios in detail.

4.1 Use Case 1: Traffic Lights Regulated Intersection Context

In this scenario, we demonstrate that people with special needs can be assisted by a context-aware traffic light system supporting a dynamic integration of devices. A device of a wheelchair user can regulate the lights switch time so they have enough time to cross a street. A device of a person who have hearing loss can communicate with a traffic lights to increase the lights intensity. Traffic lights sounds can be managed by a device of a person with visual impairment. The whole scenario takes place within the Pedestrian traffic lights context. All available roles for devices are listed in Table 1. Roles, in turn, have a number of tasks to be executed by devices (Table 2). Table 3 exhibits complex tasks. Relations between roles are regulated by contracts, which, in turn, are defined by rules (Table 4 and Table 5).

Table 1. Use Case 1: Ownership.

Device	Role	Context
Traffic lights	Manage the lights switch time	Intersection regulated by traffic lights
Traffic lights	Manage sounds	Intersection regulated by traffic lights
Traffic lights	Manage traffic lights intensity	Intersection regulated by traffic lights

Mobile device of a wheelchair user	Identify wheelchair user	Intersection regulated by traffic lights
Mobile device of a person with visual impairment	Identify a person with visual impairment	Intersection regulated by traffic lights
Mobile device of a person who have hearing loss	Identify a person who have hearing loss	Intersection regulated by traffic lights

Table 2. Use Case 1: Responsibility.

Role	Task	Context
Manage the lights switch time	Change the lights switch time	Intersection regulated by traffic lights
Manage traffic lights intensity	Change the lights intensity	Intersection regulated by traffic lights
Manage sounds	Connect beeps	Intersection regulated by traffic lights
Identify wheelchair user	Submit wheelchair user ID	Intersection regulated by traffic lights
Identify a person with visual impairment	Submit ID of a person with visual impairment	Intersection regulated by traffic lights
Identify a person who have hearing loss	Submit ID of a person	Intersection regulated by traffic lights

Table 3. Use Case 1: Task decomposition.

Role	Task	Context
Change the lights switch time	Turn on green light	Intersection regulated by traffic lights
Change the lights switch time	Keep the green light for x seconds	Intersection regulated by traffic lights
Change the lights switch time	Accelerate the pace of the green light in the last y seconds	Intersection regulated by traffic lights
Change the lights switch time	Turn of green light	Intersection regulated by traffic lights

Table 4. Use Case 1: Relations between roles.

Role	Role	Contract	Context
Identify wheelchair user	Manage the lights switch time	W	Intersection regulated by traffic lights
Identify a person with visual impairment	Manage sounds	B	Intersection regulated by traffic lights
Identify a person who have hearing loss	Manage traffic lights intensity	D	Intersection regulated by traffic lights

Table 5. Use Case 1: Contracts description.

Contract	Role
W	Rule 1: Receive and confirm wheelchaired request
W	Rule 2: Activate traffic lights timing system
D	Rule 3: Receive and confirm deaf request
D	Rule 4: Activate Pedestrian traffic lights light intensity system
B	Rule 5: Receive and confirm blind request
B	Rule 6: Activate Pedestrian traffic lights sound system

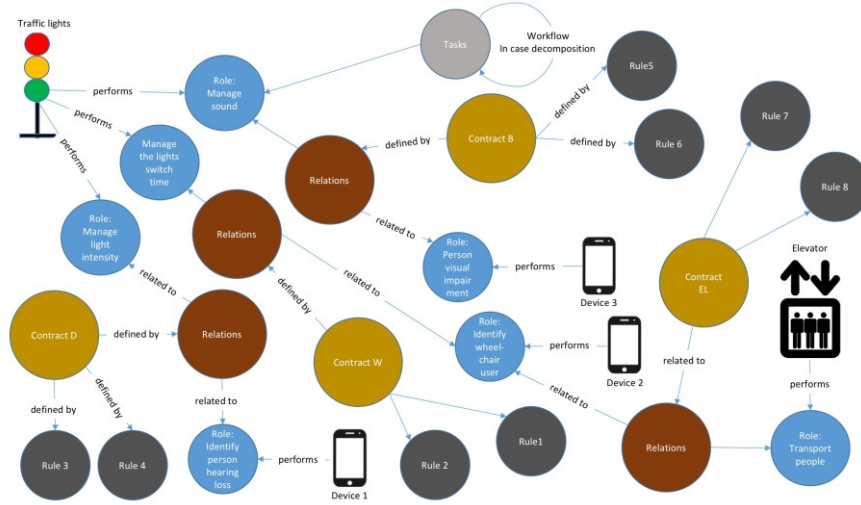
**Fig. 1.** Use case 1: Model of a system managing a pedestrian crosswalk.

Fig. 1 exhibits a simplified model of the considered use-case scenario. This model can be easily enhanced by adding new devices, cars, cross sections which will entail new roles, responsibilities and tasks. It is worth mentioning that devices start communicating within a certain degree of the proximity to each other. Additionally, roles' skills must meet the competence requirements.

4.2 Use case 2: Toll Station Context

The second scenario demonstrates the toll station system communicating with three types of vehicles. The system offers different fees depending on the vehicle occupancy and environmental friendliness. The two characteristics is considered for automatic charge of a vehicle by a toll station. Emergency vehicle is introduced to facilitate the communication with a station gate and guarantee a privileged pass in case of a traffic jam. The relations between roles, assigned tasks and contracts are shown in Tables 6–9. There is one role assigned for a toll station, while vehicles can choose one of the three available. Their communication is regulated by rules.

The simplified knowledge of participating devices and available roles with tasks are shown in Figure 2. Similar to the first scenario, the formal structure of this context-sensitive system can be enhanced by adding new roles with associated tasks.

Table 6. Use Case 2: Ownership.

Device	Role	Context
Toll station	Manage fees	Road toll station
Toll station	Manage toll station gate	Road toll station
Clean Air Vehicle	Identify Clean Air Vehicle	Road toll station
High Occupancy Vehicle	Identify High Occupancy Vehicle	Road toll station
Emergency Vehicle	Identify Emergency Vehicle	Road toll station

Table 7. Use Case 2: Responsibility.

Role	Task	Context
Manage fees	Manage the toll station fee	Road toll station
Manage toll station gate	Open toll station gate	Road toll station
Identify Clean Air Vehicle	Connect Clean Air Vehicle	Road toll station
Identify High Occupancy Vehicle	Submit High Occupancy Vehicle	Road toll station
Identify Emergency Vehicle	Submit Emergency Vehicle	Road toll station

Table 8. Use Case 2: Relations between roles.

Role	Role	Contract	Context
Identify Clean Air Vehicle	Manage fees	CAV	Road toll station
Identify High Occupancy Vehicle	Manage fees	HOV	Road toll station
Identify Emergency Vehicle	Manage toll station gate	E	Road toll station

Table 9. Use Case 2: Contracts description.

Contract	Role
CAV	Rule 1: Receive and confirm Clean Air Vehicle request
CAV	Rule 2: Activate toll station payment system
HOV	Rule 3: Receive and confirm High Occupancy Vehicle request
HOV	Rule 4: Activate toll station payment system
E	Rule 5: Receive and confirm Emergency Vehicle request
E	Rule 6: Activate toll station gate management system

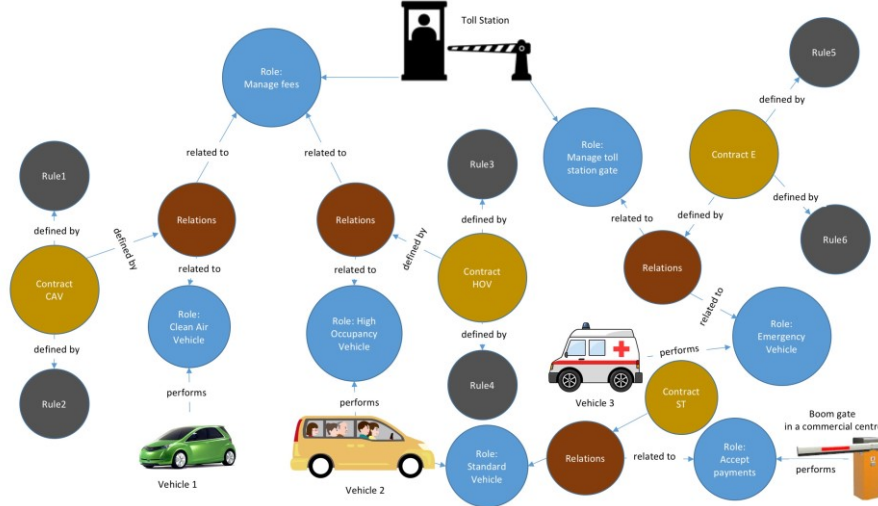


Fig. 2. Use case 2: Model of the system managing a toll station.

5 Discussion

This section debates on the proposed use cases and solutions to enable the prototyping of the extended model. Our previous research emphasized the necessity of solving the issue of the task execution [15]. In the past, such an issue would be solved by using the Web Services Business Process Execution Language to orchestrate the executable processes. The considered situation still requires a software engineering solution supporting the monitoring of task execution flow. The solution will need to be able to deal with both atomic and composite tasks.

The role delegation mechanism can be implemented through the separation of the system's functionality between a dynamic responsive web catalogue and a native mobile app. The multi-tier web system will need to have a database containing full context structure and exhaustive information about roles, and a middleware serving requests from mobile devices represented by various roles. The web system will provide a communication mechanism with devices including device registration, obtaining the context structure and responsibilities, such as tasks relations, contracts and rules, associated with a role. The mobile app, in turn, will allow users to specify a role they are willing to play, which will be sent to the web application. All required information related to the role will be sent back to the device, once it is validated and its competence is approved. We follow the concept of Erickson [32] by limiting the device only to perceive the context but not the role. The role is specified by a user.

The device certification is another limitation of the existing model. The validation mechanism can be implemented by testing not only technical capability of devices, such as sound, vibration, battery level or charging state and lights, but also an ability of a device to execute tasks associated with a role. The implementation of the former is

straightforward by using native API (for example, Android or iOS), while the former requires the utilization of various testing techniques, such as the black-box testing.

To avoid earlier proposed messaging system, Jander and Lamersdorf [33] claim that energy heavy computations should be restricted in mobile applications, thus the messaging system needs to consider these issues. Even though communication protocols exist such as Knowledge Query and Manipulation Language (KQML) and FIPA¹ Agent Communication Language, which are used in the popular agent platform JADE², our proposal consists of leveraging the HTTP protocol using RESTful services to enable light-weight communication protocols. In this context, we will need to think how to organize resources to make it efficient and robust.

Due to the intrinsic characteristics of mobile devices, such as the limited energy resources of their battery, we propose geospatially referenced context or geo-fencing. Context is naturally surroundings attached notation. Thus, any area has certain its own context, such as traffic lights, a restaurant, a university, a hospital, a toll station etc. Once a device “enters” a virtual area (i.e. geo-fence), it will eligible to receive contextual information pertinent to that area. That means a device has either constantly “sense” the location and “consume” web services for the context, or it can have it stored locally in the app. Once context is identified the device receives a list of roles given that context to start the authorization process for a preferred role.

6 Conclusion and Future Work

We presented use case scenarios utilizing our ontology-based model. The scenarios demonstrate the flexibility of the model and the potential for the applicability in variety of domains. The presented use case scenarios contribute to the debate on Aml and collective computing to improve the user experience and are aimed to change the way mobile devices are used.

The proposed model is a novel approach to enable the dynamic integration of mobile devices into a system with context-sensitive behavior. Our approach is inspired by concepts from sociology and social psychology. Devices own predefined roles exposed by the system which entails to bear an associated responsibility and the execution of certain tasks associated with roles.

Our future work will be focused on the development of the system architecture for the subsequent implementation of the prototype for the aforementioned use case scenarios.

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¹ The Foundation for Intelligent Physical Agents

² Java Agent Development Framework

<http://www.geo-c.eu/>). Carlos Granell has been partly funded by the Ramón y Cajal Programme (grant number RYC-2014-16913).

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